Alizadeh, Reza; Lund, Peter D.; Soltanisehat, Leili

Outlook on biofuels in future studies

Published in:
Renewable and Sustainable Energy Reviews

DOI:
10.1016/j.rser.2020.110326

Published: 01/12/2020

Document Version
Peer-reviewed accepted author manuscript, also known as Final accepted manuscript or Post-print

Please cite the original version:
Alizadeh, R., Lund, P. D., & Soltanisehat, L. (2020). Outlook on biofuels in future studies: A systematic literature review. *Renewable and Sustainable Energy Reviews*, *134*, Article 110326.
https://doi.org/10.1016/j.rser.2020.110326

Outlook on biofuels in future studies: A systematic literature review

Reza Alizadeh[a,*], Peter D. Lund[b], Leili Soltanisehat[a]

[a] School of Industrial and Systems Engineering, University of Oklahoma, USA
[b] School of Science, Aalto University, Finland

Abstract

Foresight methods are useful for long-range planning such as strategic energy management, energy policy, and renewable and sustainable energy planning to manage uncertainties. Futures studies may affect the anticipation and speculation of future and emerging technologies. In this paper, biofuels futures are explored based on a critical evaluation of the literature to draw the state-of-the-art for the future-oriented biofuel research. A six-fold typology mapping from two main futures studies methodologies is used. (i) descriptive scenarios, forecasts, and statistical scenarios as descriptive methods; (ii) roadmaps, visions, and backcasts as prescriptive methods. The expectations embodied in the literature are then explored through deriving research challenges about the future of biofuels: (1) the main motives and driving forces in a biofuel era; (2) the main obstacles or difficulties confronting a biofuel era; (3) the plausibility and importance of each of different scenarios; (4) key technological breakthroughs for the bioeconomy; (5) details about development, maturity and flourish; (6) biofuel era's significant achievement. The literature explains a wide range of plausible futures, from centralized systems related to technological breakthroughs to decentralized systems based on small-scale renewable. Fundamental technological elements are uncovered, and a plausible biofuel economy is drawn along with the necessary pathway to reach it. The review shows a general agreement that a biofuel economy would develop gradually, and a prompt shift to biofuels would require powerful governmental support coupled with significant disruptions such as changes in environmental principles of countries, technology breakthroughs, higher oil prices, and urgency of climate change.

Keywords: Biofuels; future studies; roadmapping; foresight; forecast; scenario planning

1 Introduction

Foresight methods such as roadmaps and scenarios are increasingly utilized in policymaking, academic research, or industrial applications to manage uncertainties in long-range planning, e.g., energy or transport policy [1-5]. This also includes published future-oriented literature on biofuel as a renewable and sustainable energy source and a perceived biofuel era as part of the energy transition to clean energy [6-9]. The literature on the future potential of biofuels is ample consisting of scientific articles [10-22], reports [6, 23-30], authoritative advocacy [31, 32], and governmental documents [23, 29, 33-35], among others. Importantly, foresight studies could potentially also influence the common outlook of the future,

* Corresponding author.
E-mail address: reza.alizadeh@ou.edu

e.g., the future of biofuels, through building rigorous expectations of the sustainability of the evolving technological advances, but also assembling financial, intellectual, institutional, and political means required for their achievement [36].

The literature on biofuel reviews is extensive, for example on biofuels in international transportation, energy market, and economic modeling were reviewed [37]. The biofuel supply chain is another important issue and includes huge uncertainty. The evolution of biofuels and the biofuel supply chain's general structure considering different degrees of uncertainity in decision-making have been reviewed in [38]. Some studies have focused on one type of biofuels only. For example, the biodiesel industry's current scenarios on glycerol production and its global markets were studied in [39]. Biodiesel development scenarios, residues, oil extraction, and biogas production have reviewed in [40]. Furthermore, the advantages of biodiesel have been compared to fossil fuel and biodiesel's potential by various feedstocks, including waste plastic and cooking oil were identified [41]. Biofuel-based hydrogen is another category that is gaining extensive attention For example, comprehensive coverage of wider use of biofuel-based hydrogen in the energy system, including recent developments and insights particularly in Europe, Asia, and the USA were provided in [43]. Future-based studies of the biofuel-based hydrogen energy sources were reviewed in [44].

The recent trends in global production and the utilization of bio-ethanol fuel were reviewed in [42]. A detailed survey of bagasse, its raw materials, the state-of-the-art for cellulosic ethanol production and its use for generating electricity were provided in [45]. Also, the published literature on the current technologies for sustainable bioethanol production from agro-residues were reviewed [46].

Also, some of the reviews have focused on a specific geographical location only, e.g. Iranian biodiesel development, including waste oil biodiesel utilization scenarios [14]. Some of the reviews are focused on models for biofuel use in the energy systems, e.g. biofuel utilization models in the UK [47]. Besides, 75 modeling tools currently used for analyzing energy and electricity systems considering biofuel as an alternative were reviewed in [48].

A state-of-the-art review on the sustainability assessment of biofuels can be found in [49]. Evaluation of the emissions characteristics of 2nd and 3rd generation biofuels were reviewed in [50]. Also, the literature on biogas life-cycle assessments based on a wide range of feedstocks and technologies were critically evaluated in [51]. Similarly, a life-cycle assessment approach was used in [52] to estimate greenhouse gas emissions produced by second and third-generation biofuels.

Some studies have reviewed the political and economic impacts of biofuels [10, 52, 53]. The potential and of combined ethanol and diesel fuel conventional engines were reviewed in [54].

Many reviews investigate the available potential supply and demand for biofuels. For instance, existing studies on biofuel potentials along with current biofuel conversion methods were reviewed in [55]. The global history, current status, trends and future of bioenergy and biofuels t were reviewed [13] in. Limited number of reviews focus on the biofuels’ share in the global energy market and future energy supply [56].

There are some limitations and gaps in the above-mentioned reviews: (1) they are mainly quantitative projections with many simplifying assumptions and casting some doubts on the numerical predictions' validity. In contrast, the current review is based on qualitative and quantitative foresight methods analyzing different uncertain scenarios without simplifying assumptions. (2) they focused either on specific kinds of biofuels, specific regions and geographical locations, or the biofuels' technical performance, without providing a complete view. This review paper will address these gaps, and it will present findings that are of interest to a broad range of target groups, including energy systems designers; energy and climate policymakers; energy and environmental engineers dealing with transportation, industry, building, electricity generation and management; and, sustainability and nutrient-energy-water nexus experts. Also, researchers, practitioners, and policymakers in futures studies and technological forecasting domains are other target groups of this review paper.

To address these gaps, a thorough overview of the contemporary future-oriented studies on biofuels is presented. The survey done intends to cover a broad range of literature on different views on the biofuel futures by classifying the studies and identifying their purposes. Important questions raised in the review include, e.g., how were the studies put together, what kind of standpoint do the studies have on the future and technological change, and what time horizons are considered, among others. To address these questions, along with keeping the generality of the paper, a clear definition of biofuel is needed. In the published literature, the definition of biofuel is broad and not always consistent. Most of the studies available refer to the first- and second-generation liquid biofuels [14, 26, 39, 42, 50, 57-62] and some to third-generation, e.g., lignocellulosic fuels [13, 16, 63-67]. Here the main focus is on biomass-derived fuels for transportation, power generation, heating, and combined heat and power. This framing of biofuels is used throughout this paper.

The layout of the review is structured as follows: In Section 2, the review process is described. In Section 3, based on goals, different approaches, and explanations of these studies, the classification of published future-oriented biofuel research is proposed. Six classes of studies were recognized, including (i) Descriptive Scenarios; (ii) Statistical scenarios; (iii) Roadmaping studies; (iv) Forecasting studies; (v) Shared visions; and (vi) Pathways and backcasts. Then, in Section 4, the literature is further analyzed against pressing research challenges on the main features of the biofuel energy era, including (1) the main motives and driving forces in a biofuel era; (2) the main obstacles or difficulties confronting a biofuel era; (3) the plausibility and importance of each of different scenarios; (4) key technological breakthroughs for the bioeconomy; (5) details about development, maturity and flourish; (6) biofuel era's significant achievement. Finally, in Section 5, the paper is concluded by providing a comprehensive discussion of the observations, takeaways, and lessons learned.

2 Method

In order to address the above research challenges, we performed a comprehensive systematic literature search through the major academic databases, including Scopus, Springerlink, ScienceDirect, IEEEXplore, and ACM Digital Library. The bibliographic databases were searched for biofuel-related fields such as all generations of biofuels and different kinds, including biodiesel, green diesel, ethanol, straight vegetable oil, biogas, bioethers, syngas, and other bioalcohols. Boolean operators “or” and “and” are used to combine the search keywords “biofuel,” “future,” and a third word determining the specific future-oriented biofuel research, including keywords such as ‘biofuel‘; ‘scenario'; ‘roadmap'; ‘foresight'; ‘forecast'; ‘economy'; ‘vision'; ‘route-map'; ‘backcasting'; ‘pathway'. The literature search was last updated on July 8, 2020.

In order to identify which articles to examine, an exclusion stage has been completed to omit non-English articles, articles that are not relevant to the biofuel, its applications and its futures, and articles that only theoretically address the technologies of biofuel (e.g., biofuel conversion and exergy technologies) in general. **Error! Reference source not found.** shows a flow diagram of the search procedure applied for this review paper.

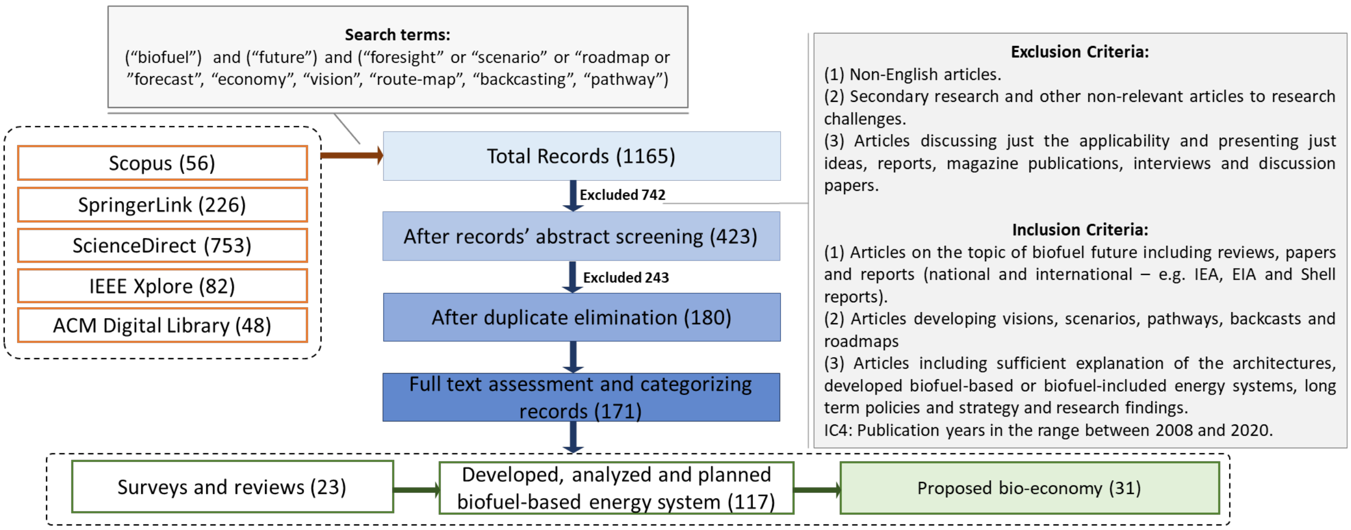

Figure 1. Article search procedure (last updated on July 8, 2020).

The studies included here explained a biofuel future or depicted a plan or path to evolve a biofuel future. The studies analyzed had a global outreach, but several of these were, in particular, relevant to the USA. Over 171 papers published from 1995 to 2020 are included in the analysis. The majority of the studies regarded biofuels in a more generic setting, including diverse production paths and practices. Some had a focus on biofuel in transportation, while a few highlighted fixed fuel cell applications. All the studies were analyzed according to a standard template to ensure consistency and develop a classification of biofuel futures.

3 Classification of biofuel futures

The review is classified into six different, but overlapping types of biofuel futures studies. They are further categorized as explanatory and prescriptive approaches. In Table 1, the details of the categorization are shown.

Table 1. Categorization of biofuel futures.

Type of study	Description
Descriptive methods	Forecasts, descriptive scenarios, and statistical scenarios are included in this category. Forecasting studies are conducted based on the statistical formulation to identify the business as usual, most probable futures as the continuation of the existent patterns. Descriptive scenarios examine potential and alternative futures. Motives are highlighted, but a predetermined pleasing destination based on that storylines are not defined. Statistical scenarios are used to investigate the plausible future biofuel-

	based technological systems. The technical viability and quantifiable consequences of each choice are emphasized instead of narrating the storylines of different scenarios.
Prescriptive methods	Visions, as one of the main prescriptive methods, are explanations of favorable and believable scenarios. The advantages of biofuels are emphasized and instead of exploring the possible scenarios a biofuel era can be evolved. Backcasts are another prescriptive method that begins from a favorable and believable future and plans backward to define strategies to achieve the desired goal. Another primary prescriptive method is roadmaping, which illustrates a series of planned actions to make the believable scenario possible.

In the following section, the specific types of futures studies found for biofuels are described in detail. The first category which has been gained the most attention is the forecasting studies category.

3.1 Forecasting studies

Forecasts are studies that use quantitative tools to foresee different scenarios using existent patterns and experts' judgment [68]. They study shorter time horizons (up to 2035). Three different roadmaps for biofuels cover predictions on market dynamics [24, 25, 27]. Usually, demand forecasts, oil price or fuel cost predictions, technological learning curves, and the features of competing technologies are utilized as input data to model how biofuel enters the market [13, 59, 69, 70]. Forecasts are sometimes used as different scenarios by changing the input assumptions to analyze how various factors affect the modeling of biofuel's future. One of the most fundamental forecasting practices in the published literature solely extrapolates selling patterns from 2005 to 2050 to predict stable biofuel market increase to 2050 [25].

Based on forecasting studies, the popularity of biofuel technologies in the future depends on their charges in comparison to surrogate methods and technologies. Nevertheless, some of the studies mentioned above analyze the impacts of policy interferences, like GHG penalties. Based on forecasting studies, in evaluating what key advancements need to take place to facilitate the development process of the biofuel economy, these studies concentrated on substantial technological issues (such as the cost of kWh electricity produced by biofuels). The focal challenge for a biofuel economy is to decrease the expense of the technologies and facilities required for biofuel development and provide the necessary facilities for biofuels to enter the market (e.g., building a refueling set up).

Contrary to other reviewed studies, biofuel is considered in a broader energy network setting and competing technologies in forecasting studies. Nevertheless, they are also criticized for their uncertainties on the future [38, 71-74] and technological transitions [75, 76], which also questions the hypothesis of substituting old mechanisms by newly developed ones without disrupting the mainstream paradigm or infrastructure where they function, also overlooking the necessity of new business models, changing institutions, new user habits and models of consumption [2, 72, 77-79]. Therefore, these projections may not be very useful in helping to realize the intricate transformation process of large-scale technological systems. In Table 2, an overview of the categories of forecasts is presented.

Table 2. Categories of forecasting studies.

Study	Summarized explanation
[13]	Studied vehicles that can use biodiesel and fuel cells (FC), their market invasion, different possible forecasts, and the sensitivity of the price of the technology to industrial development,

Study	Summarized explanation
	oil price, and environmental policies like the carbon tax. In their study, the Institute for Prospective Technological Studies (IPTS) model is used to develop different scenarios.
[59]	Used a mathematical formulation to show the distribution of FC for electricity production, investigating FC use changes based on variations in fuel prices.
[70]	Used a model to analyze the FC popularity in the energy market and forecast FC car acceptance beneath the US Green Car charge estimated investment returns and social trade-off of cost/benefit.
[68]	Used an expert judgment to predict the advancements in fuel cell technology.
[55]	Estimated the yearly demand for biomass for EU energy by 2020.

3.2 Descriptive scenarios (DS)

DS is developed to project the long-run futures (time horizon between 2030 and 2100) and contain disruptive changes (developments which can break the trend). DS aims to advise policy-making by revealing primary driving forces for the transition instead of deductive reasoning from historical data trends. In DS, generally, storylines are outlined to elaborate a range of believable scenarios based on experts' implicit knowledge and make sure that they are consistent internally. While considering the likelihood of surprising changes are known as the main advantage of this approach [2, 76-85], this likelihood is discussed explicitly in just two reviewed descriptive studies [20, 28]. However, disruptive change (e.g., extensive social principles) is mentioned in [53, 60, 86]. Likewise, although some studies have highlighted the significance of participatory methods in descriptive scenario planning [76, 80], the study only in [20], [39], and [42] included stakeholders in the scenario creation process. Some of these descriptive studies have clear evidence of technological transition hypotheses, including Schoemaker's strategic thinking viewpoint of technological change [87] used by [88], unlike the majority of studies analyzed in this article.

Three of the reviewed descriptive studies, such as the US Foresight framework [89], [28], and [90], created current scenarios. These studies investigated the possibility of biofuels in their business as usual scenarios and employed quantitative models (such as POLES [37, 91-94], purpose-built THESIS [53, 86, 95-97], Markal [98-101], or MESSAGE-MACRO [47, 48, 102-104]) to enhance and quantify the scenario outcomes. Other descriptive studies build unique outlines and scenarios to investigate the circumstances under which a biofuel future might unfold [20, 28, 42, 105]. This included recognizing driving forces that are expected to be necessary for biofuel evolution and the shift to a biofuel era. Some literature considered a robust pro-biofuel plan to study these policies' ramifications in a combination of future scenarios [88]. Table 3 summarizes our analysis of the DS. As shown in Table 3, descriptive studies are a more structured method of considering the driving forces, although they emphasize more forces on a holistic level. This method has been scrutinized as being highly top-down and holistic [87]. Nevertheless, when analyzing long-range time horizons, its ability to generate a helpful tool for obtaining various transformation aspects is arguable. Therefore, these issues are addressed in the studies critically evaluated in Table 3.

Table 3. Papers categorized as DS.

Paper	Summarized explanation	Aspects	Presumed correlations
[88]	Employed participatory practice using qualitative scenarios to elaborate likely notions for biofuel evolution.	The intensity of climate change effects Not stated as aspects for transition The offset of power: state vs. market Security of fossil fuel sources	Environmental issues change based on the relationship between the state and market, where the most market-based scenario causes the least concern
[42]	Built scenarios for different levels of biofuel apprehension based on statistical time series data.	Social and environmental principals Level of technological change Level of economic development Price of current energy sources	Economic development identifies energy price and technological change. Environmental principals the highest in the highly developed market and the least in the less developed world.
[86]	Scenarios built and explained based on Intergovernmental Panel on Climate Change (IPCC) analysis on carbon emission.	Utilized the elements of the IPCC's report on emissions plans, levels of biofuel entry into it is identified by the national administratives' support	Robust environmental principles and universally harmonized decision making let stable and constant economic development.
[53]	Assumed the scenarios created in [86] to be the reference point, and instead of that, two surrogate biofuel scenarios are analyzed, with high and low biofuel understanding.	Utilized the elements of the IPCC's report on emissions plans, levels of biofuel entry into it is identified by the national administratives' support	Robust environmental principles and universally harmonized decision making let stable and constant economic development.
[105]	Studied the development in 3 sets of infrastructures: communications, electricity grids, road transportation, and utilizes these social and technological patterns to study biofuels' future as portable interactions and electricity architectures.	Studied one future defined by three driving forces Mobility advancement Mobile energy demand advancement Mobile communications advancement	The presumed correlation between the three aspects.
[20]	Several qualitative prospects were designed about the degree	Social and environmental principals level of technological change	Increased social principals may increase the acceptability of research

	of technological transition and prevailing social principals.		and development grants and encouraging a quicker technological transition.
[28]	Studied two different future narratives: one of them elaborates a plausible scenario for biofuel coming out of radical innovation in biofuel storage.	Lack of resource Technological development Personal and social primacies	Presumed correlations are not evident.
[39]	Utilized the UK Department for Trade Industry foresight basis for building four qualitative scenarios.	Globalization vs. autonomy as governance platforms Social and environmental principals	Presumes that the level of economic development and technological change is resulting from these essential aspects of transition.

Most of the descriptive studies analyzed in this study comprise a storyline with a definite end, where GHG emissions are drastically decreased. These scenarios include fast technological shifts combined with a socially liable and internationally well-organized community and an essential biofuels role. This shows a desire to obtain ‘happy ends’ (in this case, a pro-biofuel end) in these exercises. However, descriptive scenarios are recognized as being more structured methods to understand the driving forces that shape the future. Therefore, deriving driving forces for biofuel’s future is only possible from the descriptive scenarios, and these studies are very special in that sense.

3.3 Statistical scenarios

Statistical scenarios provide more details about the system under analysis and their operation in the future. This kind of scenario aims not to forecast the adoption of a new type of vehicles or fuels but rather to analyze the ramifications of a large-scale change [106]. A wide range of plausible biofuel economies and evaluations of their consequences are examined using a given set of measures, including technical viability, economic feasibility, and environmental friendliness (GHG emissions). These studies were summarized in Table 4. Although this kind of study can help evaluate different scenarios, the social aspects of the biofuel transition are usually ignored.

In these studies, the future is seen as a set of constant technological choices, instead of narratives for a technological transition. The majority of the studies [50, 106-109] assume a future biofuel demand and design likely systems that could satisfy that demand.

In the statistical studies, technological evolution motives are reflected at a macro level, e.g., improving energy security and reducing GHG emissions. Simultaneously, the main obstacles recognized are the scarcity of renewable resources and the higher cost of biofuel technologies. Notwithstanding, these studies do not strive to analyze the dynamics of the system changes. Hence, they do not investigate the entire parameter range that could improve or prevent specific futures from evolving or how a biofuel infrastructure might emerge.

Table 4. Studies categorized as statistical scenarios.

Study	Summary of explanation
[50]	Utilized explanatory scenarios to speculate about the energy demand circumstances in 2050 time horizon and explored the greenhouse gas emissions of surrogate likely technological schemes which would satisfy that demand.
[106]	Studied consequences of meeting the demand for transportation through biofuel, based on prediction for 2050. Also, the biofuel consumption based on GHG emissions, various fuel prices, and sensitivity analysis is studied accordingly.
[107]	Outlined several candidate biofuel and FC architectures, which can supply the US's estimated transportation demand in 2050 and provided estimation on the required fund for each of them.
[108]	Described several alternative biofuels and wind energy architectures supplying the power demand. Also, computational models are developed to estimate the overall amount of each of these two alternative energies required.
[109]	Used a multi-criteria decision-making method to identify the pros and cons of different energy systems for FC electric vehicles. The social-economic analysis is also used to find the most robust options for each of the candidate systems.

3.4 Shared visions

Visions are storylines and idealistic explanations of a bioeconomy. Because of this, the bioeconomy is both favored and likely to happen. These studies are more narrative instead of being systematic and methodical. They are not supposed to estimate what will happen statistically; their salient feature is to increase the odds of obtaining the desired scenario. There is no specific planning horizon [16, 19, 63, 110].

There are two general sorts of visions known in the published literature. One of them, which is summarized in Table 5 and explained in this section, is produced by an individual or a small team, drawing an optimistic future for the biofuel era. The other one, generated using expert panels, draws a foundation for a roadmapping practice, aims at creating a mutual understanding of an ideal scenario, and the necessary steps to achieve that. This one is also recognized as Roadmaps and is summarized in Table 7.

Table 5. Papers categorized as shared visions.

Paper	Summarized explanation
[61]	Explained a universal plausible scenario, based on biofuel and renewable-based methanol.
[111]	Explained a solar-biofuel scenario for the United States
[112]	Projected a consensus on biofuel usage as fuel and creates a conceivable surrogate —an artificial fluid hydrocarbon future.
[113]	Envisaged the energy system in 2050 as the biofuel era, and explains the emergence and evolution of the bioeconomy.

Paper	Summarized explanation
[114]	Outlined a shared image of the biofuel era in which the biofuel is assumed as the only surrogate for non-renewable energy sources.
[43]	Showed a biofuel era, and introduces essential elements necessary for shifting to bioeconomy, such as highly efficient cars and the cooperation between stationary and mobile power.
[56]	Presented a local distributed picture for biofuel future and energy future, illustrating the global biofuel network.

In visions, more uncertain components are also incorporated to project different scenarios than business-as-usual. Usually, they represent a future in which institutional, infrastructural, and technological shifts happen along with a transition towards more environmentally friendly social principles and a more equitable society. In more extreme cases, the biofuel economy is proclaimed as an option to redistribute global power [56]. Some others even shape a shift to a biofuel economy as an unavoidable advancement of human growth [113].

Although some visions perceived technological changes manageable through research and development, resilient government control, taxes, and demonstration plans [43, 113], others suggest a requirement for more substantial changes in social principles [114], or radical technological shifts [10]. Nevertheless, the details of these transitions are not explained thoroughly.

The key up-level driving forces of the bioeconomy transition are considered as the essential social advantages, especially regarding air pollution [40, 41, 54, 115], geopolitical dominance [116], energy security [117, 118], and climate change [119-121]. Actions and policies by the government, such as financial support for tax programs [119, 122], demonstration plants [123, 124], and education [125, 126], are seen as crucial for the evolution of a biofuel economy. Furthermore, the growth of renewable energy and biofuel energy resources [126, 127] and their usage in transportation, residential, and commercial sectors are some of the other down-level driving forces [128].

Visions share many features, and almost all of the visions view a significant shift to an energy network where biofuel is one of the chief energy sources. Transportation will be dominated by biofuels and bio-electricity rather than fossil fuels. Hence, biofuels connect sporadic renewable energy sources, making the global transition to the green economy with zero-emission. One of the main shortcomings that visions suffer from is their propensity to overlook controversial subjects (for instance, nuclear energy and carbon capture and storage) and possible restrictions related to the expansion of biofuel energy. [112] has addressed these limitations.

3.5 Pathways and backcasts

All the studies on pathways and backcasts start with the premise that the biofuel economy is acceptable and examines the potential routes to the biofuel future. The attention to the shift is the principal advantage of this kind of studies. Backcasting uses a prescriptive scenario planning approach as its procedure. A vision for the future is developed, and the narratives go back from that specified vision to the current time [21, 129, 130]. Notwithstanding, any specific study demonstrating a comprehensive backcasting analysis on biofuels and addressing the theoretical backcasting literature, was not found.

Almost in all backcasting-based biofuel literature, no clear image of a future biofuel economy is defined [21, 131, 132]. However, objectives are shown, and a set of policies are recommended in several studies[128, 133].

The average timescale of these studies is between 2020 and 2050 [21, 64, 132, 134]. Only the California-project views the probable impacts of discontinuities and disruptive changes [35]. Despite the focus on transition challenges, a few studies only pay direct attention to hypothetical studies on transition in big technological systems. The majority of them depend on an everyday technology push-pull marketing strategy of technological transition. Reference [135] is an exception, which Schumacher's theory is massively informed on the multi-scenario technological changes [71, 87]. Table 6 summarizes the analysis of this category described above.

Table 6. The studies categorized as pathways and backcasts.

Study	Summarized explanation
[133]	Developed measures for identifying effective commercialization; studies obstacles and risks to attain that effectiveness; presented four probable evolution scenarios based on four types of fuels, namely, gasoline, biofuel, ethanol, and methanol.
[21]	Studied scenarios and policies; thereby, biofuel could be used in transportation.
[131]	Introduced a vision for biofuels' future in the US and studied the key patterns which will facilitate the change towards that vision.
[64]	Explored two different transition pathways to a biofuel future, a distributed and centralized pathway, and studies the possibilities for application in the remote and off-grid community.
[132]	Explored two scenarios on biofuel burned cars commercialization, and assessment of different types of pathways based on well-to-wheels GHG emission.
[134]	Studied how the infrastructure for biofuel refueling system might evolve.

3.6 Roadmaping studies

Roadmaps, similar to backcasts, consider the advantages of biofuels, describing a (normally vague) vision, and planning a set of runs to achieve a goal. Pathways and backcasts are different from roadmaps in how the future is seen in them, as described in the text and Table 7.

The majority of these studies integrate specific primary goals: (i) recognizing the obstacles faced in the bio-economy evolution process and the required resources to remove these obstacles. Roadmaps aim at illustrating the interactions among bio-economy future policies, strategies, and market dynamics. Three studies talked about future dynamics in the market and projected some predictions too [25, 27, 35]; (ii) Many of them satisfy a support function. Consequently, it has been recommended that many roadmaps generate extremely optimistic anticipations of a technology's future [87]; (iii) The process of road-mapping looks for collecting principal stakeholders to make a common understanding of the future: a shared scenario, outlining accepted driving forces and prompts for a response to change. Whereas this might also be a tacit feature of other sorts of scenario planning processes, it is an obvious objective of many road-mapping activities.

The road-mapping method's outstanding advantage is the recognition of obstacles and ways to overcome them and the creation of mutual goals [136]. Policies and strategies are often developed for the short time scales like five to ten years, with objectives designed over the extended timescales like till 2050 and longer [25, 26, 33, 35]. Studies like these are usually controlled by fairly linear technology push/market pull attitudes [23, 26, 27].

Table 7. The studies categorized as roadmaping studies.

Study	Summarized explanation
[11]	Created the decision points and actions for the expansion of biofuel technologies
[26]	Built phases to be pursued in 2010, 2015, and 2020 to reach zero-emission transportation.
[29]	Created roadmaps that are conducting stakeholder panel exercise, drawing important goals and decision points in the evolution of a US biofuel future.
[24]	Presented a European vision for biofuel, and drew timetables and essential acts for understanding the visions
[25]	Developed goals and decision points in critical domains of biofuel use through a stakeholder panel exercise and introduces a long-term plan along with certain evaluation criteria.
[142]	Studied the dynamics of the biodiesel market, when it will be economically feasible and commercialized.
[33]	Explored how to encourage the expansion of Biofuel in the USA.
[30]	Defined the critical targets, logical and probable roadmap to achieve those targets and obstacles to commercializing the biofuel through stakeholder panel exercise.
[23]	Presented New Zealand’s long-term goals for biofuel expansion.

4 Main takeaway points from the literature review

After outlining the major types of futures studies for biofuels, the literature on biofuel futures and technologies was analyzed in the next. The outcome of the analysis is grouped here around key questions and issues found in the publications. In Section 4.1, the main driving forces of a bio-economy is identified. In Section 4.2, obstacles, challenges, and difficulties of the biofuel economy are explained. In Sections 4.3 and 4.4, types of plausible and disruptive innovations facilitating bio-economy conditions are explored. Afterward, based on sections 4.2 to 4.4, different architectures of the bio-economy are drawn. Through Section 4.5 to Section 4.6, the evolution of the bio-economy is elaborated based on the reviewed literature, followed by the timeline of the biofuel evolution in Section 4.8.

4.1 Main driving forces of a biofuel economy

There are different perspectives about the driving forces which will form the future of the biofuel economy. Changing social values and the rise of more reliable environmental values are mentioned in almost all the visions and DS. Also, social equity appears as a driving factor, in particular, linked to the transition towards distributed energy production.

Most of the visions analyzed in this study, foresee present technological obstacles manageable if adequate financial support is available [43, 56, 113, 114]. Political and diplomatic decisions have a significant impact on shaping the biofuel economy according to these studies. Technological driving forces have been widely studied and seen as critical as economic, legal, and political factors[68, 111, 112, 132]. Some literature assumes that once technological feasibility is reached, the biofuel economy will evolve, whereas other studies focus on the economic aspects and the cost-effectiveness compared to conventional technologies [10, 70].

Moreover, the *driving force,* as a term, may be used differently. Driving forces are typically defined as wider societal shifts in the DS (such as pace of technological change and social principles). In contrast, it is interpreted as government intervention and expenditure in research and development. Nevertheless, four policy goals and overarching problems are frequently mentioned in the literature as the underpinning driving forces of a shift to a biofuel future. These are:

Higher air quality: Higher air quality is referred to as an important advantage of a biofuel economy [35, 70, 107];

Energy security: This driving force includes a plethora of challenges within the limitations of fossil fuel resources, energy rates, location and geopolitical sensitivity, and vulnerability of centralized energy networks to attacks. No study concentrated particularly on this perspective, and 18 studies out of the 171 did not touch upon this driver. Studies which emphasized this driver [29, 30, 39, 57, 113, 143] were mainly roadmaps or visions;

Affordability: Four studies referred to the affordability of the different types of biofuel energy as a key driving force through transitioning to the bio-economy [29, 42, 132, 144];

Climate change: Mitigating GHG emissions is the main driving force in many of the published literature. It is seen as the leading cause of shifting the bio-economy. Many projects are conducted to mitigate GHGs using biofuels under the United Nations' clean development mechanisms [145-149]. There is a strong connection between climate change and biofuel energy sources, explained in Part 4.9 thoroughly. A relatively controversial driving force mentioned is the possible noise pollution-reducing effect of biofuels in cities [44].

In general, biofuel is carbon-neutral [17], i.e., its GHG release is re-absorbed by the plants over time. However, the time required for compensating the emissions can be hugely dependent on the type of carbon sink [31]. For example, unsustainable use of forests could reduce the carbon sink values of trees and soil [150, 151]. Some studies show how biofuel production from forests can result in 40% more GHGs than fossil fuel [32, 152, 153].

When biofuel is a part of a traditional forest product chain [31], the CO_2-parity payback time is several decades or even higher, but could be considerably shorter when also using forest residues [15]. Yan [154] found that forest use increases GHG emission in the short run while it results in GHG mitigation in the long run.

Some authors suggest diversifying the biomass supply to conserve the forests. For example, Van Meerbeek et al. investigated biomass supply from gardens, roadsides, conservation areas, and sports fields instead of croplands and forests [55, 65]. Souza et al. explored different fossil fuel and bioenergy futures and studied alternative crops analyzing the forecasts, obstacles, and food security [58].

Also, some studies proposed new regions to harvest. For example, Hamelin et al. developed a method to evaluate the European countries' biofuel potential based on four main resources, namely, forestry, farming, municipal, and food waste residues [15]. Some studies have also discussed the balance of food security, forest conversation, and biofuel development [49]. Besides these driving forces that facilitate the evolution of the biofuel economy, there are obstacles, challenges, and difficulties that hinder this evolution.

4.2 Obstacles, challenges, and difficulties

Based on the literature, a wide range of obstacles were identified that could hamper the emergence of a biofuel economy. The most notable ones are the following: (i) The lack of refueling infrastructure [122]; (ii) Expensive zero-emission biofuel generation [34, 155]; (iii) Technology incompleteness of some types of biofuel-based vehicles, in particular onboard storage and short lifetime of fuel cells [134]. Some other challenges are unique for some biofuel scenarios and are discussed in Part 5.3 under the projected changing technological structures for bio-economy.

One of the most referred restrictions is social acceptance [11, 53, 118] and a lack of regulations [156, 157]. Numerous restrictions are extracted from several studies. For instance, social values which dismiss the environment [11]; inadequate skills basis [11]; the capability of necessary technologies to adjust to competition with biofuel [158]; lack of social acceptance [11, 53, 118, 159]; uncertainties around expenses of carbon sequestration [160]; lack of demand for biofuel products [161]; the current fossil fuel-based regulative structure [52]; the lack of surplus energy from renewables [162]; lack of international collaboration or action plans [163]; problem in reaching financial assets for technological developers [53, 164] are some of these limitations. These challenges, obstacles, and difficulties, along with the driving forces, shape different futures necessary for biofuel development.

4.3 Type of futures vital to biofuel development

The most consistent future studies type is DS. Based on these future studies, biofuels would become important in future systems in which the economy grows fast, accompanied by prompt technological growth [20, 28, 42, 86, 88, 105]. Such conditions can be envisaged when environmental concerns, particularly climate change, get important, or when conventional energy sources become vulnerable or costly [39, 53].

When the focus is on the business and profits, and the environmental and social factors are ignored, the consequences of climate change may be undermined, leading to modest technological growth. However, the same outcome may result from a bioeconomy perspective of economic growth, losing its pace. However, biofuels' emergence may be inconsistent with the above in regions without notable oil and gas supplies, thus also linking the bioeconomy to the local economy. In either of these cases, disruptive technologies and innovations would have a crucial role in the biofuel future.

4.4 Importance of disruptive innovations on the biofuel future

Biofuels were found to develop gradually in business-as-usual scenarios [20, 42, 53, 88, 132]. Only in the presence of rigorous support from governments, fast diffusion of biofuels was found to take place (even though the support alone is not considered adequate for the rapid spread) [53, 88], or massive disruptions (e.g., changes in social principles) [53, 60, 86], technological inventions which dramatically decrease expenses [20], increasing oil price [88] or expanding climate consciousness [165].

4.5 The bio-economy architecture

Motives, obstacles, and issues presented in the previous sections form different frames for imaginable biofuel economies, including various configurations, technological projections, and diverse perceptions about the definition of biofuel economy. Two types of technological topologies emerge in the studies: centralized or decentralized, as explained in the next sections and illustrated in Figures 2-3.

4.5.1 Decentralized configuration

Decentralized systems focus on regional biofuel production [166], covering the whole biofuel process from feedstock handling to pyrolysis processes and co-gasification [51, 167-169]. Several studies envision biofuel production from regional or local energy resources (e.g., small-scale biomass conversion, or micro-renewables) [64, 166, 167, 170-174]. In contrast, other authors have considered biofuel production more centralized [175-179], transporting it further to consumers either as electricity [180] or bio-ethanol [45, 46, 181-187]. Decentralized biofuel production would overcome several infrastructural obstacles confronting biofuels [188, 189].

Studies, especially on road transport [21, 30], consider on-site biofuel generation as a transitional stage to a biofuel economy. Other studies consider decentralization a crucial aspect of the biofuel economy, which yields tangible benefits in dispersed production, household refueling, and even energy democratization [56]. Decentralization with biofuels may also provide synergies between electricity, heat, and transportation sectors, e,g, selling electricity to the grid at peak demand times [42, 43, 86, 113].

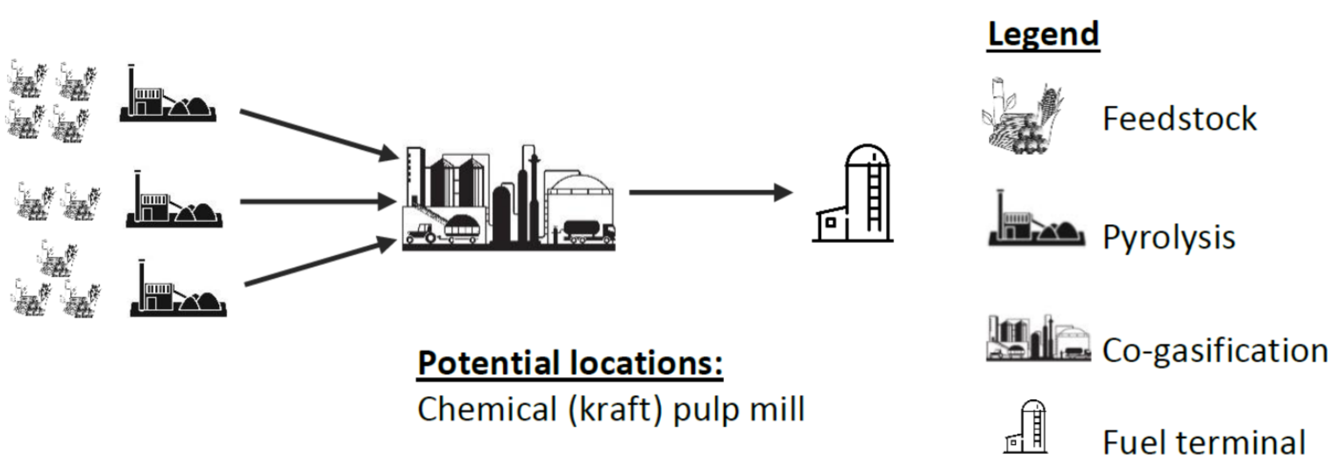

Figure 2. Schematic configuration of a decentralized biofuel productions system

4.5.2 Centralized configurations

Centralized systems can utilize a broader range of energy sources than distributed systems (e.g., coal gasification would be incompatible with distributed systems). However, they will rely on the expansion of a devoted biofuel supply setup. Many studies concentrated on the biofuel use in road transportation [175-179] and foresee regional biofuel storage and pipe networks connecting initial demonstration projects and automobile refueling stations [190, 191], thus building biofuel vessels where the demand is high. A schematic of the centralized configuration is illustrated in Figure 3.

Another different configuration that can evolve is the Shell alternative futures configuration. It foresees biofuel traded in a container as a fuel package. If this breakthrough happens, it will change the existing energy distribution mechanism entirely [28]. To be more comprehensive, most of the published literature believe in a combination of decentralized and centralized configurations, with fuelling stations where the demand is high, and with both of these configurations throughout the energy market equally [173, 192-195]. The pros and cons of decentralized and centralized configurations are summarized in Table 8.

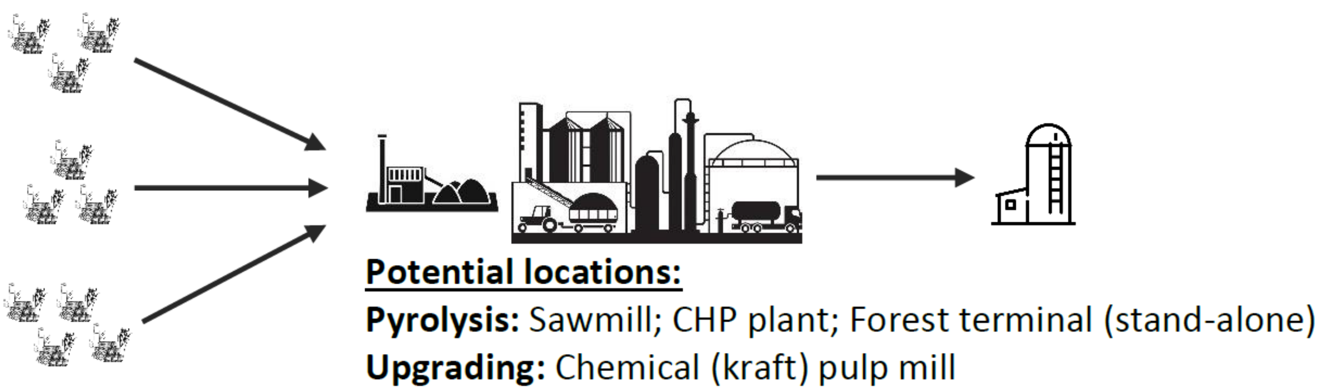

Figure 3. Schematic configuration of a centralized biofuel production system.

Table 8. Pros and cons of centralized and decentralized biofuel production systems

Biofuel production systems	Pros	Cons
Centralized	• Broder range of energy sources • Suitable for road transportation • Automobile refueling stations • Suitable when the demand is high • Low finished product price • Low maintenance cost	• Rely on the expansion of a devoted biofuel supply setup • High establishment and investment cost • Not suitable for air and water transportation

Decentralized	• Provides synergies between electricity, heat, and transportation sectors • Provides synchronization ability to the electricity grid and selling electricity to the grid at peak demand times • Low establishment cost	• High maintenance cost • High finished product cost

4.6 Development of a biofuel economy

As stated previously, the majority of the published literature has a positive perspective on a biofuel economy. Several development trends could be identified:

Most of the studies perceive the distributed system architecture crucial for overcoming the infrastructure challenge with bioeconomy [64, 166, 167, 170-174]. Still, some studies [29, 175-179] perceived centralized generation necessary as the first step connecting demonstration projects and building biofuel corridors or highways fuelled with industrially generated biofuels. Based on the evaluated literature, the timeline of the development of the biofuel economy can be derived. A well-defined timeline of the biofuel evolution can help policymakers and practitioners to be prepared for different phases of the bio-economy development process, which is explained in the next section.

4.7 Timeline of a biofuel economy

Six of the studies analyzed the biofuel economy's impact on GHG emission reduction [39, 50, 53, 86, 106, 132, 196]. It is concluded in these studies that biofuels, and specifically fuel cell cars 2020-2025, can have a crucial impact in decreasing the GHGs. Nevertheless, several studies [50, 106, 132] concluded that a shift to biofuels could occur, not before 2030–2050, and that shifting to a biofuel-based road transportation network earlier could raise overall GHG by displacing the higher GHG reductions from bio-electricity. Figure 4 draws crude timelines and intensities of the transition to biofuel-based transportation found in the studies. The pathways depicted are instead perceived as possibilities of bioeconomy futures than targets. The schedule of the transition to a biofuel based transportation system can be mainly divided into three stages, including introduction, growth, and maturity, which are described in the next.

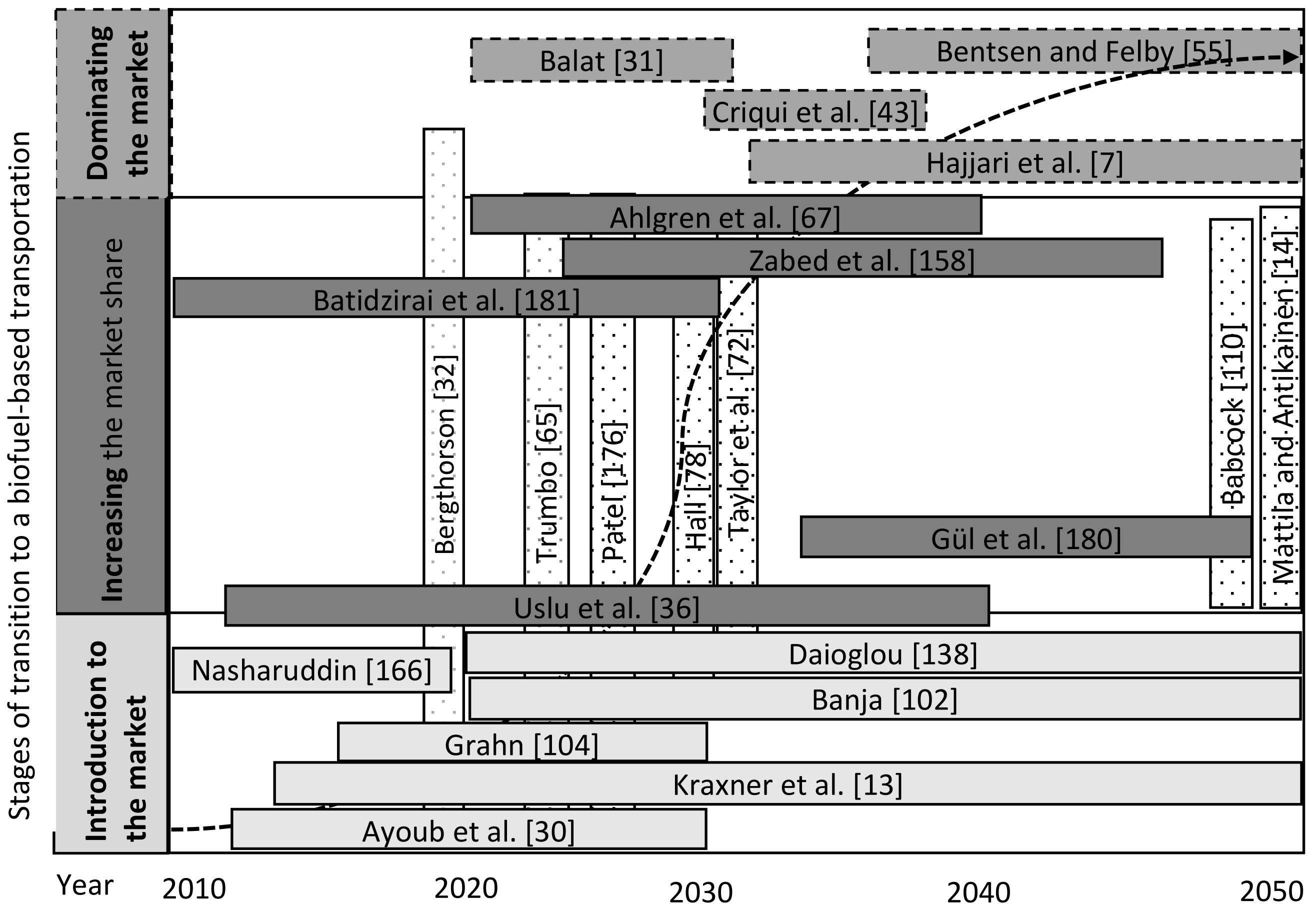

Figure 4. Timelines of the transition to a biofuel based transportation system in different studies.

4.7.1 Introduction to the market

Some of the studies such as [20, 24, 39, 53, 86, 93, 124] framed the evolution of the biofuels focusing on the market entry in the short term (by 2020) and long term (by 2050). The main assumptions of this group of studies are linked to introducing biofuels and fuel cells. These studies also assumed that any new technology introduction will progress gradually and cannot be forced in an untimely manner. Therefore, a market introduction plan must be arranged over a longer time horizon in order to build the right framework circumstances which permit then the market to develop without extra incentives [55]. These studies assume that the market introduction phase should be in force for long enough and be financially supported. During this early stage of technology adoption, the optimal allocation of resources will be important, which will require constant screening of biofuel technology successes and failures, and updating regulation. Thus, various kinds of performance indicators, along with well-designed deployment planning [20, 124], government leadership [53, 86], and enforcement of specific market goals of biofuels in transportation [39, 93] are vital factors for a successful market introduction. Besides public support [20, 53, 124], private and public collaboration are needed to improve fuel distribution [39, 86, 93]. After introducing the market, increasing the market share in the next phase of the evolution of the bio-economy.

4.7.2 Increasing the market share

Some of the studies [37, 49, 60, 135, 183] have focused on the growth of biofuels' market uptake. The main factors affecting the growth of the market after the entry phase include energy and climate policies [37, 183], technology development in industries [49, 183], oil price [37, 135], perceived biofuel potential [60, 135, 183]. The specific features of this stage are that the models used to describe the market penetration stretch over long time horizons during which many of the above-stated factors (may also change. For example, the emission limitations or penalties could depend on the rate of biofuel use [49], or an increasing climate ambition could increase the overall biofuel potential [183].

The uptake of biofuels in the transportation sector and stationary energy systems will also depend on how competing technologies will develop. For instance, assuming increasing non-biofuel-based zero-emission energies (e.g., nuclear energy) and techniques (e.g., carbon capture and storage) [49, 183], would indicate decreasing biofuel's share in power production [60, 135, 183], which in turn could leave more production for transportation [37, 49, 60, 135, 183]. On the other hand, turning into electricity-based transportation would cut the biofuels [49, 183]. The differences in assumptions and uncertainties in input data lead to a broad range in the future share of biofuels, from 0–10% [37, 49, 135] to above 40% [60, 183]; However, the majority of the studies indicates moderate biofuel demand (10-40%) [37, 49, 60, 183].

Although biofuels will not take over the transportation industry, most of the publications anticipate a considerable surge in the consummation of biofuels [37, 49]. Furthermore, zero-emission transportation modes, including electric and hybrid cars, are considered as inevitable alternatives in all the scenarios [37, 49, 60, 135, 183].

The majority of the studies perceived the biofuel economy to be fuelled in the end by renewable energy sources, with power and biofuel as the principal and substitutable energy carriers [10, 20, 52, 68, 113, 124]. There is, however, some controversy about the evolutionary path of biofuels [91]. While there is a strong consensus that the biofuel economy would start with vehicles being fueled with biofuels at gasoline stations and this would then spread out to the whole road transportation [26, 90, 114], there is controversy about what types of biofuel vehicles would first penetrate the market [45, 57, 113, 187]. Small-sized passenger vehicles seem to be preferred to reduce the weight and decrease the power and storage prerequisites of biofuels [43, 109, 128]. Other authors claim that heavy-duty vehicles are more suitable initial adopters because the weight and space prerequisites are less severe, particularly for shipping cases [61, 190]. Another matter of controversy is the sequence of introduction of biofuels, and which type will be introduced first and take a higher share in the market [59, 70, 133, 138] and biofuel is considered as one of the important alternatives which will be dominating the future energy markets in these scenarios.

4.7.3 Dominating the market

The third group of the studies is more focused on market dominance biofuels in transportation. In these studies, the consumption of different biofuels, including ethanol, biodiesel, and methanol increases gradually. The share of biofuels could increase to 35% by 2020 in road transportation and up to 70% by 2050 [90, 197-200]. Some of the underlying assumptions require strong public support such as guaranteed biofuel prices [42], tax releases [93], or guaranteed purchase of biofuel byproducts [14].

The fourth group of studies [21, 28, 47, 50, 90, 100, 130] considers all three stages framing a biofuel-based transportation system's evolution based on the suggested timeline. Typical assumptions in this group are related to the cost-effectiveness of each energy carrier under different carbon policies in the transportation industry [21, 50, 130], mitigation scenarios in climate policies [47, 90], and electricity production modes [28, 100]. The arrows in Figure 4, the dash type arrow, shows the biofuel development process as a product life cycle. Policymakers are eager to find product-market fit, the inflection point in which the product takes off, and experiences hockey-stick growth (the transition from phase one to phase two in Figure 4). However, just as important is the stagnation point or the point later in the S-curve when a product experiences growth stagnation (the transition from phase two to phase three). Many policymakers do not think about these stagnation points. However, it is necessary to pay attention to these because they determine how big the product can become. In order to proper utilization of biofuels, a set of policies is recommended in the next section.

5 Closing remarks

5.1 Futures studies in biofuel

Based on the published literature for biofuels' future, a set of complex models, descriptive narrative methods, trend analysis, rhetorical debates, and long-range plans can be identified.

One might think that how studies of 20 years ago would still be relevant or what the difference between the findings of those studies and the current paper is. In the context of foresight and futures studies, planning horizon varies from 20 to 50 years. Therefore, although more recent studies have been considered more in the current review, studies in this time horizon have not been ignored. In this review, we critically evaluated different perspectives used as the key points in these future-oriented studies. Thus, the lessons learned from these studies are the assumptions that have been used in their projections; critical uncertainties and driving forces that have been identified by them to shape the future of the biofuels; limitation, difficulties, challenges, and opportunities which have been identified by these studies; different scenarios, visions, roadmaps, and pathways developed and proposed by these studies. Critical evaluation of these key findings created an alternative for a collective thinking process (or participatory study) and provided insights for the researchers, practitioners, and policymakers in biofuel-based energy, transportation, and industrial systems.

Participatory approaches are barely used, with the exemption of many roadmaps, and some descriptive analyses. None of the backcast models showed a theoretically grounded backcasting process. Only four out of the 171 studies elaborating biofuel futures showed any reference to relevant literature on technological transition.

Six types of pathways for realizing the future of biofuel energy and technologies could be identified in the foresight studies, namely: (i) The forecasts treated biofuels as a product, which struggles in a huge generic marketplace without specific context; (ii) The descriptive scenarios showed biofuels as a possibility among others when more substantial changes take place in society; (iii) The statistical scenarios explained different biofuel configurations; (iv) The visions narrated shared image of the bio-economy, where biofuel will play a vital role in mitigating substantial societal challenges such as climate change; (v) The backcasts created a backward systematic and prescriptive long-term plan to achieve the desired end and investigated possible pathways to that point; (vi) The roadmaps considered biofuels as an answer to particular challenges, and therefore, as the main policy objective.

5.2 Limitations in forecasting biofuel futures

- Some limitations in the biofuel futures studies were identified as follows: The overall shortcoming of model results to some of the mutual futures drawbacks recognized by [12]: determinism with the novel technologies. Moreover, many studies, which have a shortcoming in the hypothetical foundation, design the impacts of technology policies in their representation of a biofuel shift, posing a hypothesis on the impacts of biofuel dissemination strategies.
- The number of experts in the process of futures studies for the biofuel future was often low, which also imposes concerns on the transparency of the process.
- The roadmaps developed are not distinct and clear about the assumptions to create a vision.
- In forecasts and visions, genuine analytical treatment with uncertainties were often missing. However, instead, previous studies were reused as the basis for specific viewpoints about the future (e.g., California's biomass development roadmap was based on the goals of New Zealand’s biofuels roadmap).
- Top-down approaches focusing on international and regional driving forces were often employed overlooking local problems and specific regions' opportunities.
- Several studies analyzed the bio-economy’s more extensive sustainability effects.
- Most of the studies treated the potential growth in biofuels in an isolated context, e.g., overlooking the wider systems transition needed for the envisioned biofuel futures.
- Several explanatory futures seemed to be biased in the drawbacks of biofuels were treated more or less as technological challenges.

Outgoing from the above limitations and findings of the literature review, more scientific and theoretical studies, in which the energy, transportation, and sustainability aspects along with technological and social dynamics of the biofuel transition are directly addressed, should be considered. Nevertheless, such critical evaluations must be balanced against the fact that many of the studies will encourage visionary assessment and could, therefore, generate distinct futures instead of reducing the choices using partial information.

Social and technical changes and technological transitions have not been studied in detail in several biofuel futures studies, but this must be balanced against the limited predictive utility of existing theoretical methods used.

5.3 Lessons learned from the biofuel futures studies

The published literature shows various ideas on plausible biofuel futures, demonstrating that there are several options for a biofuel economy, but also indicating that pure technological perceptions will not be adequate to describe a sustainable biofuel economy. More explicitly, the analysis results of Section 4 suggest common understandings in certain domains as follows: (i) Four main policy motives will influence the biofuels futures namely energy security, climate change, air pollution, and recognized competitive advantages of emerging biofuel technologies; (ii) three main obstacles in front of a biofuel economy are also evident: costs, lack of technical knowledge, and infrastructure; (iii) In scenarios which are an extension of the current trends, biofuel develops gradually and in some cases even not at all. In the published literature, biofuels will rapidly evolve only if governments act seriously when facing security threats, climate change or drastic social or technological transition happen; (iv) Researchers and policymakers have no consensus on the precise definition of a *biofuel economy*; (v) Regardless how a biofuel economy will develop and grow, a set of important notches are recognized as playing vital roles in a change such as broadly differing opinions on the possible dates of market entry for the biofuel cars; (vi) With respect to GHG emissions, major uncertainty exists about the effects of a biofuel economy in short to medium run.

As a final concluding comment, it is noteworthy to observe that mutual visions and anticipations about the future can also turn into driving forces that direct and constrain research by creating a secure environment for novel ideas to develop. This will compensate for the investments and current modest performance of these ideas with their anticipated forthcoming benefits [2, 18, 201]. This unclearness in defining the *biofuel economy* is indeed its oratorical strength since visions with a higher flexibility of interpretation are more able to outgo other likely projections of the future [158].

5.4 Policy recommendations

Three key policy perspectives of the bioeconomy can be identified based on the development process and timeline provided described in Sections 4.6 and 4.7: Environmental sustainability is the primary driver for the future bio-economy emphasizing sustainability-based policy routes for the bioeconomy such as those in Section 4.7. In this context, some studies suggest creating global environmental awareness based on academic projections [114, 118, 150, 165], some others suggest more specific measures such as (i) civic training programs [125, 126], (ii) enhanced research and development [26, 35, 163], (iii) tax tariffs for cars and incentives for biofuels [132], and (iv) improving the infrastructure [107, 109, 134, 188, 189]. The policy recommendations also include mandates or goals for zero-emission cars [50, 69, 121, 192], standards and codes [156], support to encourage confidence in biofuel investments [116], development of biofuel industry and governmental support [35, 122], funding for sustainable and renewable energies [163], sound transition plans to increase confidence and decrease uncertainty [38, 153, 161, 176], and enhance skills base in biofuels [88, 170, 183] explained in Section 4.7. According to the reviewed literature, these policies would be necessary for increasing the market share within the environmental sustainability perspective (Section 4.7.2 and 4.7.3).

The second perspective is the market dominanace of biofuels, where the main driver would be technological breakthroughs to make bio-economy cost-effective in the energy and transportation markets (Sections 4.7.2 and 4.7.3). The policy recommendations include an inherent dilemma between lock-in and winner-picking. Namely, in a winner-picking policy identifying the best technology beforehand is very risky and questionable, and could lead to a policy failure [26, 156]. On the other hand, an incremental policy approach in which winners are not chosen by creating an objective-oriented policy structure (e.g., incentives for zero-carbon cars) could lead to a lock-in to present technological pathways preventing more disruptive pathways for a bioeconomy [50, 69, 121, 192].

The third perspective is to protect the investments on biofuel development driven by economic and supply-side energy security (Section 4.7.3). Accordingly, the dominance of biofuels in the market would depend on a continuous, robust and sustainable supply chain. The studies suggest hybrid centralized and decentralized supply chains. Infrastructures with large biomass flows will enjoy economy-of-scale benefits, which may well compensate for the higher transportation costs to the distribution sites. Mostly, centralized architecture is more environmentally friendly in small regions, while decentralization is becoming a more sustainable option with increasing area [202-204]. Based on our findings, case-specific decentralization scheme should be implemented due to different optimal decentralization level

References

[1] Proskuryakova L. Energy technology foresight in emerging economies. Technological Forecasting and Social Change. 2017;119:205-10.
[2] Alizadeh R, Lund PD, Beynaghi A, Abolghasemi M, Maknoon R. An integrated scenario-based robust planning approach for foresight and strategic management with application to energy industry. Technological Forecasting and Social Change. 2016;104:162-71.
[3] Melander L, Dubois A, Hedvall K, Lind F. Future goods transport in Sweden 2050: Using a Delphi-based scenario analysis. Technological Forecasting and Social Change. 2019;138:178-89.
[4] Melander L. Scenario development in transport studies: Methodological considerations and reflections on delphi studies. Futures. 2018;96:68-78.
[5] Trutnevyte E, McDowall W, Tomei J, Keppo I. Energy scenario choices: Insights from a retrospective review of UK energy futures. Renewable and sustainable energy reviews. 2016;55:326-37.
[6] IEA. World Energy Outlook. Paris2018.
[7] Mofijur M, Masjuki HH, Kalam M, Rahman SA, Mahmudul H. Energy scenario and biofuel policies and targets in ASEAN countries. Renewable and Sustainable Energy Reviews. 2015;46:51-61.
[8] Azad AK, Rasul M, Khan MMK, Sharma SC, Hazrat M. Prospect of biofuels as an alternative transport fuel in Australia. Renewable and Sustainable Energy Reviews. 2015;43:331-51.
[9] Cremonez PA, Feroldi M, de Araújo AV, Borges MN, Meier TW, Feiden A, et al. Biofuels in Brazilian aviation: Current scenario and prospects. Renewable and Sustainable Energy Reviews. 2015;43:1063-72.
[10] Demirbas A. Biofuels sources, biofuel policy, biofuel economy and global biofuel projections. Energy conversion and management. 2008;49:2106-16.
[11] Faaij A, Londo M. Socio-economic aspects of different biofuel development pathways: A roadmap for biofue in Europe. Biomass and Bioenergy. 2010;34:237-43.
[12] Geels FW, Smit WA. Failed technology futures: pitfalls and lessons from a historical survey. Futures. 2000;32:867-85.
[13] Guo M, Song W, Buhain J. Bioenergy and biofuels: History, status, and perspective. Renewable and Sustainable Energy Reviews. 2015;42:712-25.
[14] Hajjari M, Tabatabaei M, Aghbashlo M, Ghanavati H. A review on the prospects of sustainable biodiesel production: A global scenario with an emphasis on waste-oil biodiesel utilization. Renewable and Sustainable Energy Reviews. 2017;72:445-64.
[15] Hamelin L, Borzęcka M, Kozak M, Pudełko R. A spatial approach to bioeconomy: Quantifying the residual biomass potential in the EU-27. Renewable and Sustainable Energy Reviews. 2019;100:127-42.

[16] Hu Q, Sommerfeld M, Jarvis E, Ghirardi M, Posewitz M, Seibert M, et al. Microalgal triacylglycerols as feedstocks for biofuel production: perspectives and advances. The Plant Journal. 2008;54:621-39.
[17] Johnson E. Goodbye to carbon neutral: Getting biomass footprints right. Environmental impact assessment review. 2009;29:165-8.
[18] Kayakutlu G, Daim T, Kunt M, Altay A, Suharto Y. Scenarios for regional waste management. Renewable and Sustainable Energy Reviews. 2017;74:1323-35.
[19] Kiran B, Kumar R, Deshmukh D. Perspectives of microalgal biofuels as a renewable source of energy. Energy Conversion and Management. 2014.
[20] Kraxner F, Nordström E-M, Havlík P, Gusti M, Mosnier A, Frank S, et al. Global bioenergy scenarios – Future forest development, land-use implications, and trade-offs. Biomass and Bioenergy. 2013;57:86-96.
[21] Mattila T, Antikainen R. Backcasting sustainable freight transport systems for Europe in 2050. Energy Policy. 2011;39:1241-8.
[22] Nabuurs G-J, Pussinen A, Van Brusselen J, Schelhaas M. Future harvesting pressure on European forests. European Journal of Forest Research. 2007;126:391-400.
[23] Scion. New Zealand Biofuels Roadmap Summary Report 2018.
[24] HyNet. Towards a European Hydrogen Roadmap. Ottobrunn, Germany: L-B-Systemtechnik GmbH; 2004.
[25] IEA. Technology Roadmap Biofuels for Transport. Paris: International Energy Agency (IEA); 2011.
[26] Macgowan C. Foresight Vehicle, Technology Roadmap, Technology and Research Directions for Future Road Vehicles. 2004.
[27] Phaal R. Foresight Vehicle Technology Roadmap London: Centre for Technology Management, Institute for Manufacturing, University of Cambridge 2004.
[28] Shell. Shell energy scenarios to 2050. 2017.
[29] USDE. National Hydrogen Energy Roadmap. Washington, DC.: United States Department of Energy; 2002.
[30] USNHA. Hydrogen Commercialization Plan. US National Hydrogen Association; 2004.
[31] Aszalós R, Ceulemans RJ, Glatzel G, Hanewinkel M, Kakaras E, Kotiaho J, et al. Multi-functionality and sustainability in the European Union's forests. 2017.
[32] Matthews R, Sokka L, Soimakallio S, Mortimer N, Rix J, Schelhaas M, et al. Review of literature on biogenic carbon and life cycle assessment of forest bioenergy. Final Task 1 report. Farnham, UK: The Research Agency of the Forestry Commission; 2014.
[33] BRDTAC. Roadmap for Bioenergy and Biobased Products in the United States. Biomass Research and Development Technical Advisory Committee; 2007.
[34] Canada FC. Canadian Fuel Cell Commercialisation Roadmap. Industry Canada, Vancouver, BC. 2003.
[35] CEC CEC. A Preliminary Roadmap for the Development of Biomass in California. California Enegy Commission; 2006.
[36] Weber KM. Expectations, foresight and policy portfolios: shaping of or adapting to the future? Expectations in Science and Technology, Risø National Laboratory. Roskilde, Denmark2004.
[37] Ahlgren EO, Börjesson Hagberg M, Grahn M. Transport biofuels in global energy–economy modelling–a review of comprehensive energy systems assessment approaches. Gcb Bioenergy. 2017;9:1168-80.
[38] Awudu I, Zhang J. Uncertainties and sustainability concepts in biofuel supply chain management: A review. Renewable and Sustainable Energy Reviews. 2012;16:1359-68.
[39] Ayoub M, Abdullah AZ. Critical review on the current scenario and significance of crude glycerol resulting from biodiesel industry towards more sustainable renewable energy industry. Renewable and Sustainable Energy Reviews. 2012;16:2671-86.
[40] Mahmudul HM, Hagos FY, Mamat R, Adam AA, Ishak WFW, Alenezi R. Production, characterization and performance of biodiesel as an alternative fuel in diesel engines – A review. Renewable and Sustainable Energy Reviews. 2017;72:497-509.

[41] Othman MF, Adam A, Najafi G, Mamat R. Green fuel as alternative fuel for diesel engine: A review. Renewable and Sustainable Energy Reviews. 2017;80:694-709.
[42] Balat M, Balat H. Recent trends in global production and utilization of bio-ethanol fuel. Applied energy. 2009;86:2273-82.
[43] Ball M, Weeda M. The hydrogen economy–Vision or reality? International Journal of Hydrogen Energy. 2015;40:7903-19.
[44] McDowall W, Eames M. Forecasts, scenarios, visions, backcasts and roadmaps to the hydrogen economy: A review of the hydrogen futures literature. Energy Policy. 2006;34:1236-50.
[45] Bezerra TL, Ragauskas AJ. A review of sugarcane bagasse for second-generation bioethanol and biopower production. Biofuels, Bioproducts and Biorefining. 2016;10:634-47.
[46] Gupta A, Verma JP. Sustainable bio-ethanol production from agro-residues: a review. Renewable and sustainable energy reviews. 2015;41:550-67.
[47] Hall LMH, Buckley AR. A review of energy systems models in the UK: Prevalent usage and categorisation. Applied Energy. 2016;169:607-28.
[48] Ringkjøb H-K, Haugan PM, Solbrekke IM. A review of modelling tools for energy and electricity systems with large shares of variable renewables. Renewable and Sustainable Energy Reviews. 2018;96:440-59.
[49] Batidzirai B, Smeets EMW, Faaij APC. Harmonising bioenergy resource potentials—Methodological lessons from review of state of the art bioenergy potential assessments. Renewable and Sustainable Energy Reviews. 2012;16:6598-630.
[50] Bergthorson JM, Thomson MJ. A review of the combustion and emissions properties of advanced transportation biofuels and their impact on existing and future engines. Renewable and sustainable energy reviews. 2015;42:1393-417.
[51] Farzad S, Mandegari MA, Görgens JF. A critical review on biomass gasification, co-gasification, and their environmental assessments. Biofuel Research Journal. 2016;3:483-95.
[52] Demirbas A. Political, economic and environmental impacts of biofuels: A review. Applied energy. 2009;86:S108-S17.
[53] Di Mario F, Lacobazzi A, Infusion R, Mattucci A. Socioeconomic aspects of hydrogen economy development. 2003.
[54] Shahir SA, Masjuki HH, Kalam MA, Imran A, Ashraful AM. Performance and emission assessment of diesel–biodiesel–ethanol/bioethanol blend as a fuel in diesel engines: A review. Renewable and Sustainable Energy Reviews. 2015;48:62-78.
[55] Bentsen NS, Felby C. Biomass for energy in the European Union - a review of bioenergy resource assessments. Biotechnology for biofuels. 2012;5:25-.
[56] Berndes G, Hoogwijk M, Van den Broek R. The contribution of biomass in the future global energy supply: a review of 17 studies. Biomass and bioenergy. 2003;25:1-28.
[57] Berndes G, Hansson J, Egeskog A, Johnsson F. Strategies for 2nd generation biofuels in EU – Co-firing to stimulate feedstock supply development and process integration to improve energy efficiency and economic competitiveness. Biomass and Bioenergy. 2010;34:227-36.
[58] Souza SP, Seabra JEA, Nogueira LAH. Feedstocks for biodiesel production: Brazilian and global perspectives. Biofuels. 2018;9:455-78.
[59] Szulczyk KR, McCarl BA. Market penetration of biodiesel. Renewable and Sustainable Energy Reviews. 2010;14:2426-33.
[60] Uslu A, van Stralen J, Elbersen B, Panoutsou C, Fritsche U, Böttcher H. Bioenergy scenarios that contribute to a sustainable energy future in the EU27. Biofuels, Bioproducts and Biorefining. 2013;7:164-72.
[61] Olah GA. Beyond oil and gas: the methanol economy. Angewandte Chemie International Edition. 2005;44:2636-9.

[62] Beynaghi A, Moztarzadeh F, Shahmardan A, Alizadeh R, Salimi J, Mozafari M. Makespan minimization for batching work and rework process on a single facility with an aging effect: a hybrid meta-heuristic algorithm for sustainable production management. Journal of Intelligent Manufacturing. 2019;30:33-45.
[63] Jegathese SJP, Farid M. Microalgae as a Renewable Source of Energy: A Niche Opportunity. Journal of Renewable Energy. 2014;2014:10.
[64] Sawatdeenarunat C, Nam H, Adhikari S, Sung S, Khanal SK. Decentralized biorefinery for lignocellulosic biomass: Integrating anaerobic digestion with thermochemical conversion. Bioresource technology. 2018;250:140-7.
[65] Van Meerbeek K, Muys B, Hermy M. Lignocellulosic biomass for bioenergy beyond intensive cropland and forests. Renewable and Sustainable Energy Reviews. 2019;102:139-49.
[66] Zamani Sabzi H, Abudu S, Alizadeh R, Soltanisehat L, Dilekli N, King JP. Integration of time series forecasting in a dynamic decision support system for multiple reservoir management to conserve water sources. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects. 2018;40:1398-416.
[67] Soltanisehat L, Alizadeh R, Mehregan N. Research and development investment and productivity growth in firms with different levels of technology. Iranian Economic Review. 2019;23:795-818.
[68] Demirbas A. Progress and recent trends in biofuels. Progress in Energy and Combustion Science. 2007;33:1-18.
[69] Menten F, Chèze B, Patouillard L, Bouvart F. A review of LCA greenhouse gas emissions results for advanced biofuels: the use of meta-regression analysis. Renewable and Sustainable Energy Reviews. 2013;26:108-34.
[70] Thomas C, James BD, Lomax Jr FD. Market penetration scenarios for fuel cell vehicles. International Journal of Hydrogen Energy. 1998;23:949-66.
[71] Schoemaker PJ. Forecasting and scenario planning: the challenges of uncertainty and complexity. Blackwell handbook of judgment and decision making. 2004:274-96.
[72] Chermack TJ. Improving decision-making with scenario planning. Futures. 2004;36:295-309.
[73] Bishop P, Hines A, Collins T. The current state of scenario development: an overview of techniques. foresight. 2007;9:5-25.
[74] van Notten PWF, Sleegers AM, van Asselt MBA. The future shocks: On discontinuity and scenario development. Technological Forecasting and Social Change. 2005;72:175-94.
[75] Popper R. How are foresight methods selected? foresight. 2008;10:62-89.
[76] Amer M, Daim TU, Jetter A. A review of scenario planning. Futures. 2013;46:23-40.
[77] Godet M. The art of scenarios and strategic planning: tools and pitfalls. Technological forecasting and social change. 2000;65:3-22.
[78] Godet M. Creating futures: Economica; 2001.
[79] Saritas O, Aylen J. Using scenarios for roadmapping: The case of clean production. Technological Forecasting and Social Change. 2010;77:1061-75.
[80] Chermack TJ, Lynham SA, Ruona WE. A review of scenario planning literature. Futures Research Quarterly. 2001;17:7-32.
[81] Varum CA, Melo C. Directions in scenario planning literature – A review of the past decades. Futures. 2010;42:355-69.
[82] Alizadeh R, Khodaei R, Maknoon R. A combined model of scenario planning and assumption-based planning for futurology, and robust decision making in the energy sector. Journal of energy policy and planning research. 2016;2:7-32.
[83] Alizadeh R, Soltanisehat L. Stay competitive in 2035: A scenario-based method to foresight in the design and manufacturing industry. foresight. 2020.
[84] Sadaghiani M, Alizadeh R, Bahrami M. Scenario-based planning for energy foresight case study: Iran's transportation industry. The 10th international Energy Conference (IEC 2014), Tehran2014. p. 1-26.

[85] Abolghasemi M, Alizadeh R. A Bayesian framework for strategic management in the energy industry. International Journal of Scientific Engineering and Technology. 2014;3:1360-6.
[86] Barreto L, Makihira A, Riahi K. The hydrogen economy in the 21st century: a sustainable development scenario. International Journal of Hydrogen Energy. 2003;28:267-84.
[87] Schoemaker PJ. Scenario planning: a tool for strategic thinking. Sloan management review. 1995;36:25.
[88] Sims RE, Mabee W, Saddler JN, Taylor M. An overview of second generation biofuel technologies. Bioresource technology. 2010;101:1570-80.
[89] EIA. Annual Energy Outlook 2017 with projections to 2050 2017.
[90] IEA. ENERGY TO 2050 Scenarios for a Sustainable Future. 2017.
[91] Trumbo JL, Tonn BE. Biofuels: A sustainable choice for the United States' energy future? Technological Forecasting and Social Change. 2016;104:147-61.
[92] Kitous A, Criqui P, Bellevrat E, Chateau B. Transformation Patterns of the Worldwide Energy System-Scenarios for the Century with the POLES Model. The Energy Journal. 2010;31:49-82.
[93] Criqui P, Mima S, Viguier L. Marginal abatement costs of CO2 emission reductions, geographical flexibility and concrete ceilings: an assessment using the POLES model. Energy Policy. 1999;27:585-601.
[94] Russ P, Wiesenthal T, Van Regemorter D, Císcar JC. Global Climate Policy Scenarios for 2030 and beyond. Analysis of Greenhouse Gas Emission Reduction Pathway Scenarios with the POLES and GEM-E3 models, JRC Reference report EUR 23032 EN (http://ipts jrc ec europa eu/publications/pub cfm? id= 1510). 2007.
[95] Shafiei Kaleibari S, Gharizadeh Beiragh R, Alizadeh R, Solimanpur M. A framework for performance evaluation of energy supply chain by a compatible network data envelopment analysis model. Scientia Iranica. 2016;23:1904-17.
[96] Beiragh RG, Alizadeh R, Kaleibari SS, Cavallaro F, Zolfani SH, Bausys R, et al. An integrated multi-criteria decision making model for sustainability performance assessment for insurance companies. Sustainability. 2020;12:789.
[97] Alizadeh R, Beiragh RG, Soltanisehat L, Soltanzadeh E, Lund PD. Performance evaluation of complex electricity generation systems: A dynamic network-based data envelopment analysis approach. Energy Economics. 2020:104894.
[98] Zonooz MRF, Nopiah ZM, Yusof AM, Sopian K. A review of MARKAL energy modeling. European Journal of Scientific Research. 2009;26:352-61.
[99] Kannan R. The development and application of a temporal MARKAL energy system model using flexible time slicing. Applied Energy. 2011;88:2261-72.
[100] Taylor PG, Upham P, McDowall W, Christopherson D. Energy model, boundary object and societal lens: 35 years of the MARKAL model in the UK. Energy Research & Social Science. 2014;4:32-41.
[101] Suganthi L, Samuel AA. Energy models for demand forecasting—A review. Renewable and Sustainable Energy Reviews. 2012;16:1223-40.
[102] Messner S, Schrattenholzer L. MESSAGE–MACRO: linking an energy supply model with a macroeconomic module and solving it iteratively. Energy. 2000;25:267-82.
[103] Jebaraj S, Iniyan S. A review of energy models. Renewable and Sustainable Energy Reviews. 2006;10:281-311.
[104] Sullivan P, Krey V, Riahi K. Impacts of considering electric sector variability and reliability in the MESSAGE model. Energy Strategy Reviews. 2013;1:157-63.
[105] Agnolucci P, McDowall W. Technological change in niches: auxiliary power units and the hydrogen economy. Technological Forecasting and Social Change. 2007;74:1394-410.
[106] Neupane B, Rubin J. Implications of US biofuels policy for sustainable transportation energy in Maine and the Northeast. Renewable and Sustainable Energy Reviews. 2017;70:729-35.
[107] Ogden JM. Developing an infrastructure for hydrogen vehicles: a Southern California case study. International Journal of Hydrogen Energy. 1999;24:709-30.

[108] Alanne K, Saari A. Distributed energy generation and sustainable development. Renewable and sustainable energy reviews. 2006;10:539-58.
[109] Meyer PE, Winebrake JJ. Modeling technology diffusion of complementary goods: The case of hydrogen vehicles and refueling infrastructure. Technovation. 2009;29:77-91.
[110] Rafiqul I, Weber C, Lehmann B, Voss A. Energy efficiency improvements in ammonia production—perspectives and uncertainties. Energy. 2005;30:2487-504.
[111] Weldekidan H, Strezov V, Town G. Review of solar energy for biofuel extraction. Renewable and Sustainable Energy Reviews. 2018;88:184-92.
[112] Bossel U. Does a hydrogen economy make sense? Proceedings of the IEEE. 2006;94:1826-37.
[113] Sharma S, Ghoshal SK. Hydrogen the future transportation fuel: from production to applications. Renewable and sustainable energy reviews. 2015;43:1151-8.
[114] Singh RS, Pandey A, Gnansounou E. Biofuels: production and future perspectives: CRC Press; 2016.
[115] Mofijur M, Rasul MG, Hyde J, Azad AK, Mamat R, Bhuiya MMK. Role of biofuel and their binary (diesel–biodiesel) and ternary (ethanol–biodiesel–diesel) blends on internal combustion engines emission reduction. Renewable and Sustainable Energy Reviews. 2016;53:265-78.
[116] Brutschin E, Fleig A. Geopolitically induced investments in biofuels. Energy Economics. 2018;74:721-32.
[117] Taghizadeh-Hesary F, Rasoulinezhad E, Yoshino N. Energy and Food Security: Linkages through Price Volatility. Energy Policy. 2019;128:796-806.
[118] Yaghoubi J, Yazdanpanah M, Komendantova N. Iranian agriculture advisors' perception and intention toward biofuel: Green way toward energy security, rural development and climate change mitigation. Renewable energy. 2019;130:452-9.
[119] Correa DF, Beyer HL, Fargione JE, Hill JD, Possingham HP, Thomas-Hall SR, et al. Towards the implementation of sustainable biofuel production systems. Renewable and Sustainable Energy Reviews. 2019;107:250-63.
[120] Lago C, Herrera I, Caldés N, Lechón Y. Nexus Bioenergy–Bioeconomy. The Role of Bioenergy in the Bioeconomy: Elsevier; 2019. p. 3-24.
[121] O'Connell A, Kousoulidou M, Lonza L, Weindorf W. Considerations on GHG emissions and energy balances of promising aviation biofuel pathways. Renewable and Sustainable Energy Reviews. 2019;101:504-15.
[122] Banja M, Sikkema R, Jégard M, Motola V, Dallemand J-F. Biomass for energy in the EU–The support framework. Energy Policy. 2019;131:215-28.
[123] Palage K, Lundmark R, Söderholm P. The impact of pilot and demonstration plants on innovation: The case of advanced biofuel patenting in the European Union. International Journal of Production Economics. 2019;210:42-55.
[124] Grahn M, Hansson J. Prospects for domestic biofuels for transport in Sweden 2030 based on current production and future plans. Wiley Interdisciplinary Reviews: Energy and Environment. 2015;4:290-306.
[125] Watkinson I, Bridgwater A, Luxmore C. Advanced education and training in bioenergy in Europe. Biomass and bioenergy. 2012;38:128-43.
[126] Sallee CW, Edgar DW, Johnson DM. Student Perceptions of Instructional Methods towards Alternative Energy Education. Journal of Agricultural Education. 2013;54:130-42.
[127] Sorda G, Banse M, Kemfert C. An overview of biofuel policies across the world. Energy Policy. 2010;38:6977-88.
[128] Angrisani G, Canelli M, Roselli C, Sasso M. Integration between electric vehicle charging and micro-cogeneration system. Energy conversion and management. 2015;98:115-26.
[129] Robinson JB. Energy backcasting A proposed method of policy analysis. Energy Policy. 1982;10:337-44.
[130] Babcock BA. The impact of US biofuel policies on agricultural price levels and volatility. China Agricultural Economic Review. 2012;4:407-26.

[131] Schelhas J, Hitchner S, Brosius JP. Envisioning and Implementing Sustainable Bioenergy Systems in the US South. Handbook of Sustainability and Social Science Research: Springer; 2018. p. 301-14.
[132] Thompson W, Johansson R, Meyer S, Whistance J. The US biofuel mandate as a substitute for carbon cap-and-trade. Energy Policy. 2018;113:368-75.
[133] Partnership CFC. Bringing Fuel Cell Vehicles to Market: Scenarios & Challenges with Fuel Alternatives. Sacramento, California.2001.
[134] Campíñez-Romero S, Colmenar-Santos A, Pérez-Molina C, Mur-Pérez F. A hydrogen refuelling stations infrastructure deployment for cities supported on fuel cell taxi roll-out. Energy. 2018;148:1018-31.
[135] Dixon T, Connaughton J, Green S. Understanding and Shaping Sustainable Futures in the Built Environment to 2050. Sustainable Futures in the Built Environment to 2050: A Foresight Approach to Construction and Development. 2018:337.
[136] de Alcantara DP, Martens ML. Technology Roadmapping (TRM): a systematic review of the literature focusing on models. Technological Forecasting and Social Change. 2019;138:127-38.
[137] Daim TU, Yoon B-S, Lindenberg J, Grizzi R, Estep J, Oliver T. Strategic roadmapping of robotics technologies for the power industry: A multicriteria technology assessment. Technological Forecasting and Social Change. 2018;131:49-66.
[138] Romanski B, Daim T. A Technology Roadmap to Uncontested Market Space Using Autonomous Vehicles in the Transportation Industry. IEEE Engineering Management Review. 2019;47:67-76.
[139] da Silveira Junior LAB, Vasconcellos E, Guedes LV, Guedes LFA, Costa RM. Technology roadmapping: A methodological proposition to refine Delphi results. Technological Forecasting and Social Change. 2018;126:194-206.
[140] Daim TU, Meissner D, Carayannis E. Roadmapping for engineering and technology management. Elsevier; 2019.
[141] Sourav K, Daim T, Herstatt C. Technology Roadmap for the Single-Aisle Program of a Major Aircraft Industry Company. IEEE Engineering Management Review. 2018;46:103-20.
[142] J. Blair A. Working toward producing sustainable biodiesel in the Pacific Northwest: Analysis and implementation using the T-plan technology roadmapping approach2009.
[143] Wachtmeister H, Henke P, Höök M. Oil projections in retrospect: Revisions, accuracy and current uncertainty. Applied Energy. 2018;220:138-53.
[144] Fischer G, Prieler S, van Velthuizen H, Lensink SM, Londo M, de Wit M. Biofuel production potentials in Europe: Sustainable use of cultivated land and pastures. Part I: Land productivity potentials. Biomass and Bioenergy. 2010;34:159-72.
[145] Alizadeh R, Majidpour M, Maknoon R, Salimi J. Iranian energy and climate policies adaptation to the Kyoto protocol. International Journal of Environmental Research. 2015;9:853-64.
[146] Alizadeh R, Majidpour M, Maknoon R, Kaleibari SS. Clean development mechanism in Iran: does it need a revival? International journal of global warming. 2016;10:196-215.
[147] Alizadeh R, Soltanisehat L, Lund PD, Zamanisabzi H. Improving renewable energy policy planning and decision-making through a hybrid MCDM method. Energy Policy. 2020;137:111174.
[148] Alizadeh R, Maknoon R, Majidpour M, Salimi J. Energy policy in Iran and international commitments for GHG emission reduction. Journal of Environmental Science and Technology. 2015;17:183-98.
[149] Alizadeh R, Maknoon R, Majidpour M. Clean development mechanism, a bridge to mitigate the greenhouse gasses: Is it broken in iran. 13th International Conference on Clean Energy (ICCE). Istanbul, Turkey2014. p. 399-404.
[150] Smyth C, Kurz WA, Rampley G, Lemprière TC, Schwab O. Climate change mitigation potential of local use of harvest residues for bioenergy in Canada. GCB Bioenergy. 2017;9:817-32.

[151] Soimakallio S, Brandão M, Ekvall T, Cowie A, Finnveden G, Erlandsson M, et al. On the validity of natural regeneration in determination of land-use baseline. The International Journal of Life Cycle Assessment. 2016;21:448-50.
[152] Makipaa R, Linkosalo T, Niinimaki S, Komarov A, Bykhovets S, Tahvonen O, et al. How Forest Management and Climate Change Affect the Carbon Sequestration of a Norway Spruce Stand?(<Special Issue>Multipurpose Forest Management). Journal of Forest Planning. 2011;16:107-20.
[153] Bradford MA, Wieder WR, Bonan GB, Fierer N, Raymond PA, Crowther TW. Managing uncertainty in soil carbon feedbacks to climate change. Nature Climate Change. 2016;6:751.
[154] Yan Y. Integrate carbon dynamic models in analyzing carbon sequestration impact of forest biomass harvest. Science of The Total Environment. 2018;615:581-7.
[155] Hoekman SK. Biofuels in the US–challenges and opportunities. Renewable energy. 2009;34:14-22.
[156] Gao S, Gurian PL, Adler PR, Spatari S, Gurung R, Kar S, et al. Framework for improved confidence in modeled nitrous oxide estimates for biofuel regulatory standards. Mitigation and adaptation strategies for global change. 2018;23:1281-301.
[157] Aso SN, Pullammanappallil PC, Teixeira AA, Welt BA. Biogasification of Cassava Residue for On-Site Biofuel Generation for Food Production with Potential Cost Minimization, Health and Environmental Safety Dividends. Environmental Progress & Sustainable Energy. 2019.
[158] Papachristos G. Diversity in technology competition: The link between platforms and sociotechnical transitions. Renewable and Sustainable Energy Reviews. 2017;73:291-306.
[159] Chin H-C, Choong W-W, Alwi SRW, Mohammed AH. Issues of social acceptance on biofuel development. Journal of cleaner production. 2014;71:30-9.
[160] Fridahl M. Socio-political prioritization of bioenergy with carbon capture and storage. Energy Policy. 2017;104:89-99.
[161] Bot P, van Donk DP, Pennink B, Simatupang TM. Uncertainties in the bidirectional biodiesel supply chain. Journal of Cleaner Production. 2015;95:174-83.
[162] McCormick K, Kåberger T. Key barriers for bioenergy in Europe: economic conditions, know-how and institutional capacity, and supply chain co-ordination. Biomass and Bioenergy. 2007;31:443-52.
[163] Aleixandre-Tudó JL, Castelló-Cogollos L, Aleixandre JL, Aleixandre-Benavent R. Renewable energies: Worldwide trends in research, funding and international collaboration. Renewable energy. 2019;139:268-78.
[164] Carriquiry MA, Du X, Timilsina GR. Second generation biofuels: Economics and policies. Energy Policy. 2011;39:4222-34.
[165] Daioglou V, Doelman JC, Wicke B, Faaij A, van Vuuren DP. Integrated assessment of biomass supply and demand in climate change mitigation scenarios. Global Environmental Change. 2019;54:88-101.
[166] Antizar-Ladislao B, Turrion-Gomez JL. Decentralized energy from waste systems. Energies. 2010;3:194-205.
[167] You S, Tong H, Armin-Hoiland J, Tong YW, Wang C-H. Techno-economic and greenhouse gas savings assessment of decentralized biomass gasification for electrifying the rural areas of Indonesia. Applied energy. 2017;208:495-510.
[168] Andersson J, Lundgren J, Furusjö E, Landälv I. Co-gasification of pyrolysis oil and black liquor for methanol production. Fuel. 2015;158:451-9.
[169] You S, Wang W, Dai Y, Tong YW, Wang C-H. Comparison of the co-gasification of sewage sludge and food wastes and cost-benefit analysis of gasification-and incineration-based waste treatment schemes. Bioresource technology. 2016;218:595-605.
[170] Fiorese G, Catenacci M, Bosetti V, Verdolini E. The power of biomass: experts disclose the potential for success of bioenergy technologies. Energy Policy. 2014;65:94-114.
[171] Bruins ME, Sanders JP. Small-scale processing of biomass for biorefinery. Biofuels, bioproducts and biorefining. 2012;6:135-45.

[172] Hunsberger C, German L, Goetz A. “Unbundling” the biofuel promise: Querying the ability of liquid biofuels to deliver on socio-economic policy expectations. Energy policy. 2017;108:791-805.
[173] Ye F, Li Y, Yang Q. Designing coordination contract for biofuel supply chain in China. Resources, Conservation and Recycling. 2018;128:306-14.
[174] Salomón M, Savola T, Martin A, Fogelholm C-J, Fransson T. Small-scale biomass CHP plants in Sweden and Finland. Renewable and Sustainable Energy Reviews. 2011;15:4451-65.
[175] Seabra JE, Tao L, Chum HL, Macedo IC. A techno-economic evaluation of the effects of centralized cellulosic ethanol and co-products refinery options with sugarcane mill clustering. Biomass and bioenergy. 2010;34:1065-78.
[176] Li Q, Hu G. Supply chain design under uncertainty for advanced biofuel production based on bio-oil gasification. Energy. 2014;74:576-84.
[177] Kim S, Dale BE, Jin M, Thelen KD, Zhang X, Meier P, et al. Integration in a depot-based decentralized biorefinery system: Corn stover-based cellulosic biofuel. GCB Bioenergy. 2019.
[178] Montgomery TD, Han H-S, Kizha AR. Modeling work plan logistics for centralized biomass recovery operations in mountainous terrain. Biomass and Bioenergy. 2016;85:262-70.
[179] Paulson JS. Logistics of integrating a biomass conversion technology into a centralized biomass recovery operation supply chain: Humboldt State University; 2016.
[180] Rodríguez-Monroy C, Mármol-Acitores G, Nilsson-Cifuentes G. Electricity generation in Chile using non-conventional renewable energy sources–A focus on biomass. Renewable and Sustainable Energy Reviews. 2018;81:937-45.
[181] Hill J, Nelson E, Tilman D, Polasky S, Tiffany D. Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels. Proceedings of the National Academy of sciences. 2006;103:11206-10.
[182] Crutzen PJ, Mosier AR, Smith KA, Winiwarter W. N2O release from agro-biofuel production negates global warming reduction by replacing fossil fuels. Paul J Crutzen: A pioneer on atmospheric chemistry and climate change in the anthropocene: Springer; 2016. p. 227-38.
[183] Zabed H, Sahu J, Suely A, Boyce A, Faruq G. Bioethanol production from renewable sources: Current perspectives and technological progress. Renewable and Sustainable Energy Reviews. 2017;71:475-501.
[184] Lee OK, Lee EY. Sustainable production of bioethanol from renewable brown algae biomass. Biomass and Bioenergy. 2016;92:70-5.
[185] Rastogi M, Shrivastava S. Recent advances in second generation bioethanol production: an insight to pretreatment, saccharification and fermentation processes. Renewable and Sustainable Energy Reviews. 2017;80:330-40.
[186] Hemansi RG, Yadav G, Kumar G, Yadav A, Saini JK, Kuhad RC. Second Generation Bioethanol Production: The State of Art. Sustainable Approaches for Biofuels Production Technologies, 1st ed; Srivastava, N, Srivastava, M, Mishra, PK, Upadhyay, SN, Ramteke, PW, Gupta, VK, Eds. 2019:121-46.
[187] Soccol CR, Faraco V, Karp SG, Vandenberghe LP, Thomaz-Soccol V, Woiciechowski AL, et al. Lignocellulosic bioethanol: current status and future perspectives. Biofuels: Alternative Feedstocks and Conversion Processes for the Production of Liquid and Gaseous Biofuels: Elsevier; 2019. p. 331-54.
[188] Arnold U, Yildiz Ö. Economic risk analysis of decentralized renewable energy infrastructures–A Monte Carlo Simulation approach. Renewable Energy. 2015;77:227-39.
[189] Di Silvestre ML, Favuzza S, Sanseverino ER, Zizzo G. How Decarbonization, Digitalization and Decentralization are changing key power infrastructures. Renewable and Sustainable Energy Reviews. 2018;93:483-98.
[190] Nasharuddin R, Zhu M, Zhang Z, Zhang D. A technoeconomic analysis of centralised and distributed processes of ammonia dissociation to hydrogen for fuel cell vehicle applications. International Journal of Hydrogen Energy. 2019;44:14445-55.

[191] Havrysh V, Nitsenko V, Bilan Y, Streimikiene D. Assessment of optimal location for a centralized biogas upgrading facility. Energy & Environment. 2019;30:462-80.
[192] Negi A, Mathew M. Study on Sustainable Transportation Fuels Based on Green House Gas Emission Potential. 2018 International Conference on Power Energy, Environment and Intelligent Control (PEEIC): IEEE; 2018. p. 420-4.
[193] Jiang Y, Zhang Y. Supply chain optimization of biodiesel produced from waste cooking oil. Transportation Research Procedia. 2016;12:938-49.
[194] Marbán G, Valdés-Solís T. Towards the hydrogen economy? International Journal of Hydrogen Energy. 2007;32:1625-37.
[195] Braimakis K, Atsonios K, Panopoulos KD, Karellas S, Kakaras E. Economic evaluation of decentralized pyrolysis for the production of bio-oil as an energy carrier for improved logistics towards a large centralized gasification plant. Renewable and Sustainable Energy Reviews. 2014;35:57-72.
[196] Panoutsou C, Eleftheriadis J, Nikolaou A. Biomass supply in EU27 from 2010 to 2030. Energy Policy. 2009;37:5675-86.
[197] Gielen D, Fujino J, Hashimoto S, Moriguchi Y. Biomass strategies for climate policies? Climate policy. 2002;2:319-33.
[198] Gül T, Kypreos S, Turton H, Barreto L. An energy-economic scenario analysis of alternative fuels for personal transport using the Global Multi-regional MARKAL model (GMM). Energy. 2009;34:1423-37.
[199] Gielen D, Fujino J, Hashimoto S, Moriguchi Y. Modeling of global biomass policies. Biomass and Bioenergy. 2003;25:177-95.
[200] Akashi O, Hanaoka T. Technological feasibility and costs of achieving a 50% reduction of global GHG emissions by 2050: mid-and long-term perspectives. Sustainability Science. 2012;7:139-56.
[201] Geels FW. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. Research Policy. 2002;31:1257-74.
[202] Iglesias L, Laca A, Herrero M, Díaz M. A life cycle assessment comparison between centralized and decentralized biodiesel production from raw sunflower oil and waste cooking oils. Journal of Cleaner Production. 2012;37:162-71.
[203] Chen Q, Liu T. Biogas system in rural China: upgrading from decentralized to centralized? Renewable and Sustainable Energy Reviews. 2017;78:933-44.
[204] Patel M, Oyedun AO, Kumar A, Doucette J. The development of a cost model for two supply chain network scenarios for decentralized pyrolysis system scenarios to produce bio-oil. Biomass and Bioenergy. 2019;128:105287.