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Review

Navigating the Uncertain Terrain: Venezuela's Future Using the Shared Socioeconomic Pathways Framework—A Systematic Review

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Abstract: We investigate Venezuela's potential "futures" under Shared Socioeconomic Pathways (SSPs) through a systematic literature review, including systematic mapping and thematic analysis of 50 scientific articles. We categorised the SSP scenarios into two generational categories and classified the outcomes into positive, negative, and neutral futures. Under first-generation SSP scenarios, increasing poverty could be reversed, and the country's economic growth could be stimulated by adopting unambitious climate measures. However, second-generation SSP scenarios paint a more challenging picture. They suggest that Venezuela could face heat waves, droughts, an increase in diseases, loss of biodiversity, and an increase in invasive species and pests during the remainder of the 21st century as a direct consequence of climate change. Venezuela's geographic and topographic diversity could exacerbate these impacts of climate change. For instance, coastal areas could be at risk of sea-level rise and increased storm surges, while mountainous regions could experience more frequent and intense rainfall, leading to landslides and flash floods. The urgency of conducting additional research on the factors that could influence the severity of climate change's impact, considering Venezuela's geographic and topographic diversity, cannot be overstated. We also identified the critical need to explore alternative paths to move away from the current extractive development model. The potential actions in this regard could be instrumental in aligning the country with global adaptation and mitigation commitments.

Keywords: climate change; development; shared socioeconomic pathways; IPCC scenarios; Venezuela

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1. Introduction

Climate change projections have allowed the global community to agree on each country's efforts to reduce its impacts on natural and human systems and develop adaptation strategies. A significant achievement has been representing the complex interconnections between human activity and climate within a conceptual framework for analysing climate change scenarios, including their potential to affect greenhouse gas (GHG) emissions and the average temperature change of the Earth's surface in ways that static models cannot capture [1].

In response to the Intergovernmental Panel on Climate Change (IPCC) request to develop new climate change projections, as assessed in their Fifth Assessment Report, the scientific community developed the Shared Socioeconomic Pathways (SSPs). These are a set of plausible future scenarios that describe how society could evolve over the 21st century, depending on how we address climate change. SSPs outline five potential outcomes: demographics, economics, technology, lifestyle, and governance. They comprise qualitative narratives describing future developments and quantitative projections of critical elements such as nationwide population growth, education, urbanisation, economic growth, energy, land use, and emissions. SSPs project futures in two dimensions, addressing global challenges up to 2100: the challenges of adapting to and mitigating climate change. They are crucial for understanding and planning climate change management under different scenarios. They provide a comprehensive framework for understanding the complex interactions between socioeconomic development and climate change and how these interactions could shape the future.

SSP developers aimed to have their scenarios adopted in future rounds of climate change projections and to explore the broader implications for sustainability, including developing climate policies based on the proposed scenarios [2]. SSPs analyse climate change in two dimensions: climate exposure (characterised by temperature level) and socioeconomic development, classified by routes [3].

SSPs help to analyse scenarios across a range of multidisciplinary fields, such as projecting the impacts of climate change, the emergence of hotspots around the globe [4], population exposure to decreased rainfall [5], extreme precipitation events [6], sea level rise [7], the spread of diseases [8], biome affectation [9], primate conservation [10], biodiversity and food security [11], as well as projections in energy and future emissions [12], governance [13], income inequality [14], and risks of armed conflict [15].

However, using SSPs in specific national, subnational, or sectoral contexts still needs to be improved [16,17]. Examples from Latin America (Honduras and Peru) show its use as a strategic planning tool for decision-makers regarding climate change, agriculture, and food security programs [18]. Researchers used the SSP framework in Chile to conduct precipitation and temperature projections for the end of the century (2080–2099) [19]. Meanwhile, in Ecuador, a comprehensive examination of hydropower scenarios up to 2050 was undertaken [20]. Notably, Peru and Ecuador carried out high-resolution climate projections [21].

In Colombia, the direct impacts of climate change on sea levels were studied along the Atlantic and Pacific coasts. These impacts were closely linked to the socioeconomic vulnerability of local inhabitants, with the analysis grounded in SSP scenarios [22]. In Mexico, sub-national population studies were conducted, considering the diverse climate hazards and socioeconomic disparities across different regions and states [23].

This review focuses on Venezuela, a climate-vulnerable country. More official national-level information is needed to analyse SSPs [24] to facilitate access and use for those formulating mitigation and adaptation policies. The scholarly output related to climate change in Venezuelan scientific journals is limited and scattered and lacks a thorough analysis of scenarios [25] due to the insufficient institutionalization of research efforts in this field [26].

The average temperature in Venezuela will increase by 1.5 °C to 2 °C and rainfall will decrease by 15% to 20% by mid-century, although this will not be evenly distributed [27]. In rain-fed agriculture regions, extreme heat periods increase and rainfall decreases, intensifying the emergence of pests or new diseases [28]. An escalation in drought occurrences could severely impact agricultural growth and food security [29–32].

These projections are alarming due to Venezuela's unparalleled complex humanitarian crisis in Latin America [33–37], hindering its ability to adapt to climate change.

This review presents a conceptual scheme to discern future conceptual development potentials using SSP scenarios applicable to Venezuela in a systematic literature review format to characterise these futures as positive, negative, or neutral. The SSP scenarios present an uncertain future, showing predictions of multiple effects on ecosystems, productive systems and population, Gross Domestic Product per capita (GDP per capita), and risks of latent social conflicts. They suggest that more than the climate policies agreed upon by Venezuela in its Nationally Determined Contribution (NDC) of 2021 will be needed to respond to future mitigation and adaptation demands, compromising expectations of achieving low carbon development. Our approach will facilitate identifying and representing scientific production on this topic, simplifying data location, and understanding future trajectories that could influence Venezuela's future climate, economic, and social agenda, helping national-level climate public policymakers.

This study also contributes to our understanding of the association between the development style of a country with over a century of extractive activity, such as Venezuela [38], and the potential futures to which it is exposed. This exposure results from the impact of human activities on the Earth system. Consequently, this study becomes part of the ongoing discussion about the Anthropocene. Although not formally designated as a geological epoch [39], the Anthropocene is understood as a continuous event characterized by a diachronic set of transformations that have accelerated during the 20th and 21st centuries, impacting, at an ever-increasing rate, the physical and climatic fabric of the planet [40].

Moreover, this review is significant because it employs a convergent mixed design that combines data from an analytical framework based on methodologically and conceptually quantitative scenarios (such as SSPs) with a qualitative interpretive perspective. This integration occurs through embedding, facilitating the organization, linkage, and merging of valuable information for scientists and social actors.

2. Conceptual Framework

SSPs Two Generations

We have classified Shared Socioeconomic Pathways (SSPs), grouping them into first and second generations according to the Scenario Model Intercomparison Project (ScenarioMIP) for the sixth phase of the Coupled Model Intercomparison Project (CMIP6) [41]. From this, we discerned a first generation of SSP scenarios: potential future socioeconomic trajectories without climate change or policy interventions to mitigate [41].

These non-climatic scenarios [42], or "reference" pathways [43], are comprehensively detailed as follows [44]: SSP1 envisages a sustainable future, SSP2 an intermediate future, SSP3 a future marked by regional rivalry, SSP4 is a future marked by inequality, and SSP5 is a future driven by fossil fuel development. These scenarios include demographics, human development, economics and lifestyle, policies and institutions, technology, the environment, and natural resources.

Since their creation, it was foreseeable that the SSP scenarios would merge elements linked to climate forcing, climate change and climate policies as part of a conceptual framework for integrated assessments of research on mitigation, adaptation and residual climate impacts [45]. We adopted a periodisation criterion, allowing us to work with two generations of SSPs, where the distinctive feature between both is the consideration of the integration of climatic factors with the shared socioeconomic routes initially built by Moss et al. [46], van Vuuren et al. [47], and Kriegler et al. [3]. Indeed, developing the SSPs was a three-phase process. Initially, the Integrated Assessment Modelling (IAM) community formulated the so-called Representative Concentration Pathways (RCPs), which project the magnitude and extent of climate change under varying forcing levels. Subsequently, the SSPs were developed as socioeconomic reference scenarios. Finally, in the third phase, the RCPs, SSPs and associated climate change projections were integrated to create scenarios [48].

The second generation of SSP scenarios, ScenarioMIP [41], denoted as SSPx-y, integrates a specific SSP narrative (x) with a particular forcing level (y) [49], which facilitates the exploration of potential future trajectories concerning socioeconomic and climatic variables. Based on the Scenario MIP, the IPCC [50] Sixth Assessment Report-AR6 has selected priority scenarios (level 1) SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5. In addition, in response to the 1.5 °C warming target set by the Paris Agreement, the SSP1-1.9 scenario is included. The SSP4-6.0 scenario has been excluded as it is a low reference scenario [51], given that its forcing level refers to a stabilisation level reached beyond 2100 [41]. Table 1 provides an overview of the two-generation conceptual framework of SSPs, as discussed in this article.

Table 1. SPPs Two generation conceptual framework.

First Generation		Second Generation		
Stage Name [41]	Narrative Title	Stage Name [41]	Forcing category	Forcing at 2100 W/m^2
SSP1	Sustainability—Taking the green road	SSP1-2.6	Low	2.6
		SSP1-1.9 [50]	Low	1.9
SSP2	Middle of the road	SSP2-4-5	Middle	4.5
SSP3	Regional rivalry—A rocky road	SSP3-7.0	High	7.0
SSP4	Inequality—A road divided	-	-	-
SSP5	Fossil-fueled development—Taking the highway	SSP5-8.5	High	8.5

Note: The first- and second-generation classification is up to the authors.

3. Materials and Methods

We combine mapping methods and a systematic narrative literature review, following the guidelines established by Petersen et al. [52] and Booth et al. [53]. This approach enables the identification, classification, and analysis of scientific production on SSP scenarios that are thematically applied to Venezuela. Parsifal is a key tool in our methodology, which we have utilised to organise high-level systematic literature reviews [54]. Parsifal plays a crucial role in the three stages of our literature review: Planning, Conducting, and Reporting.

3.1. Planning

First, we formulated the research questions using the two selected review methods. Systematic Literature Mapping (SM) aims to transparently convey the parameters of construction and the resulting temporal, geographical, conceptual, and thematic trends in the literature retrieved [55]. Thematic Literature Analysis (TA) provides practical insight into the progression of knowledge within each topic and aids in identifying future research directions [56]. Table 2 presents the questions about the SM and TA stages.

Table 2. Questions for Systematic Literature Mapping and Thematic Literature Analysis.

Identifier	Question
SM1	What is the geographical distribution of authors of scientific publications dealing with SSP scenarios related to Venezuela?
SM2	Between 2013 and 2023, which journals published studies on the first and second generation of SSP scenarios considering Venezuela's case?
SM3	In which fields of knowledge and topics are the studies on first and second-generation SSP scenarios located when considering Venezuela?
TA	What are the main findings and research needs reported in studies on first- and second-generation scenarios of SSP related to the Venezuelan case?

We employed the International Standard Classification of Education Fields of Education and Training 2013 (ISCED-F 2013) [57] to enhance the classification of the literature reviewed. This enabled the categorisation of the selected works into broad, narrow, and detailed fields, facilitating the identification of trends and knowledge generation related to the first- and second-generation SSPs.

For this study, the inclusion criteria consisted of scientific articles published between 2013 and 2023, which demonstrate the application of SSP scenarios to Venezuela, individually or as part of a broader sample of countries. The search used the following keywords: Shared Socioeconomic Pathways Venezuela, SSP Venezuela, and Climate Change Venezuela. Parsifal suggested the search string ("Shared Socioeconomic Pathways Venezuela" OR "SSP Venezuela" OR "Climate Change Venezuela"), which facilitated the review of articles in Scopus and ScienceDirect, as well as the import of studies from other databases. We checked the document between 30 June and 20 October 2023. The inclusion and exclusion criteria are those specified in Table 3.

Table 3. Inclusion and Exclusion criteria.

Inclusion Criteria (IC)		**Exclusion Criteria (EC)**	
Identifier	**Criteria**	**Identifier**	**Criteria**
IC1	Articles that utilize the SSPs framework to project climate or non-climate variables.	EC1	Articles focusing exclusively on Representative Concentration Pathway (RCP) scenarios without considering SSPs.
IC2	Articles incorporating Venezuela as a case study or as part of a sample and applying the SSPs.	EC2	Articles that do not consider SSPs in their analysis.
IC3	Articles that present findings in text, tables, images, or graphics explicitly referencing Venezuela's application of SSPs.	EC3	Articles that include Venezuela as part of a broader sample must provide detailed and individualised data on the country.
IC4	Articles that include projections related to Venezuela in their appendices or Supplementary Materials while applying SSPs.	EC4	Articles that present information on maps encompassing Venezuela but do not allow drawing specific geophysical or socioeconomic conclusions.

Using the Parsifal tool, we applied the quality assessment criteria outlined in Table 4. Parsifal suggested the following ratings: Yes (1.5), Partially (0.5), and No (0), resulting in a maximum possible score of 10 and a minimum score of 0.

Table 4. Quality assessment criteria (QAC).

Identifier	**Criteria**
QAC 1	Venezuela is the sole focus of the document.
QAC 2	The document presents specific data about Venezuela through text, graphics, images, and maps.
QAC 3	A reputable journal supports the publication.
QAC 4	The document provides background information on the subject.
QAC 5	The methodology used is clearly described.
QAC 6	The model used for scenario development is explicitly stated.
QAC 7	The results are presented understandably.
QAC 8	Data is presented in graphical form.
QAC 9	The results are compared with those of other studies.
QAC 10	The conclusions are consistent with the stated objectives.

3.2. Conducting

We searched Scopus and ScienceDirect and imported studies from IOPSCIENCE, JSTOR, and PubMed, identifying and removing duplicates and applying inclusion and exclusion criteria. The review started with 79 articles, of which 12 duplicates were excluded, and 17 papers did not pass the ECs (EC1 = 2; EC2 = 7; EC3 = 4; EC4 = 4). A total of 50 papers were selected. The methodological process was adapted in accordance with the PRISMA flow diagram (Figure 1) [58].

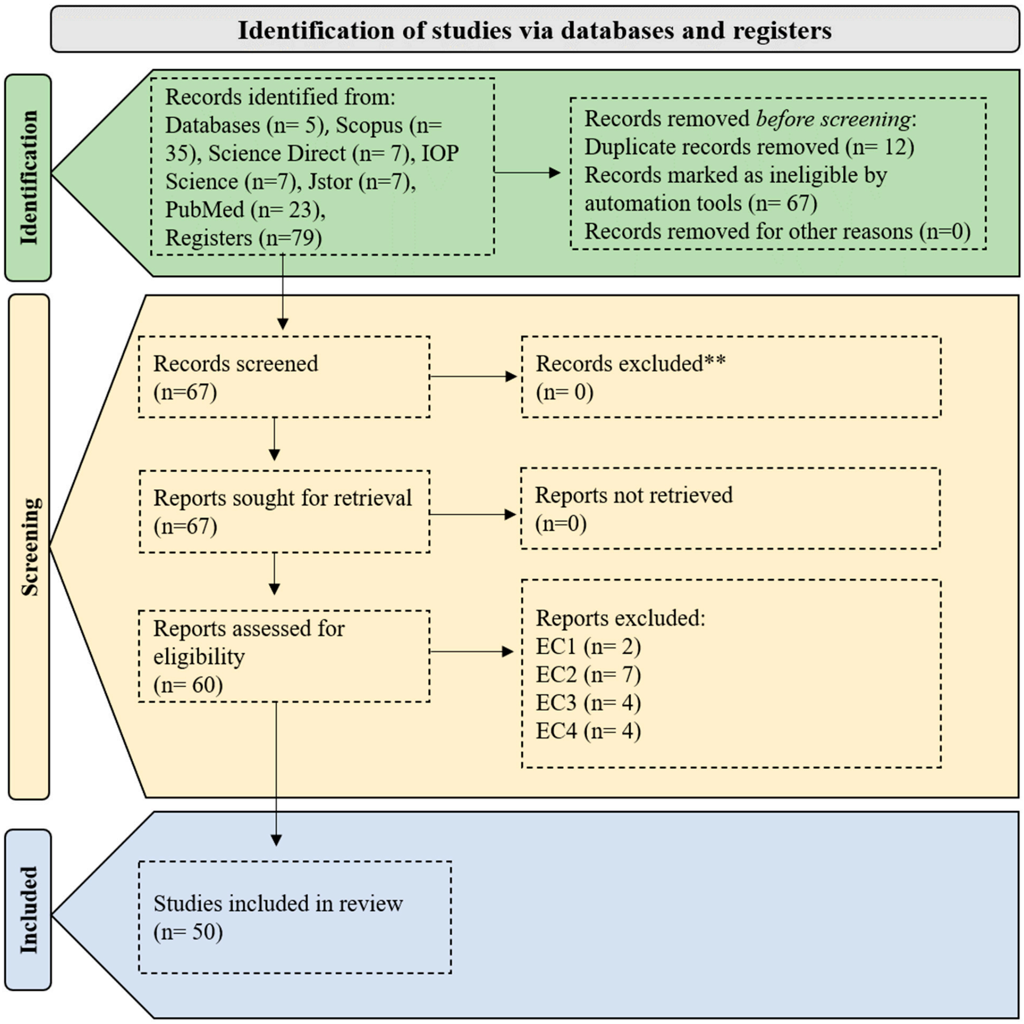


Figure 1. PRISMA flow diagram according to Page et al. [58]. ** If automation tools were used, indicate how many records were excluded by a human and how many were excluded by automation tools.

We assessed the quality of each selected record, revealing that only one document achieved the maximum score by adhering to all Quality Assessment Criteria (QACs). Twenty-seven papers did not meet QAC1 but fulfilled the remaining criteria, ranking above eight points. All selected articles scored higher than 7, fully complying with QAC 3, QAC 4, QAC 5, QAC 6, QAC 7, QAC 8, QAC 9, and QAC 10 (Appendix A). Finally, we prepared and completed extraction forms beforehand, considering both SM and TA.

3.3. Reporting

Data extraction uses a Google Sheets spreadsheet entitled "SSP Venezuela (2023)". The reports reveal the data extracted for SM and TA. For the data SM visualisation, we employed the tool RAWGraphs 2.0 beta [59]. This versatile and user-friendly platform facilitates the creation of a wide range of visualisations from structured data; it can effectively transform complex datasets, such as those derived from the scientific review exploring Venezuela's potential future through the Shared Socioeconomic Pathways framework, into insightful visual representations. By utilising this platform, the study was able to streamline the process of translating categorical dimensions into intuitive and informative graphical formats.

To address TA, we followed an inductive qualitative content analysis, which involved generating emergent categories from examining a specific corpus of documents. The aim was to classify these documents according to their conceptual frameworks or central themes [60]. Consequently, upon reviewing the 50 papers, we discerned the following inductive categories (C) and subcategories (SC). It is evident that the C and SC arose from ideas explicitly associated with envisaged futures for Venezuela, as identified in the texts scrutinised (Table 5).

Table 5. Identified Thematic Categories and Subcategories within the Surveyed Literature.

Identifier	Categories	Identifier	Subcategories
C1	Climate	SC1.1	Temperature
		SC1.2	Precipitation
C2	Risk	SC2.1	Heat
		SC2.2	Flood
C3	Biological and ecological aspects	SC3.1	Vectors
		SC3.2	Invasive species
		SC3.3	Plague
		SC3.4	Biodiversity
C4	Economy and lifestyle	SC4.1	Growth and Per Capita Income
		SC4.2	Climate finance
		SC4.3	Poverty
		SC4.4	Consumption and Diet
		SC4.5	Demand for services
C5	Energy	SC5.1	International fossil fuel trade
		SC5.2	Renewable energies
		SC5.3	Carbon storage and flux
C6	Agriculture	SC6.1	Crops
		SC6.2	Food insecurity

We categorised our findings according to the previously identified C and SC, juxtaposing them with the two generations of SSPs (Table 1). This approach provided a perspective on the topics considered in each scenario group. Our research team reached a consensus on evaluating and qualifying the futures generated for Venezuela by the reviewed prospective studies. These futures were then re-categorised (RC) as positive, negative, or neutral, following the approach used in sustainability scenario evaluations [61]. Due to its simplicity, this perspective is understandable and useful for researchers and policy decision-makers.

The RC process within scenario analysis relies on the criterion that the narratives that outline plausible futures fulfil a communicative function. Although these do not project precise or inaccurate situations, they allow us to distinguish between what Kopfmüller and Barton [62] consider threats and opportunities.

Table 6 presents the possible deduced futures and their meanings. According to expert judgment on the dominant trend of opportunities and threats identified in the reviewed literature for different natural and human systems, we qualify the expected futures and their respective meanings as positive, negative, or neutral.

The primary methodological limitations of our review become apparent through the diversity of thematic areas and variables projected within the framework of shared socioeconomic pathways (SSPs). Additionally, the studies consulted provide various criteria for selecting scenarios [4,6,63–65]. These limitations are particularly evident in the sections corresponding to SC1.1 and SC1.2.

Similarly, Venezuela—a country rich in oil resources yet economically challenged—is classified differently across the consulted studies. Geopolitical, socioeconomic, and commercial criteria are considered when selecting samples of countries, as observed in the case of SC4.2, SC4.3, SC4.4, and SC5.1. Notable works [66–69] contribute to this understanding.

Table 6. Expected futures and their meaning.

Expected Futures	Meaning
Positive	It entails projecting one or more enhancement opportunities for natural or human systems.
Negative	It involves projecting one or more threats to natural or human systems' survival or living conditions.
Neutral	It entails projecting a confluence of threats and opportunities for natural and human systems, which can constrain the individual impact of each variable. Results that do not forecast a future that can be positively or negatively qualified, without accounting for other intervening variables not considered in the surveyed study, are also categorised as neutral.

Lastly, the review highlights information gaps related to Venezuela, particularly in areas such as SC4.2 and SC4.4. To address these limitations, the TA stages play a crucial role in regrouping (RG) studies based on the first and second generations of SSP scenarios, C, SC, RC, and identifying research needs (RN). Table 7 summarises the application of TA to each limitation.

Table 7. Application of TA to each methodological limitation.

Limitation	TA Stages				
	Scenario Generation	C	SC	RC	RN
Thematic diversity					
Diversity in the selection of scenarios					
Venezuela's various classification criteria					
Information gaps					

Functions of the TA stages: RG: regrouping (Green), RN: research needs (Yellow), C: Categories, SC: Subcategories, RC: Re-categorisation.

4. Results

We present the reports generated during the data extraction, each addressing a specific SM and TA. Only the article from Viloria et al. [64] focuses exclusively on Venezuela; the remaining articles are part of regional or global samples. From these documents, we extracted findings isolated in texts or images with projections for Venezuela in one or more SSP scenarios. We conserved the terminology employed within each scrutinised study and the acronyms denoting the amalgamation of SSP-RCP scenarios. Hence, SSP-RCP and RCP-SSP are used interchangeably throughout the text.

4.1. SM1: What Is the Geographical Distribution of Authors of Scientific Publications Dealing with SSP Scenarios Related to Venezuela?

Figure 2 presents a geographical representation of the distribution of research efforts, highlighting countries that have actively participated in research through the framework of shared socioeconomic pathways, with Venezuela included as part of the sample. The map categorises countries into three groups based on the number of documents contributed, considering the location of the first author. Group 1 represents countries that have contributed substantially to research, including the United Kingdom (UK) with ten articles and the United States (USA) with eight articles. China falls into Group 2 with seven articles, representing countries with moderate contributions. Group 3 includes countries that have contributed fewer than three articles, such as Colombia (3), Italy (3), Brazil (2), Japan (2), Mexico (2), Spain (2), Sweden (2), Austria (1), Benin (1), Canada (1), Ecuador (1), India (1), Korea (1), Qatar (1), Switzerland (1), and Venezuela (1).

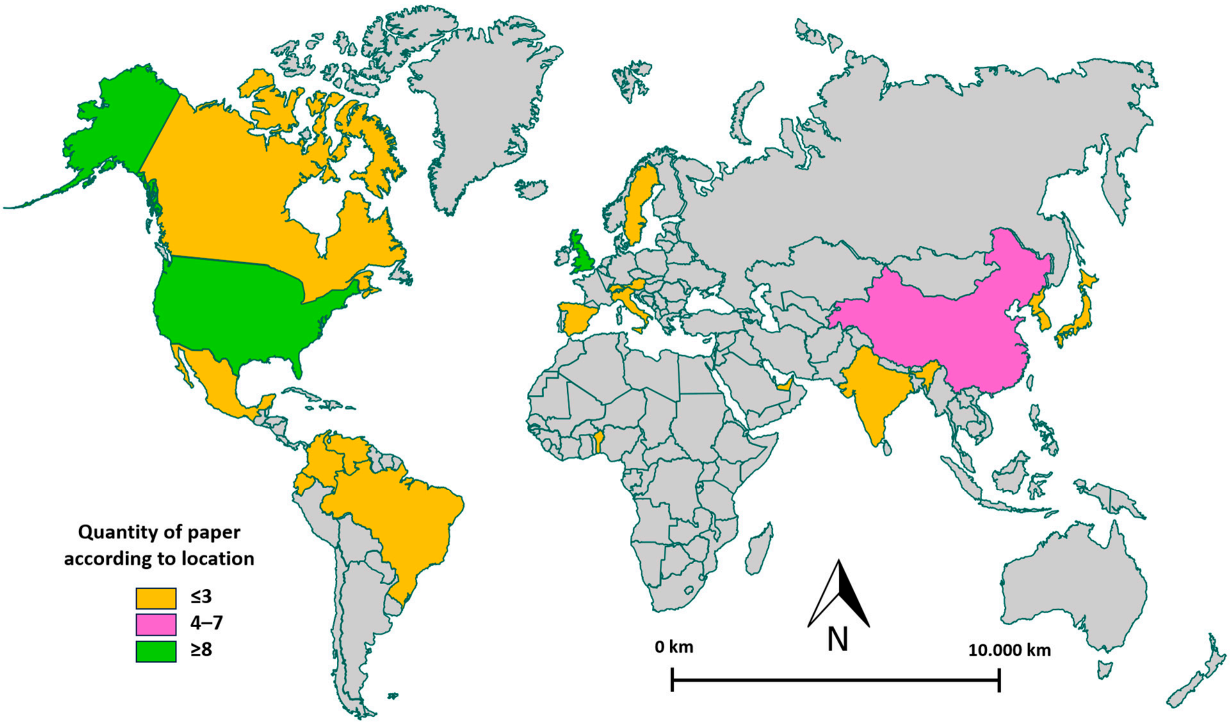


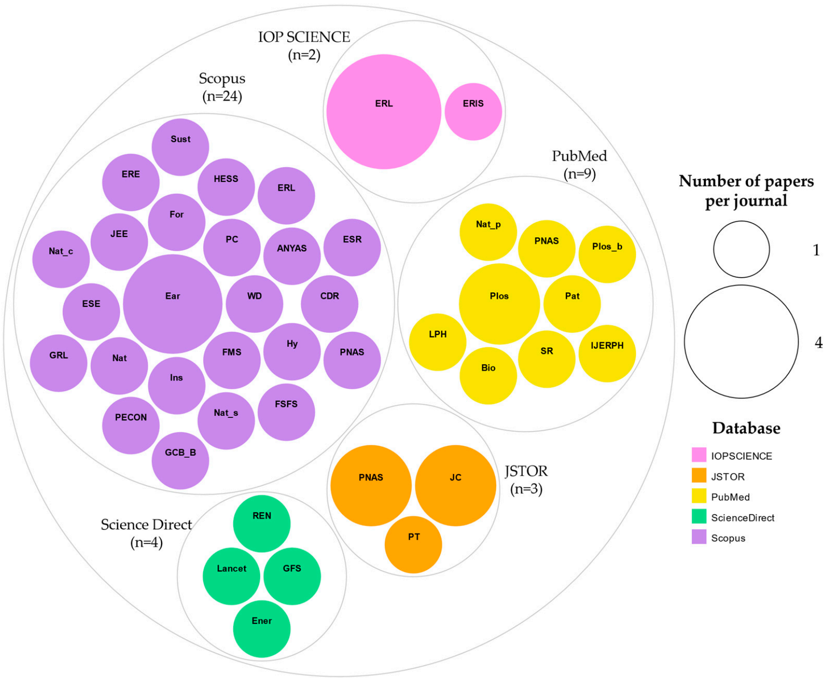
Figure 2. Geographic distribution of the first author in the scientific publications of the review and quantity of papers according to location (n = 50).

4.2. SM2: Between 2013 and 2023, Which Journals Published Studies on the First and Second Generation of SSP Scenarios Considering Venezuela's Case?

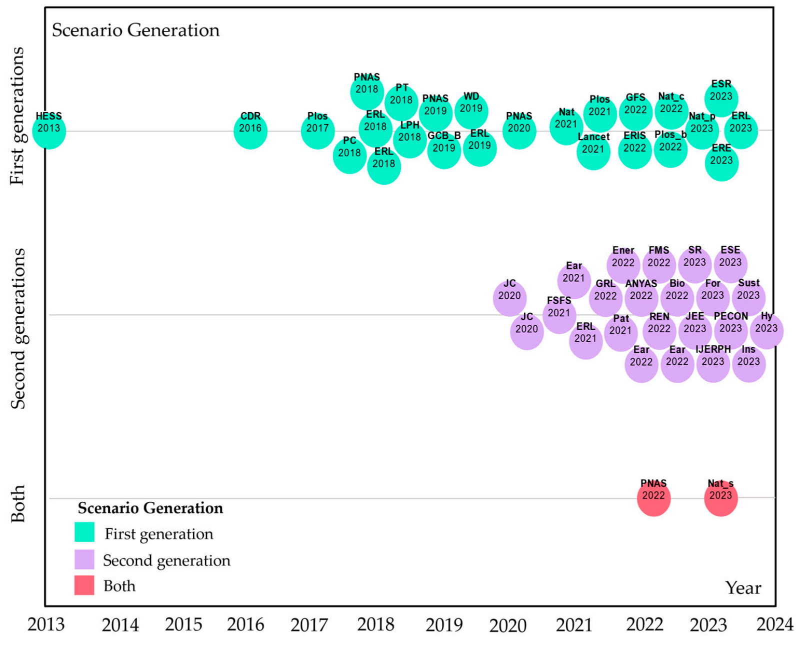
The distribution of journals per database (Figure 3a) indicates the Scopus source (n = 26), PubMed (n = 10), JSTOR (n = 5), IOP SCIENCE (n = 5), and Science Direct (n = 4). The distribution of journals in different databases shows the multidisciplinarity of the study and the breadth of perspectives addressed by the researchers, including the environment, society, health, and physics. The number of published journals indicates the scientific community's research trends, focus areas, and engagement over time (Figure 3b).

The scientific journals with the most articles published on Shared Socioeconomic Pathways (PSS) scenarios that include Venezuela are Environmental Research Letters (ERL) (n = 5), followed by Proceedings of the National Academy of Sciences (PNAS) (n = 4), Earth's Future (Ear) (n = 3), Journal of Climate (JC) and PLOS ONE (Plos) (n = 2), and with one article: Biology, The Lancet Planetary Health (LPH), Earth Systems and Environment, World Development (ESE), Nature Communications (Nat_c), Frontiers in Marine Science (FMS), Journal of Economic Entomology (JEE), The Lancet (Lancet), Global Food Security (GFS), Palgrave Communications (PC), Renewable Energy (REN), Energy Reports (Ener), Scientific Reports (SR), Nature Plants (Nat_p), Hydrology and Earth Systems Sciences (HESS), Frontiers in Sustainable Food Systems (FSFS), Forests (For), Insects (Ins), Nature Sustainability (Nat_s), Perspectives in Ecology and Conservation (PECON), Pathogens (Pat), Environmental Research: Infrastructure and Sustainability (ERIS), Economic Systems Research (ESR), Cuadernos de Desarrollo Rural (CDR), Environmental & Resource Economics (ERE), PLOS BIOLOGY (Plos_b), Annals of the New York Academy of Sciences (ANYAS), GCB Bioenergy (GCB_B), International Journal of Environmental Research and Public Health (IJERPH), Hydrology (Hy), Geophysical Research Letters (GRL), Philosophical Transactions (PT), Sustainability (Sust), and Nature (Nat).

Figure 3b illustrates that studies using the first generation of SSPs extend throughout the period considered to date. Studies based on the second generation of SSPs are presented following the introduction of the ScenarioMIP by O'Neill et al. [41]. Only two studies combined both generations of SSPs.



(**a**)



(**b**)

Figure 3. (**a**) Circle Packing of total journals per database and the number of papers per journal. Coloured circles represent each scientific journal included in the review. The circles are nested based on the consulted database. Pink circles reveal the number of articles in IOPSCIENCE, orange in JSTOR, yellow in Publimed, green in ScienceDirect, and purple in Scopus. The size of each circle indicates the number of articles per journal. (**b**) Beeswarm plot of total papers for SSP generations. Years: 2013–2023 (n = 50). Lines and colours represent the generations of SSP scenarios. Light blue corresponds to the first generation, purple to the second generation, and pink to both generations. The lines group the publications for each scenario generation. Circles indicate the journals where the consulted publications were produced and the publication year. The circled area illustrates the extent of SSP studies over the years.

4.3. SM3: In Which Fields of Knowledge and Topics Are the Studies on First and Second-Generation SSP Scenarios Located When Considering Venezuela?

The circular dendrogram (Figure 4) visualises the number of citations for various papers related to the study on exploring the potential future of Venezuela through the SSPs framework. A node on the dendrogram represents each paper, and the nodes are grouped based on their areas of knowledge [57] and more specific narrow fields within those areas.

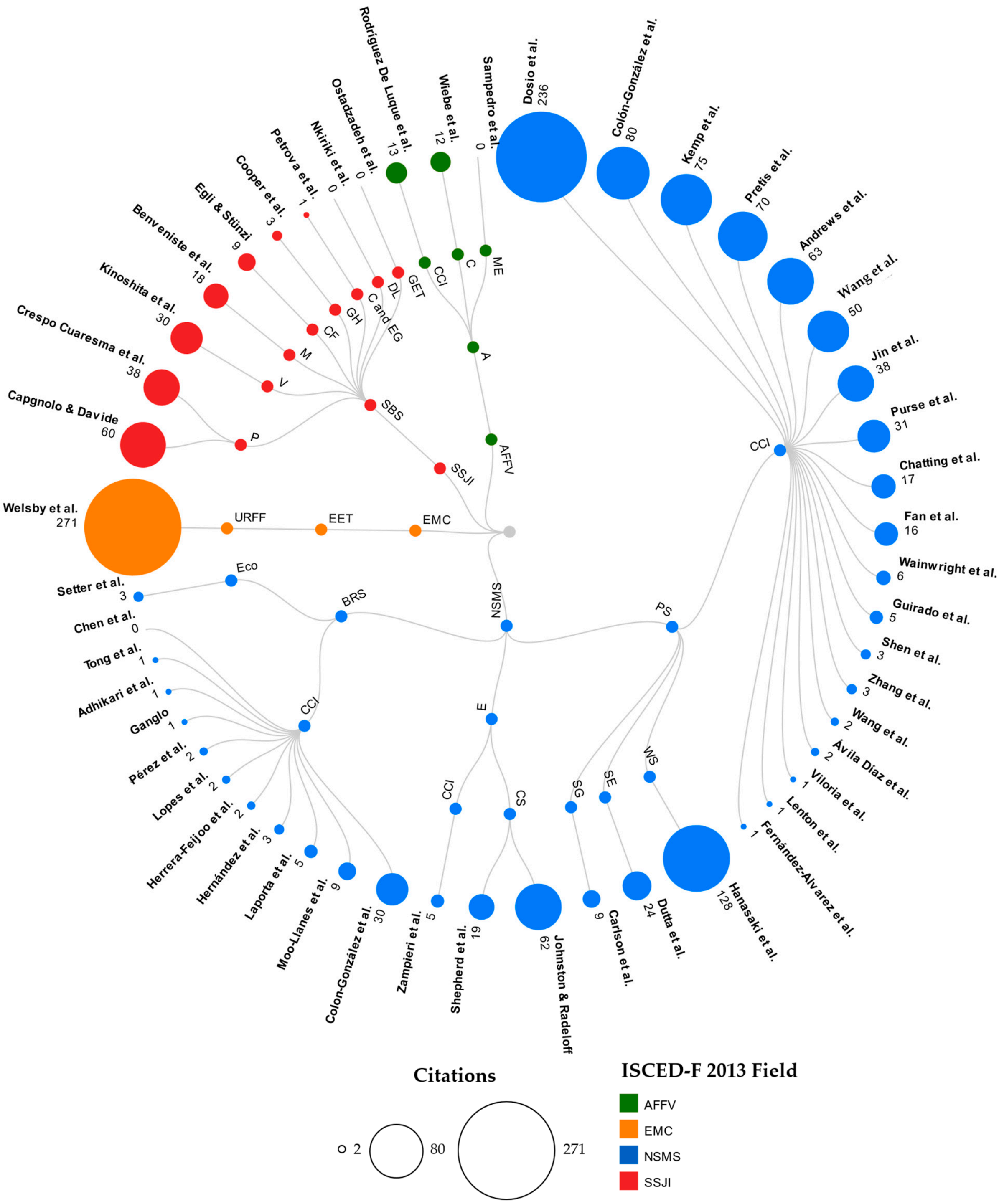


Figure 4. Circular dendrogram of the areas of knowledge scientific articles (n = 50) and their citations, Zhang et al. [4], Ávila Díaz et al. [6]; Fan et al. [63]; Viloria et al. [64]; Wang et al. [65]; Egli and Stünzi [66]; Crespo Cuaresma et al. [67]; Campagnolo and Davide [68]; Ostadzadeh et al. [69];

Adhikari et al. [70]; Andrews et al. [71]; Benveniste et al. [72]; Carlson et al. [73]; Chatting et al. [74]; Chen et al. [75]; Colón-González et al. [76]; Colón-González et al. [77]; Cooper et al. [78]; Dosio et al. [79]; Dutta et al. [80]; Fernández-Alvarez et al. [81]; Ganglo [82]; Guirado et al. [83]; Hanasaki et al. [84]; Hernández et al. [85]; Herrera-Feijoo et al. [86]; Jin et al. [87]; Johnston &and Radeloff [88]; Kemp et al. [89]; Kinoshita et al. [90]; Laporta et al. [91]; Lenton et al. [92]; Lopes et al. [93]; Moo-Llanes et al. [94]; Nkiriki et al. [95]; Pérez et al. [96]; Petrova et al. [97]; Pretis et al. [98]; Purse et al. [99]; Rodríguez De Luque et al. [100]; Sampedro et al. [101]; Setter et al. [102]; Shen et al. [103]; Shepherd et al. [104]; Tong et al. [105]; Wainwright et al. [106]; Wang et al. [107]; Welsby et al. [108]; Wiebe et al. [109]; Zampieri et al. [110]. Coloured nodes and lines represent the relationships between the Knowledge Field, Narrow Field [57], and the subject areas identified in the consulted articles. Field: Manufacturing and Construction); NSMS (Natural Sciences, Mathematics and Statistics) and SSJI (Social Sciences, Journalism, and Information). Narrow Field: (A) (Agriculture), BRS (Biological and Related Sciences), EET (Engineering and Engineering Trades) E Environment, PS (Physical Sciences) SBS (Social and Behavioural Sciences). Subject areas: CS (Carbon Sequestration), CCI (Climate Change Impacts), CF (Climate Finance), C and EG (Conflict, Economic Growth), (C) (Crops), DL (Demand for Land-based Transportation Services) Eco (Ecosystems), GET (Global Energy Trade), GH Global hunger, (M) Migration (ME) Methane Emissions, P (Poverty), SG (Solar Geoengineering) (SE) Solar Energy, (URFF) (Unextractable Reserves of Fossil Fuels), V (Vulnerability) and WS Water Scarcity Further individual article details are available in the Supplementary Materials. Box indicates: Green: AFFV; Orange: EMC; Blue: NSMS and Red SSJI. See Supplementary Materials for references [4,6,63–110].

The dendrogram is divided into sections representing different areas of knowledge, including "Natural Sciences, Mathematics and Statistics" (NSMS), "Social Sciences, Journalism, and Information" (SSJI) "Agriculture, Forestry, Fisheries and Veterinary" (AFFV), and "Engineering, Manufacturing, and Construction" (EMC). Within each area of knowledge, there are narrower fields. For example, under NSMS, there are "Physical sciences" (PS), "Biological and related sciences" (BRS), and "Environment" (E). Similarly, under SSJI, there is "Social and Behavioural Sciences" (SBS).

The connections between nodes indicate similarities in their subject matter or thematic relevance. Papers that are clustered together share common themes or research topics. Several thematic clusters can be observed. For instance, a significant cluster of documents related to "Climate change impacts" within the "Physical sciences" field is an essential focus in studying Venezuela's future.

The size of each node represents the number of citations the corresponding paper has received. Larger nodes indicate higher citation counts. Notable papers with high citation counts include those authored by Welsby et al. [108] (271 citations), Dosio et al. [79] (236 citations), and Hanasaki et al. [84] (128 citations), suggesting that these papers have made significant contributions and are central to the study's themes, so have gained more attention and recognition within the scholarly community. The dendrogram also highlights the interdisciplinarity of the research, as papers from different areas of knowledge and fields are interconnected, reflecting the multifaceted nature of exploring the potential future of Venezuela within the context of socioeconomic pathways and climate change impacts.

We organised the alluvial diagram (Figure 5) based on four main categorical dimensions: scenario generation, representative concentration pathways (RCP), thematic focus, and detailed field ISCED-F 2013 [57] (knowledge areas). According to Scenario Generation, this dimension represents different generations of scenarios or methodologies used to explore potential futures. The articles were grouped into "First generation", "Second generation", and both.

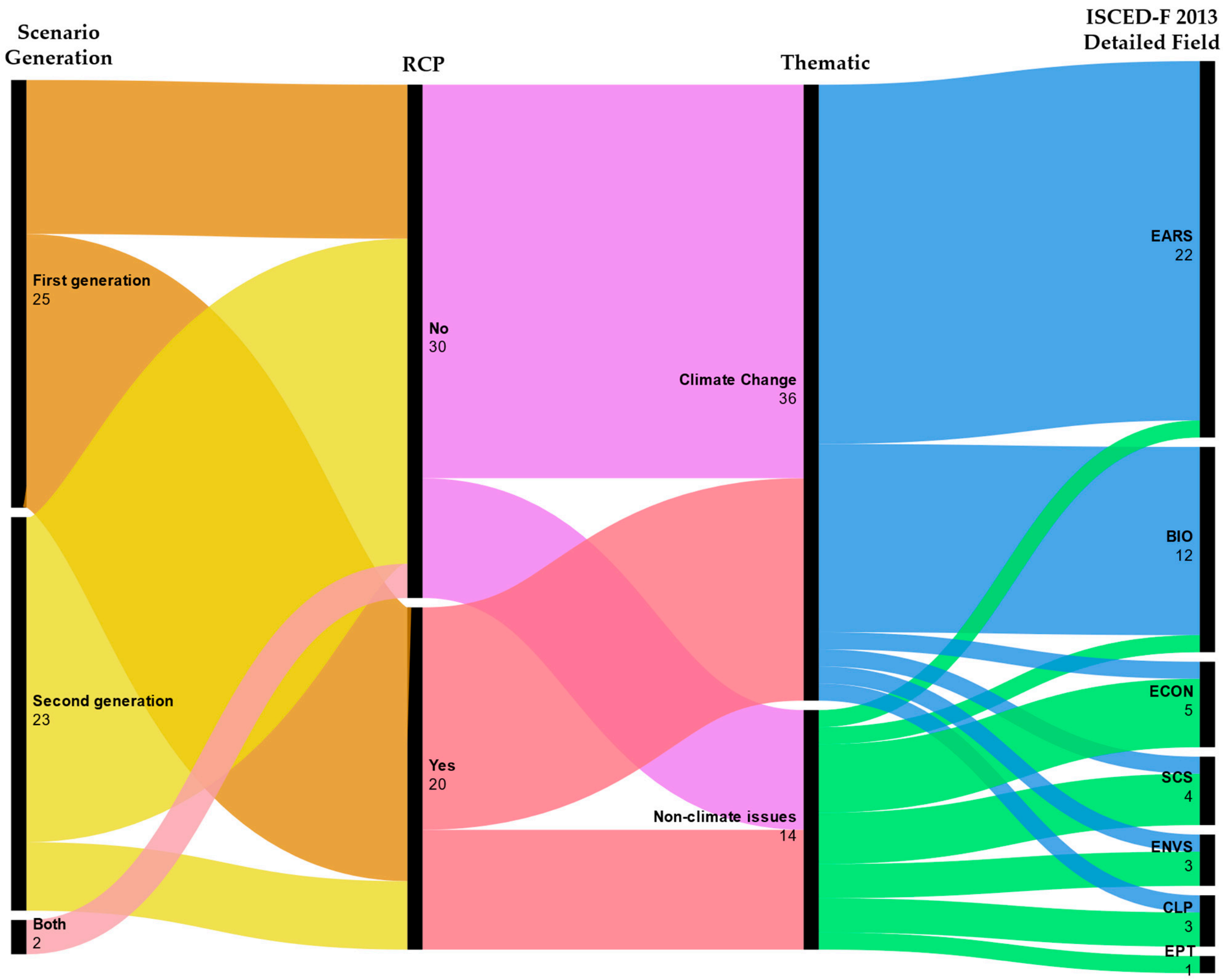


Figure 5. Alluvial diagram of the correlations between categorical dimensions Scenario Generation, Representative Concentration Pathways (RCP), Thematic Focus, and ISCED-F 2013 Detailed Field (areas of knowledge) (n = 50).

Articles were classified according to whether they use CPR ("Yes") or not ("No") and according to their thematic focus as related to "Climate Change" or "Non-climate issues". Regarding the detailed field, the articles were classified according to their specific areas of knowledge: "ENVS" (Environmental Sciences), "EARS" (Earth Sciences), "BIO" (Biology), "SCS" (Sociology and cultural studies), "CLP" (Crop and livestock production) "ECON" (Economics), and "EPT" Environmental Protection Technology.

As shown in Figure 5, most identified studies utilise the first generation of SSPs (n = 25). These articles are primarily combined with RCP scenarios when the research focuses on the BIO field. The diagram's flows indicate that studies conducted in the SCS and ECON fields adopt this SSP generation for non-climatic themes. It is worth noting that some EARS studies aimed at projecting climate change scenarios also use first-generation SSPs to provide the socioeconomic context. Studies using the second generation of SSPx-y (n = 23) tend towards the BIO CLP, EARS, ENVS, or EPT fields of knowledge.

Table 8 categorises the studies included in the review based on the scenario generation employed; the Supplementary Materials details each study's projected variables, climatic or non-climatic focus, and other aspects.

Table 8. Categorisation of Reviewed Studies.

Scenario Generation	Reference
First	Egli and Stünzi [66]; Crespo Cuaresma et al. [67]; Campagnolo and Davide [68]; Ostadzadeh et al. [69]; Andrews et al. [71]; Benveniste et al. [72]; Carlson et al. [73]; Colón-González et al. [76]; Colón-González et al. [77]; Cooper et al. [78]; Dosio et al. [79]; Guirado et al. [83]; Hanasaki et al. [84]; Johnston and Radeloff [88]; Kinoshita et al. [90]; Nkiriki et al. [95]; Petrova et al. [97]; Pretis et al. [98]; Purse et al. [99]; Rodríguez De Luque et al. [100]; Sampedro et al. [101]; Setter et al. [102]; Shepherd et al. [104]; Welsby et al. [108]; Wiebe et al. [109]
Second	Zhang et al. [4]; Ávila Díaz et al. [6]; Fan et al. [63]; Viloria et al. [64]; Wang et al. [65]; Adhikari et al. [70]; Chatting et al. [74]; Chen et al. [75]; Dutta et al. [80]; Fernández-Alvarez et al. [81]; Ganglo [82]; Hernández et al. [85]; Herrera-Feijoo et al. [86]; Jin et al. [87]; Laporta et al. [91]; Lopes et al. [93]; Moo-Llanes et al. [94]; Pérez et al. [96]; Shen et al. [103]; Tong et al. [105]; Wainwright et al. [106]; Wang et al. [107]; Zampieri et al. [110]
Both	Kemp et al. [89]; Lenton et al. [92]

4.4. TA: What Are the Main Findings and Research Needs Reported in Studies on First—And Second-Generation Scenarios of SSP Regarding the Venezuelan Case?

The categorised results in Figure 6 show a range of possible futures for Venezuela, ordered by the leading indicators given by the authors consulted. In the table, we presented the first- and second-generation scenarios (1st Scenario; 2nd Scenario) separately with their respective categories and subcategories. We classified results as positive, negative, or neutral based on the documents analysed and presented below.

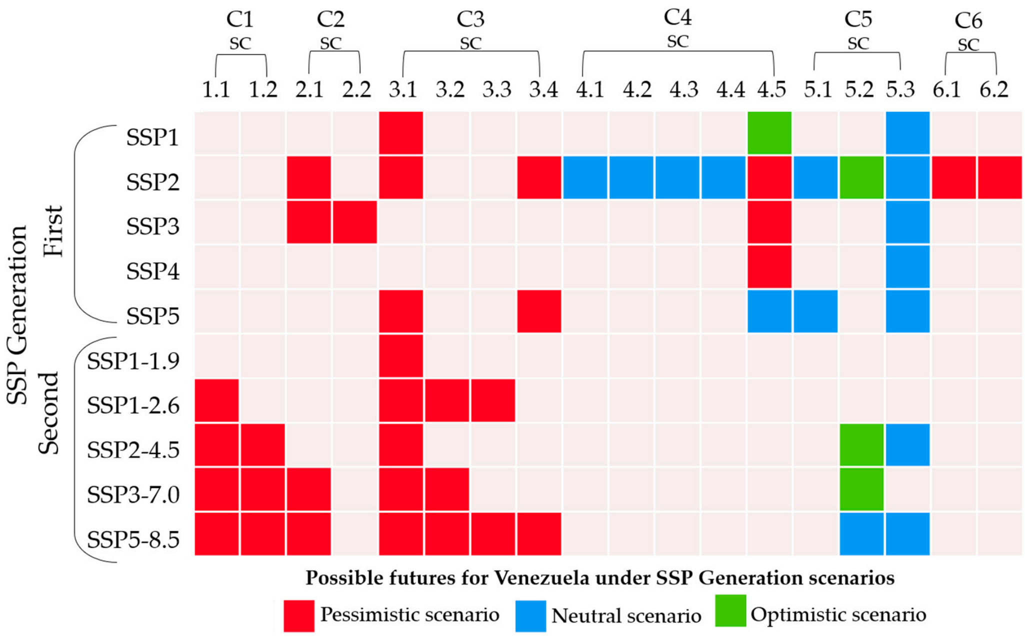


Figure 6. Possible futures for Venezuela under SSP Generation scenarios.

5. Discussion

This section discusses the literature review of the possible futures under SSP generation scenarios for categories (C) and subcategories (SC).

For C1 SC1.1, the surveyed literature shows an unfavourable climate future for Venezuela due to a projected temperature increase characterised by an increase in the number of warm days and nights and a decrease in the number of cold days, especially between 2021 and 2050 in the SSP5-8.5 scenario [6]. Some studies project climate change hotspots in all SSPx-y priority scenarios, indicating warming of 1 °C in SSP1-2.6, 2 °C in SSP2-4.5, 2.5 °C in SSP3-7.0, and 3 °C in SSP5-8.5 between 2080 and 2099. However, they suggest a hotspot will occur around 2040 [63]. From 2041 to 2060, the average annual temperature in Venezuela is projected to increase by 0.9 °C in the SSP3-7.0 scenario [64]. From 2070 to 2099, warming of 3.5 °C and 4.0 °C is projected under the SSP3-7.0 and SSP5-8.5 scenarios, respectively [4].

The consensus of several studies points to a worrying trend of warming across the country. However, further insight into the underlying assumptions and parameters of the various models used in these studies is needed to understand the basis for the observed differences in these projections. In addition, the 'emergence period' around 2040, projected by Fan et al. [63], provides an opportunity to further explore the possible catalysts for this abrupt change and its potential social and environmental impacts. The differences in warming between the different scenarios of SSP provoke debates on possible policies and ways to mitigate climate change to steer the future of Venezuela in a more sustainable and less extreme direction. These discussions suggest a spectrum of potential pathways for future climate policy, contingent upon the SSP narrative deemed both actual and feasible. It is incumbent upon policymakers to possess this strategic framework about climatic matters, thereby ensuring a proactive stance in the intermediate and long term.

For C1 SC1.2, the literature consulted consistently forecasts a decrease in rainfall in Venezuelan territory, which is a harmful trend. Under the SSP3-7.0 scenario, an average reduction of 100 mm in annual precipitation is estimated between 2041 and 2060 [64]. In the SSP2-4.5 scenario, an average decrease in rainfall of 1 mm per day is projected between 2065 and 2100 [65]. In this context, precipitation in central and northern Venezuela will likely decrease between 25 and 50 mm in the SSP3-7.0 and SSP5-8.5 scenarios [4]. Similarly, under the SSP2-4.5 scenario, the annual change in the projected monsoon year in the northern Venezuelan monsoon region will remain at 0.8 mm per day between 2065 and 2100, compared to the period from 1979 to 2014 [87].

Climate models also project more extreme precipitation and drought events in Venezuela from 2021 to 2050 in the SSP5-8.5 scenario [6]. The duration of the dry season in the central, northern, and eastern regions will increase by four days under the SSP2-4.5 scenario from 2070 to 2099, with significant changes in the north Venezuelan Amazon. In the far northwest, the dry season would lengthen by two days. In addition, dry season surface temperatures are projected to increase by 2.5 °C across the country during this period under the SSP2-4.5 scenario [106].

While the reviewed literature shows a consistent trend of decreasing precipitation, more research is needed on the possible links between changing global climate patterns, such as ocean currents and atmospheric circulation, and their local effects on precipitation in Venezuela to provide a more nuanced interpretation of these projections. Examining the factors that could lead to different impacts in central, northern, and eastern regions can shed light on the complex interplay of geography, topography, and climate dynamics in shaping the future of the country's hydrological regime.

C2 SC2.1 was rated negative. Surveyed literature indicates that Venezuela could experience extreme heat stress under +2 °C by 2100 in the SSP2 scenario [71]. Under the SSP3 scenario, Venezuela's heat wave severity index will likely reach extreme levels. In a 1.5 °C warming world, severe heat waves would occur with a return period of less than five years, while extreme heat waves could occur every 20 to 30 years. In contrast, in a world with 2 °C warming, severe and extreme heat waves could happen less than every five years, mainly in the country's north [79].

Towards the end of the 21st century, hot and dry composite summer events would increase by 0.8 to 0.9 months per year compared to the current SSP5-8.5 scenario, exposing between 10 and 20 million Venezuelans to these events [4].

By 2070, under +2.7 °C, about 55% of Venezuela's land area will be affected by extreme heat, likely disturbing between 15 and 19 million people in SSP2 [92]. Approximately

10 million people living in the north-central region of Venezuela could be exposed to extreme heat with annual temperatures above 29 °C under SSP3-7.0 scenarios. As a fragile state, Venezuela exhibits institutional, political, economic, and social vulnerabilities exacerbated by elevated temperatures [89].

All projections under the first and second SSP scenarios highlight the thresholds at which heat stress turns from discomfort to a severe public health concern. Assessing the adaptive capacity of different areas in Venezuela and evaluating potential measures to reduce the expected impacts on vulnerable populations can guide intervention measures and strategies. Furthermore, an interdisciplinary approach that considers meteorological factors and social and economic dimensions is essential to understanding the broader impacts of increasing heat stress.

For C2 SC2.2, under the SSP3-RCP2.6 scenarios, the risk of death from flooding will increase by 50% in Venezuela between 2081 and 2100. However, the risk would decrease by 30% to 50% under the other first-generation SSP scenarios. Similarly, the risk of economic losses could increase by 700% to 2000% in all SSP scenarios [90]. The projected increase in mortality risk could be better understood by examining factors such as community resilience and adaptative capacity, which helps clarify the potential vulnerabilities and challenges of this development pathway. Likewise, a detailed examination of increases in economic losses in all SSP scenarios is essential to understand the possible impacts of flooding on different economic sectors.

For C3, SC3.1 under all SSP scenarios, a negative future is plausible for Venezuela's geographical distribution of habitats and disease vectors. While some reviewed studies suggest that the potential spread of *Aedes egypti* and *A. albopictus* in Venezuela could decrease between 2021 and 2100 under the SSP3-7.0 scenario [91], under RCP2.6-SSP1, RCP2.6-SSP2, RCP4.5-SSP2, RCP6.0-SSP2, and RCP8.5- SSP5, the duration of the dengue transmission season could increase up to four months in the Andean region and the north of the Amazonas state, while it could decrease for a similar period in the rest of the country, particularly in the RCP8.5-SSP2 and RCP8.5-SSP5 scenarios during the period 2070 to 2099. Evidence shows that transmission time in the central-western region and western plains will shorten by four to five months under the RCP8.5-SSP2 and RCP8.5-SSP5 scenarios from 2070 to 2099 [77].

The expected decrease in malaria risk in some regions under the RCP8.5-SSP5 scenario could be compromised by the anticipated increase in the use of solar geoengineering to combat climate change, which could contribute to colder temperatures by 2070 [73]. For the SSP2 scenario, the number of dengue cases (in thousands) was compared under the 3.7 °C and 1.5 °C warming scenarios. The projected mean and range of absolute difference between the two scenarios are 89.7 (23.0–321.0) for the 2050s and 272.0 (43.2–1161.0) for the 2080s [76].

Under the SSP1-RCP2.6 and SSP1-RCP8.5 and SSP5-RCP2.6 and SSP5-RCP8.5 scenarios, cases of cutaneous leishmaniasis in 2050 would continue to occur in the northwestern region and Amazonas state, with an increase of about 5%. In the western and eastern plains, a decrease of about 10% is expected, with an even more significant reduction under the SSP5-RCP2.6 and SSP5-RCP8.5 scenarios [99].

Studies show that the spread of *R. parkeri*, the causative agent of rickettsial fever, is concentrated at specific points on the Venezuelan coast under scenarios SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5 [94]. In addition, under the SSP2-4.5 and SSP5-8.5 scenarios, *R. sanguineus* (dog tick) in northern Venezuela is projected to increase between 2050 and 2070 [96]. Considering the SSP5-8.5 scenario with the highest emissions, habitat suitability for *Cx tritaeniorhynchus*, a vector of Japanese encephalitis, has increased significantly in southern Venezuela [105].

It would be valuable to explore possible interactions between different disease vectors and how their overlapping distribution might exacerbate or reduce disease transmission risks. Given the dynamic nature of vector habitats, it is also essential to discuss the potential for vectors to adapt to changing conditions and the factors that influence their spread.

For C3, SC3.2, the projected spread of invasive species is another negative impact of climate change in Venezuela. For example, the number of invasive grass species would reach between seven and nine species in the western part of the country by 2100 under scenarios SSP1-2.6 and SSP3-7.0, while under scenario SSP5-8.5, the number of species is expected to be between nine and ten in the west and between seven and nine in the eastern region of the country [93].

Other studies show that the potential range of *Parthenium hysterophorus*, one of the most damaging invasive weeds in the world, will also be extensive in Venezuela under the SSP2-4.5 and SSP5-8.5 scenarios. The area of suitable habitat would increase from 183,393 km^2 between 2021 and 2040 to 192,505.5 km^2 between 2081 and 2100 under the SSP2-4.5 scenario, while it would increase from 192,334.5 km^2 between 2021 and 2040 to 192,595.5 km^2 between 2081 and 2100 under the SSP5-8.5 scenario [70].

Further exploration of methods for predicting the spread of invasive species, including incorporating factors such as biotic interactions and land-use change, could improve the reliability of these predictions. Investigating potential interactions and competition between invasive species within predicted landscapes can provide a more comprehensive understanding of their collective impacts on native ecosystems. Furthermore, discussing the possible impacts of invasive species on ecosystem services, biodiversity, and human livelihoods can highlight the urgency of effective management strategies.

For C3, SC3.3, the occurrence of pests in Venezuela in the context of climate change is highly expected and was rated negative. For example, although the potential for the spread of *Piezodorus guildinii*, a highly destructive soybean pest native to the Neotropics, will not be adequate in the country under the SSP1-2.6 scenario, favourable conditions for its spread are expected under the SSP5-8.5 scenario in 2030 to 2090 [75]. The species *Aeneolamia lepidor* and *A. reducta*, known to be the most important tropical pests of cultivated grasses in Central and South America, have more suitable habitats in Venezuela, where the projected risk is highest for 2050 under the SSP1-2.6 and SSP5-8.5 scenarios [85].

In this context, it is necessary to investigate further possible interactions between invasive pests and native species and their impact on agricultural and natural ecosystems to provide a comprehensive perspective on the cascading effects of these changes in Venezuela. Possible management strategies and interventions to counteract the projected increase in pest risk, considering both ecological and economic considerations, are also essential.

For C3, SC3.4, the future of Venezuelan biodiversity was rated negative. Species such as *Chrysophyllum albidum*, a tree from the Sapotaceae family prized in several African countries for its high nutritional value, could be successfully introduced into Venezuela around 2060 under the SSP5-8.5 scenario [82]. Additionally, under this same scenario for 2081–2100, minimal changes are expected in terms of gains or losses for the forests of the north and the non-arid lands of southern Venezuela [83].

Other studies predict that under the SSP5-8.5 scenario from 2051 to 2100, there will be significant losses in the resilience of primary vegetation production, exceeding 15% in more than 50% of the country [110]. Consequently, a negative trend is expected in SC3.4. A concrete example is the case of *Swietenia macrophylla* King (Mahogany), which is estimated to lose 56.0% of its suitable habitats by 2070 under scenario SSP5-8.5 [86]. According to the RCP4.5-SSP2 and RCP8.5-SSP5 scenarios, the ideal time for appropriate environmental conditions for coral reef ecosystems in northwestern Venezuela will permanently be exceeded after 2050 [102].

From the above, it is clear that the mechanisms responsible for the predicted losses in the resilience of primary vegetation need to be explored more deeply, especially the factors contributing to the estimated threshold of 15%. Focusing on species such as *S. macrophylla* King, which would lose suitable habitat, brings discussions on potential conservation measures, evaluation of assisted migration strategies, and broader impacts on forest ecosystem services. Addressing potential conflicts between species introductions, adaptation strategies, and native biodiversity conservation can help develop more holistic and effective approaches to managing the impacts of climate change.

For C4 SC4.1, the futures were rated neutral. The literature evidence is that under +2 °C compared to no additional warming, Venezuela's GDP per capita would decrease by 2.5% in the SSP2 scenario [98]. Similarly, under the same SSP2 scenario, Petrova et al. [97] suggest that the risk of social conflict could reduce the country's GDP by approximately 19%. However, Campagnolo and Davide [68] estimate that GDP could increase by 4% in 2030 in the SSP2 scenario if Venezuela does not implement the mitigation objectives of its unconditional commitment set at 20% by 2030.

By 2065, Venezuela's per capita income will increase more in the SSP2 scenario (>5%) than in the SSP5 (2–5%) and SSP3 (1–2%) scenarios [88]. In the SSP2 scenario, the border policy would not impact Venezuela's per capita income from remittances between 2015 and 2100, regardless of whether the border is open [72]. From the above, more studies are needed on the intervening variables related to the impact of climate change on Venezuela's GDP, such as those related to productivity, health, and social conflict.

For C4 SC4.2, future climate finance was considered neutral. Venezuela's climate financing obligation under the Paris Agreement would amount to USD 630 million per year under the SSP2 scenario [66]. The humanitarian emergency that the country faces and its extractive development style constitute a challenge to obtain financing for its mitigation commitments and to address the expected climate damages. This scenario forces the government to abandon its extractive development style in the medium term as it moves towards low-carbon development without neglecting the current needs of the population and its low capacity to adapt to climate change.

The C4 and SC4.3 scenarios were rated neutral. Despite Venezuela being one of the 20 countries worldwide where poverty would rise from 2017 to 2030 [67], the country's unambitious climate policies would contribute to a 10% reduction in poverty over the next decade within the SSP2 scenario, even if this does not result in decreased inequality [68]. Poverty in Venezuela is a historical phenomenon of a structural nature, the reduction of which would be possible within the framework of a new development approach focused on diversifying the economy, promoting individual freedoms, and improving social services such as health and education.

For C4 SC4.4, the futures were rated neutral under the SSP2 scenario. The average availability of macronutrients and minerals in Venezuela by 2030 exceeds adequate levels. The projected Vitamin Adequacy Index for a representative consumer in Venezuela shows excesses and deficiencies for a wide range of vitamins recommended daily. Under this scenario, increased agricultural productivity can lead to an increase in dietary energy intake of more than 50% by 2030 [109]. These projections can guide early adjustments in consumption and the nutritional patterns of Venezuelans. Likewise, they can facilitate the analysis of health impacts according to the availability of nutrients and vitamins in their diet.

For C4 SC4.5, the futures are positive, negative, and neutral. Venezuela's projected municipal water consumption is lower in scenarios SSP1 and SSP2, ranging from 0.8 to 1.2 $m^3\ s^{-1}$. In scenarios SSP2, SSP3, and SSP4, consumption will be higher, ranging between 1.2 and 2.0 $m^3\ s^{-1}$ and 2.0 and 4.0 $m^3\ s^{-1}$, respectively. In scenarios SSP1 and SSP5, the estimated demand for abstracted domestic water will be lower, ranging between 0.5 and 1.2 $m^3\ s^{-1}$, respectively. However, in scenarios SSP2, SSP3, and SSP4, the demand is estimated to be higher, ranging between 2.0 and 4.0 $m^3\ s^{-1}$, respectively [84].

The demand for passenger transportation services in Venezuela is projected to increase by approximately 5% between 2020 and 2050 under all SSP scenarios, while the demand for cargo services will increase by approximately 2% during the same period and in all SSP scenarios [95].

Prospective studies concerning future demands for goods and services in Venezuela, conducted within the Shared Socioeconomic Pathways (SSP) framework, necessitate thoroughly examining demographic variables. These include population density, growth, migratory balance, and the age and gender distribution of the population, as well as socioeconomic factors such as income, purchasing power, and wealth distribution. We should view these considerations in light of the potential trajectories that the humanitarian crisis may follow in the coming years. Given the current circumstances in Venezuela, it is crucial to develop a vision tailored to the existing context while also addressing the challenges and opportunities arising from this complex situation.

For C5 SC5.1, the energy international trade subcategory futures are rated as neutral. By 2050, under the SSP5 scenario, it is projected that Venezuela's bilateral energy trade relations with China and India will be among the strongest in the world. Under the SSP5 scenario, the world leadership in fossil fuel exports could shift from Russia to Venezuela, among other oil markets, accounting for 64% of global energy exports [69]. However, under the SSP2 scenario, it is expected that the percentage of non-extractable fossil fuels in Venezuela must exceed 60% for oil, more than 70% for methane, and more than 80% for coal in 2050 if the country aims to meet the global warming goal of 1.5 °C [108].

The above warns about the challenge it represents for Venezuela to join global efforts to meet climate goals and achieve more significant economic growth while maintaining its extractivist development style. The country requires further research into the short-term energy market futures to explore specific opportunities that will enable it to diversify its economy and join the energy transition that is taking place on a global scale as soon as possible.

For C5 SC5.2, the futures are considered positive to neutral. The literature review indicates that the Orinoco basin could experience a reduction in runoff under the SSP5-8.5 scenario, ranging from −15% to −30% [107], affecting hydroelectric power generation capacity. In contrast, under the SSP2 scenario, Venezuela ranks third in the world regarding bioenergy potential during the 2010–2099 and 2090–2099 periods. Between 2010 and 2099, a total yield of 0.064 Gt/year is projected, with a total energy production of 0.995 EJ/year, a total soil C gain of 4249 Mt/year, and a total C sequestration of 33.05 Mt/year. From 2090 to 2099, total crop yield would increase to 0.109 Gt/year, with total energy production of 1693 EJ/year, total C gain of 1621 Mt/year, and total C sequestration of 50.67 Mt/year [104].

Between 2081 and 2100, wind speed north of Venezuela is projected to increase by more than 0.2 m/s in the SSP2-4-5, SSP3-7.0, and SSP5-8.5 scenarios [103]. Considering SSP2-4.5 for 2049–2053, an average annual increase in wind energy density is projected with values of 80–160 W/m^2 [81].

According to the SSP2-4.5 and SSP5-8.5 scenarios, between 2015 and 2040, Venezuela's solar photovoltaic potential would increase by about 4% in the March-April-May and September-November-December seasons. However, the country's concentrated solar energy would decrease by about 2% in the September-October-November, December-January-February, and March-April-May seasons under the SSP1-2.6, SSP2-4.5, and SSP5-8.5 scenarios, respectively [80].

From the above, it is evident that Venezuela needs to conduct more detailed studies on the viability of energy transition projects, including a realistic cost-benefit analysis of its institutional, financial, and technological capacities to implement projects of this magnitude.

For C5 SC5.3, the futures of carbon storage and energy flux in Venezuela are considered neutral. Per capita carbon stocks would remain between 2 and 5 t CO_2 in 2065, while the annual carbon flux in the SSP2, SSP3, and SSP5 scenarios is estimated to be between 5 and 10 Mt CO_2. The quotient of products remaining unaccounted for by the IPCC Good Practice Guidance [111] is projected to lie between 5% and 10% by 2065 within all delineated SSP scenarios [88]. The potential carbon reserves in mangroves could range between 4.10% and 8.91% in SSP2-4.5 and between 0.45% and 9.61% in SSP5-8.5 [74].

It is well known that Venezuela needs to be more transparent in accounting for its carbon reserves, flows, and GHG emissions. Although the national scientific community makes efforts to carry out studies to estimate these requirements and draw up the respective inventories, the investment of the state and economic actors is decisive in obtaining a realistic view of the country's GHG-emitting sources and carbon sinks. With this, Venezuela can formulate the mitigation measures required to meet its NDC commitments to 2030.

For C6 SC6.1, the future scenarios for crops in Venezuela are negative. Under the SSP2 scenario, the demand, production, area, and yield of corn and beans will be negatively affected by 2045. Under the same period and SSP scenario, rice demand and cultivated area will also be affected [100].

Literature surveys reveal that the seasonal average of ozone attributable to methane during the growing season in Venezuela is 0.05 parts per billion by volume (ppbv), based on the SSP2 narrative for July 2020. The global maximum recorded is 0.12 ppbv. Relative yield losses due to methane in 2020 would vary from 0% for maise and rice to 0.06% for soybean in the SSP2 scenario in northern Venezuela [101].

In this case, it is advisable to investigate how different climatic factors affect crops, particularly those that are part of the Venezuelan essential diet, such as corn and rice. There must also be an exploration of the complex relationships between methane-induced ozone levels and crop yield losses, particularly the differences between different crops, by offering the opportunity to examine specific pathways through which air quality interacts with agricultural productivity.

For C6, SC6.2, the future of food security is negative for Venezuela. By 2030, up to 40% of Venezuelans could be affected by moderate food insecurity and 20% by severe food insecurity [78]. The proportion of the population at risk of hunger will increase by 17.8% by 2045, the highest rate in Latin America [100]. In this context, examining the possible social, economic, and political factors that could exacerbate or reduce the projected food insecurity is necessary. Short-term studies on current food insecurity and its relationship to the perceived impacts of climate change in Venezuela are needed.

6. Conclusions

This review depicts diverse futures for Venezuela under the two generations of Shared Socioeconomic Pathways (SSP) and Representative Concentration Pathways (RCP) scenarios analysed, providing a comprehensive view of the potential risks and benefits in the coming years.

First- and second-generation SSP scenarios (1st and 2nd Scenarios) project future specific risks of heat (e.g., + 2 °C by 2100 in the SSP2), flooding, vector-borne diseases (e.g., dengue, and cutaneous leishmaniasis), and a decrease in GDP per capita due to climate change in the coming decades.

The 1st Scenario paints a stark picture of Venezuela, suggesting that the country must accept its responsibility for global climate financing, which is a consequence of the environmental damage caused by its consumption of fossil fuels and its development style based on oil exports. In this context, Venezuela could become the epicentre of the global oil trade, displacing Russia. However, this is only possible if the world aligns with the SSP5 narrative, which could boost demand for Venezuela's oil due to its high energy content and low production costs.

However, 1st Scenario indicates a rise in poverty in Venezuela. Paradoxically, adopting less stringent climate policies could alleviate poverty, creating a dichotomy between poverty alleviation and climate change mitigation efforts in the current circumstances of low socioeconomic development. They also project that a significant increase in agricultural productivity could halt food insecurity. Regarding GHG emissions, the rise in methane emissions could substantially reduce the production and yields of corn and rice, jeopardising food security. Finally, they project a greater demand for transportation and water consumption services in the coming decades.

The potential futures under the above scenarios underscore the need for more research on Venezuela's current development style and the options available to adapt to the Sustainable Development Goals. Socioeconomic studies are needed to analyse the viability of development routes other than extractive, leading towards a sustainable path to enable the response to the evolution of internal demands in the context of the country's humanitarian crisis.

While Venezuela's immediate future as an oil-exporting country may seem fixed, the exploration of SSP-RCP scenarios offers a beacon of hope. If effectively implemented, these scenarios could pave the way for a future that combines growth and equity and is consistent with the national and global climate change mitigation agendas. The projections of first-generation SSP scenarios serve as a stark reminder for political decision-makers, taking high levels of poverty as a critical indicator of national vulnerability to climate change and a barrier to achieving higher levels of development. Therefore, poverty alleviation should be a part of the same process of social transformation, where enhanced equity aligns with more climate adaptation (e.g., optimising cultivation strategies, staple crops of the Venezuelan diet, improving yields while reducing methane emissions, and lowering food prices). However, poverty in Venezuela is a structural problem, recognised as a complex human crisis affecting the country for more than a decade, demanding solutions to the origin of its causes (based on oil rents).

Both the 1st and 2nd Scenarios applicable to Venezuela project an increase in temperature and a decrease in precipitation. The 1st Scenarios are based on assumptions about future societal development, while the 2nd Scenarios incorporate more detailed information about the factors that could influence these developments. Nevertheless, the projections under 2nd Scenarios are generally less conclusive than those of the first generation. Some studies project a greater frequency and alternation of severe droughts and extreme precipitation events. Therefore, Venezuela's climate futures suggest the increased occurrence of mixed (warm and arid) summer events and emergency hotspots around 2040, increasing the risks of pest spread and invasive species while affecting the biodiversity and resilience of native species and invasive species.

The trends observed in this review highlight the need to expand the scope and depth of the research using the SSPx-y (second-generation SSP) scenario framework to address the Venezuelan case specifically.

Future research should focus on potential sea-level changes, coastal geomorphology, systems with long return periods, slow biological or ecological changes that may face considerable climate changes during their life spans, and uncertainty.

Research should also address specific options identified in the studies reviewed under the first- and second-generation SSP scenarios, such as field studies, modelling, or policy analysis, so that they lead to an adequate adaptation response to future climate events and mitigation measures that contribute to compliance with the country's commitments to the 2030 climate agenda. The contributions to this research will play a crucial role in shaping Venezuela's future.

Political decision-makers, universities, scientific academies, and research centres in Venezuela bear the responsibility and challenge of aligning research efforts with the framework of the Shared Socioeconomic Pathways (SSPs). However, it is the role of political authorities to encourage, integrate, and synergistically leverage these efforts. By doing so, they can transform them into a new development agenda for Venezuela—one that allows the nation to define its own narratives regarding possible futures in the short, medium, and long term.

Finally, this study has demonstrated that a multidisciplinary approach to Shared Socioeconomic Pathways (SSPs) provides a comprehensive vision of the future to which natural and human systems will be subjected under a changing climate. The impacts of human activity, which for many researchers is known as the Anthropocene, continue to progress as this document is finalised. These impacts originate from social interactions, translating into public policies and economic activities, ultimately manifesting as environmental impacts. In essence, it is a chain of entirely interconnected factors. Each scientist can contribute essential information from their respective fields of expertise to ensure a sustainable future for humanity.

7. Limitations

Venezuela faces significant institutional constraints in achieving heightened levels of transparency concerning its national data. This predicament is exacerbated by the ongoing humanitarian crisis, which renders the establishment of a reliable baseline for comparative scenario analyses or systematic reviews exceedingly challenging. Despite existing studies on the matter, scant information exists regarding the humanitarian crisis's scope and potential evolution. Furthermore, no studies have effectively linked the narratives of diverse Shared Socioeconomic Pathways (SSPs) to a crisis-stricken nation like Venezuela. Consequently, projections concerning the socioeconomic future of this country remain inherently limited.

Thus, the primary limitation of the results presented in this study is the inability to reveal the spectrum of SSP narratives that could best fit the future of Venezuela. Upon completion of the review process, we continue to navigate uncertain terrain. Although the findings were simplified into a system of inductive categories to facilitate their identification and review, it is important to clarify that it is not possible to establish a clear trend regarding the positive or negative nature of Venezuela's futures.

Although a set of research needs has been identified, further studies are required to determine the most appropriate conceptual and methodological framework for analysing the scenarios of Venezuela's trajectories during the present century and their implications for the formulation of public policies.

Supplementary Materials: The following supporting information can be downloaded at: https://n9.cl/0lvfp, (accessed on 29 June 2024).

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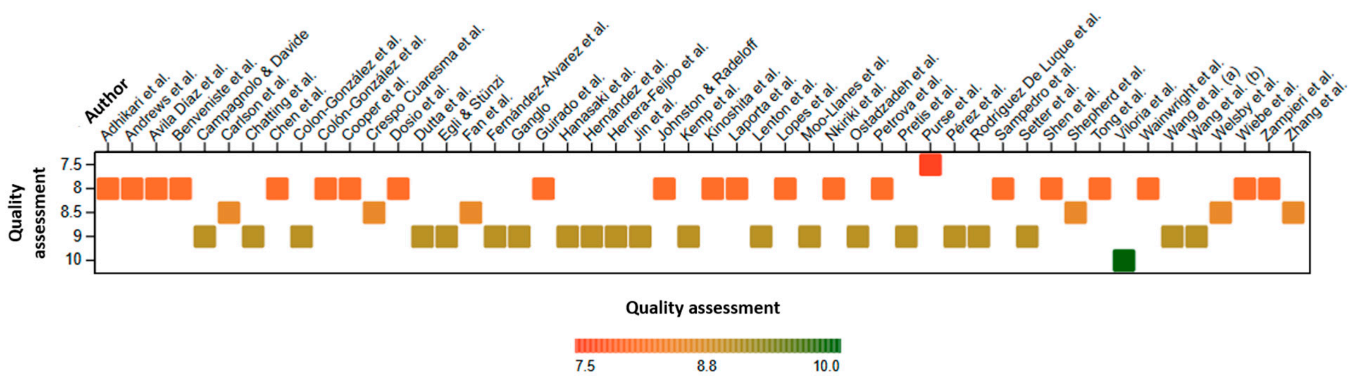
Appendix A. Quality Assessment [4,6,63–110]



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