Energy and transport research towards net zero targets and climate change mitigation. A systematic review of evidence communication for policy makers.

Evangelos Danopoulos[1], Aarushi Shah[1], Claudia Schneider[1.2], John Aston[1]

[1]Statistical Laboratory, Department of Pure Mathematics and Mathematical Statistics, University of Cambridge, United Kingdom

[2]School of Psychology, Speech and Hearing, University of Canterbury, New Zealand

Abstract

Background: Scientific studies often put forward policy recommendations (PRs) to bridge the gap between science and policy making. Climate change is one of the areas that PRs can be useful and have major impact, but only if they are based on scientific findings and are communicated trustworthily. The objective of this systematic review is to appraise the quality of PRs in the areas of green energy and transportation.

Methods: Four databases (Web of Science, Scopus, GeoRef and GreenFile) were searched from 2019. Studies with an environmental focus in the areas of green energy (wind power and hydrogen energy) and transportation that included PRs for tackling climate change or reaching net zero targets were included. The novel Evidence Communication Rules for Policy (ECR-P) critical appraisal tool was used to assess the individual study quality, specifically targeting PRs. The Collaboration for Environmental Evidence Critical Appraisal Tool (CEECAT) was also used. Findings were synthesized narratively based on ECR-P.

Results: Twenty-three studies were included, most focusing on wind power, followed by hydrogen energy and transportation. The majority of studies used econometric and empirical modelling. According to CEECAT, study quality was found to be medium to poor. ECR-P was piloted and validated, the rating results indicated poor quality of PRs across all studies. The areas addressing the papers inherent bias towards advocacy against providing information and to disclose uncertainties were found to present most concerns.

Discussion: Communication quality was markedly better regarding study findings and conclusion than PRs. Researchers must use the same scientific rigour and reporting standards in PRs as in any other section of their studies. A reporting guideline for scientific-based PRs could be of great assistance. More research in other disciplines is needed to validate our results and provide further data.

Introduction

Scientific evidence is constantly produced and disseminated, with peer-review journals being the main source of distribution. The caveat in this evidence communication would be that, in most disciplines, evidence is presented in a way to be easily recognizable by members of the same field, thus many times making it inaccessible to 'outsiders'. Although this is perfectly acceptable within the scientific community, it does create a barrier to knowledge mobilization beyond academia and even between disciplines. In addition, the number of new papers published every day even for one topic is often prohibitive for non-experts[1]. Furthermore, the quality of evidence communication will undoubtedly affect accessibility, comprehension and use in decision making[2]. Evidence communication targeted at policy makers can be seen as part of knowledge mobilization and can be part of primary research dissemination in a peer-review papers[3].

Evaluation of the outcomes of evidence communication requires conceptualization of knowledge, knowledge exchange and their intended outcomes[4]. The use of scientific evidence in policy formulation follows a versatile route and depends on a wide range of factors outside the narrow scientific plain. The wider process is often described in terms of the ROAMEF (rationale, objectives, appraisal, monitoring, evaluation, feedback) policy cycle or the policy funnel which provide a coherent conceptualization but is often criticized for not capturing the inherent complexity of the policy making reality[5]. This includes a range of stakeholders, from civil servants, specialist committees and knowledge providers to lobbyists and politicians[6]. One of the key inputs into every policy is evidence gathering and

consultation[7]. Timely access to research evidence of good quality has been recognized as a key factor in influencing the use of evidence[1].

The quality of evidence communication can be examined using the five rules for evidence communications that were recently developed by the Winton Centre for Risk and Evidence Communication[2]. This approach proposes that when scientists communicate evidence they should: inform not persuade (refrain from advocacy); offer balance, but not false balance; disclose uncertainties; state evidence quality, and; inoculate against misinformation (pre-empt misunderstandings). Notwithstanding the complexity and variety of factors and pressures contributing to the final piece of policy, scientific evidence remains in the heart of the policy making process.

Mitigating climate change and the race to reach net zero is more critical and topical than ever. The term Net Zero refers to efforts to reduce global emissions of greenhouse gases to as close to zero as possible with the rest being tackled by greenhouse gas removals either natural or technological[8]. A significant amount of scientific evidence in this area is continuously produced. The evidence often has implications for potentially invaluable policy making opportunities.

The aims of this systematic review is to identify the methods and the quality of communication of scientific evidence with policy making implications in studies with an environmental focus, and more specifically in the fields of green energy (wind power, hydrogen energy) and transportation. The aims are further tailored to the needs of a wider project focusing on offering

solutions for intractable engineering problems for net zero using AI and machine learning tools, in the areas of wind farms, safe hydrogen operations and road transport.

Objectives of the review – review questions:

- How is scientific evidence communicated in the areas of green energy (wind power, hydrogen energy) and transportation (vehicles) for net zero and climate change mitigation environmental policies?
- What it the quality of scientific evidence communication in the areas of green energy (wind power, hydrogen energy) and transportation (vehicles) for net zero and climate change mitigation environmental policies?

Methods

The systematic review followed the guidance specified in the Cochrane Handbook for Systematic Reviews of Interventions[9] and the guidance by the Centre for Reviews Dissemination[10], while reporting is based on the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement[11]. The research protocol was published on the Research Registry (UIN: reviewregistry1795).

Eligibility criteria and search strategy

According to the eligibility criteria, only research with an environmental focus in the areas of green energy, specifically wind power and hydrogen energy, and transportation (road vehicles) were included. Research design could either be experimental, observational, computational or case studies, including those based on machine learning and artificial intelligence. In addition, only studies reporting on an outcome of policy implications/recommendations for climate change mitigation or/and

reaching net zero targets (decarbonisation) were to be included. There was no limitation on the study publication language but only studies published in the last five years were included. The five-year limit is in line with the scope and the research objectives of this systematic review, focusing of the current state of evidence communication. This time limit was also reflected in the search strategy. Systematic reviews were only included for reference checking and background information. Reviews, opinion pieces, commentaries, perspective articles, economic studies and any type of conference abstracts were excluded.

Multiple online data bases/sources were searched from 2019 to present. The final searches were executed on 08-02-2024. The Web of Science core collection and Scopus were searched as multidisciplinary sources. In addition, the subject specific databases GeoRef and GreenFile were also searched in order to identify any additional geoscience and ecology literature. Separate search strategies were developed for each database according to their configuration. In addition, in order to validate that all relevant studies were included, the reference lists of the systematic reviews that were identified by the search strategy were hand searched. Search strategies were piloted before the final version in order to achieve a balance between sensitivity and specificity. There were no restrictions on publication status or publication language. Search terms included: net zero; climate change; renewable/ sustainable/ green; energy/ power/ fuel; transportation; wind; hydrogen; policy recommendation/ implication/ suggestion; policy making; policy makers, etc. The full search strategy including the applied Boolean operators is reported in supplementary material 1.

Selection and data collection process

The citations of the articles identified by the search strategy were extracted and managed using EndNote software. EndNote was also be used for the initial de-duplication of the records. Screening of the identified records was executed independently by two reviewers (ED, AS) in two stages. In the first stage titles and abstracts were screened against the eligibility criteria. Discrepancies between the reviewers were resolved by consensus and by seeking advice from a third reviewer (JA). Full papers were consequently retrieved for the records which fulfilled the eligibility criteria. These full papers were then screened in the second screening stage following the same method.

Data were extracted in pre-piloted data extraction forms (Excel) by one reviewer (ED) and checked by a second reviewer (AS). Disagreements between the reviewers were resolved by consensus and by seeking advice from a third reviewer (JA). The following data items were extracted: study design; discipline; language; methodology; methods; data source; area of research; country; study aims; funding; primary/secondary outcomes; study conclusions; policy recommendations; limitations. The key outcome the systematic review focused on was policy recommendations (PRs).

Study risk of bias assessment and synthesis

Risk of bias was based on the Collaboration for Environmental Evidence Critical Appraisal Tool (CEECAT) Version 0.3[12], using five criteria: risk of confounding biases, risk of selection biases, risk of detection biases, risk of outcome reporting biases, and risk of outcome assessment biases. The

overall rating attributed by this tool is low risk of bias (RoB), medium RoB and high RoB, denoting high quality, medium quality and low quality, respectively.

In line with the methodological focus of this systematic review the Evidence Communication Rules for Policy (ECR-P) critical appraisal tool was also used. This is a novel critical appraisal tool that was used for assessing the quality of evidence communication specifically focusing on PRs. The conceptualization of the tool was based of the five rules for evidence communication as developed by the Winton Centre for Risk and Evidence Communication[2]. This novel critical appraisal tool can be found in supplementary file 2. The overall risk of bias assessment followed the guidelines proposed by the Cochrane collaboration[9].

Quality assessment, using both tools, was executed by one reviewer (ED) and checked by a second one (AS). Any discrepancies were resolved by consensus. A third reviewer (JA) was consulted when issues remained after consensus. The results of the quality appraisal are used in evidence synthesis addressing individual study quality as well as the quality of the overall body of evidence.

Extracted data were only suitable for narrative synthesis and analysis. Data are presented in tabular form and figures and summarized in text. Heterogeneity of studies and quality are discussed in the narrative synthesis.

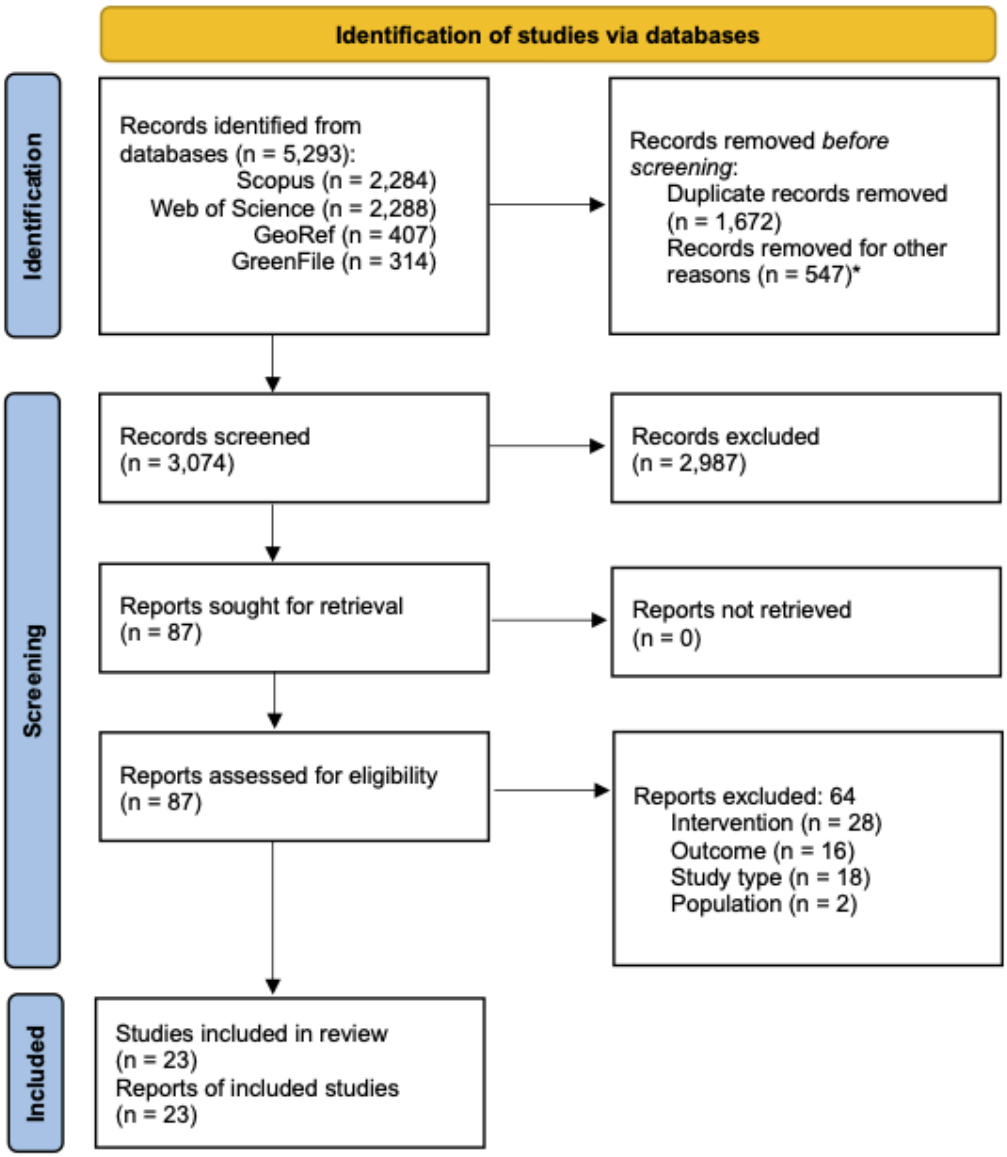
Results

Study selection and study characteristics

The search strategies in the four bibliographic databases identified 5,293 records, which were reduced to 3,621 unique records after deduplication. In addition, 547 further records were excluded as their type was beyond the scope of this systematic review, thus leaving 3,074 records for the first stage of screening. During titles and abstracts-based screening, 87 records met the eligibility criteria and were sought for the second stage of full paper screening. Twenty-three studies[13-35] were ultimately included in the systematic review concluding the full paper screening. The selection process, including the reasons for exclusion during full paper screening, is illustrated in a PRISMA flowchart in Figure 1. A list of the excluded studies along with the reason for exclusion can be found in Table S1.

Details of the included studies are presented in Table 1. Out of the 23 studies, 18[15-32] included wind power as an intervention in tackling climate change or reaching the net zero target (decarbonization), while one focused on hydrogen[35] and one[33] on transportation alone. Three studies focused on more than one of the themes of this systematic review. One study[13] looked at both wind power and transportation, one[14] at both wind power and hydrogen energy and one[34] at both hydrogen energy and transportation.

Figure 1: PRISMA flow diagram



*Records of books (n = 268), conference proceedings (n = 179) and theses (n = 100), were removed before screening as they are beyond the focus of this SLR.

Fifteen of the studies focused their analysis on one country and the rest eight on multiple countries (Table 1). The vast majority of the studies used a type of modelling for their analysis. Most studies (14 out of 23) employed an econometric methodology in their analysis, three used traditional modelling approaches and two energy system modelling. Economic modelling, dynamic risk transmission modelling, multiple criteria decision-making

modelling were used by each of the remaining studies, while there was also a case study. Further details on the applied methods can be found in Table 1.

Only one study[31] collected primary data for their analysis using a bespoke online portal. The rest of the studies used a mix of sources for the modelling data coming from: publicly available sources, such as the World Development Indicators (WDI) from the World Bank databank[36] and International Energy Agency (IEA) reports[37]; national authorities/companies, such as the National energy Council of Indonesia (DEN) and the Korea electric power corporation (KOSIS); data from peer-reviewed papers; and, data from commercial companies such as the PB energy outlook reports[38] (Table 1).

Table 1. Study details

Study	Area of research	Methodology	Methods	Data source (for models)	Research country of origin	Research country focus	Intervention
Jahanger et al. 2023 [17]	wind power	econometric / empirical modelling	MMQR; DK-SE	WDI	China, United Arab Emirates, Turkey, Taiwan, Nigeria, Australia, Bangladesh	10 countries[a]	Technology and renewable energy impact on energy efficiency and carbon neutrality
Zhao et al. 2023 [18]	wind power	econometric / empirical modelling	IV-GMM	WDI, BP	China	77 countries[b]	Renewable energy use for carbon unlocking
Raihan et al. 2023 [19]	wind power	econometric / empirical modelling	ARDL; DOLS	WDI	Malaysia	Thailand	Dynamic effects of economic growth, renewable energy use, urbanization, industrialization, tourism, agricultural productivity, and forest area on CO^2 emissions in

							Thailand.
Hossain et al. 2023 [20]	wind power	econometric / empirical modelling	DARDL; ARDL; FMOLS	BP, OECD, WDI, peer-reviewed paper	Bangladesh, China, Australia, USA	USA	Eco-innovation, nuclear energy consumption, fossil fuel consumption, and renewable energy consumption impact on Load Capacity Factor
Raihan et al. 2022 [21]	wind power	econometric / empirical modelling	DOLS	WDI	Malaysia	Turkey	Dynamic effects of economic growth, renewable energy use, urbanization, industrialization, tourism, agricultural productivity, and forest area on CO^2 emissions in Turkey.
Raihan et al. 2022 [22]	wind power	econometric / empirical modelling	ARDL; DOLS	WDI	Malaysia	Bangladesh	Dynamic impacts of economic growth, renewable energy use, and technological innovation on CO^2 emissions in Bangladesh
Raihan et al. 2022 [23]	wind power	econometric / empirical modelling	ARDL; DOLS	WDI	Malaysia	Bangladesh	Dynamic impacts of economic growth, renewable energy use, urbanization, industrialization, technological

							innovation, and forest area on CO^2 emissions
Raihan et al. 2022 [24]	wind power	econometric / empirical modelling	ARDL; DOLS	WDI	Malaysia	Peru	Dynamic impacts of economic growth, renewable energy use, and agricultural land expansion on CO^2 emissions
Horobet et al. 2022 [25]	wind power	econometric / empirical modelling	dynamic system-GMM panel model	OWID, WDI	Romania	163 countries, (not specified)	Contribution of nuclear, fossil (coal, oil, and gas), and renewable (hydro, solar, wind, biofuel) electricity sources to pollution measured as tonnes of CO^2
Obobisa et al. 2022 [26]	wind power	econometric / empirical modelling	AMG; CCEMG	WDI	China	73 countries[c]	Financial development, renewable energy consumption, fossil fuel energy consumption, and economic growth effect on CO^2 emissions
Cheng et al. 2021 [27]	wind power	econometric / empirical modelling	OLS; MG; CCEMG; AMG; PMG; DFE	China Statistical Yearbook, China Energy Statistical	China	China (30 provinces[d])	Impact of renewable energy technology innovation on carbon intensity with provincial panel data

				Yearbook, CEIC, PSS-System by CNIPA			in China
Cheng et al. 2019 [28]	wind power	econometric / empirical modelling	OLS; fixed-effect panel quantile regression	WDI, OECD	China, UK	BRIICS	The effects of six determinant variables (renewable energy supply, development of environmental patents, economic growth, exports, foreign direct investment and domestic credit to the private sector) on the CO^2 emissions per capita from 2000 to 2013 for the BRIICS countries.
Sun et al. 2022 [29]	wind power	economic modelling	multi-hierarchy meta-frontier DEA	IEA, BP	China	58 countries[e]	CO^2 reduction inefficiency and potential in nuclear power and three renewable power industries (wind power, solar power, hydro power) in 58 countries.
Song et al. 2023 [15]	wind power	case study/ observational	descriptive statistics	Chongming statistical yearbooks	China	China, Chongming island	Energy transition analysis of Chongming's world-

							class ecological island.
Zhao et al. 2023 [16]	wind power	dynamic risk transmission modelling	network modelling; cascading failure framework and linear threshold model	UN COMTRADE	China	211 countries[f]	Mitigation of risk in the global wind turbine trade network.
Handayani et al. 2019 [30]	wind power	energy system modelling	LEAP model	PLN, DEN, DJK-ESDM	The Netherlands, Indonesia, Australia	Indonesia	Five scenarios for the Java-Bali electricity system's expansion to satisfy the projected future demand to achieve renewable energy targets.
Govindarajan et al. 2021 [31]	wind power	modelling	evaluation framework: building a renewable energy index based on 3 composite indicators	Bespoke online portal	India	India,45 cities (not defined)	Climate Smart Cities Assessment Framework on the use of renewable energy for electricity in 45 Indian cities under smart city mission.
Ifaei et al. 2022 [32]	wind power	TESE analysis; *MCDM approach*	deep and stacked neural networks; HOMER;	KMA, KPX, K-water, KEPCO, KOSIS; peer-reviewed	South Korea, Australia	South Korea	Sustainability challenges in the Korean energy sector.

			WEC nexus model; multi-variate statistical analysis; FA-TOPSIS; stochastic linear mathematical model	papers			
Sun et al. 2023 [13]	wind power; transportation	econometric / empirical modelling	CCEMG; AMG; Dumitrescu and Hurlin's panel causality analysis	WDI; IEA; BP	China, Australia, The Netherlands	5 countries[g]	Role of electric vehicles in alleviating environmental pollution and impact of using renewable energy on CO^2.
Gilmore et al. 2023 [14]	wind power; hydrogen energy	modelling	TSSolver	Australian Energy Market Operator	Australia	Australia	Optimal mix of firming technologies (pumped hydro, batteries and 'zero emission' open-cycle gas turbines) so that Australia's National Electricity Market can be supplied by 100% variable renewable energy.
Calvillo et al. 2020 [33]	transportation	energy system modelling	Integrated MARKAL-EFOM	UK DfT, IEA, ENSG, Scottish	UK	UK	Impacts of the planned large-scale EV rollout in the UK in

			(TIMES); UKTM	Power, National Grid, Bloomberg New Energy Finance, peer-revied papers			terms of network investments, changes in fuel use, fuel cost and emissions;
Logan et al. 2020 [34]	hydrogen energy; transportation	modelling	TEAM-UK; further scenario modelling developed by the authors	BEIS, CCC, World Nuclear Association, National Grid	UK, Australia	UK	Use of electric and hydrogen buses to reduce greenhouse emissions.
Qadeer et al. 2023 [35]	hydrogen energy	econometric / empirical modelling	quantile-on-quantile regression	CSIRO, daily market index of Australia, Australian Parliament	China; Malaysia; Saudi Arabia	Australia	Hydrogen energy for reducing emissions.

AMG, Augmented mean group; ARDL, Autoregressive Distributed Lag; BEIS, Department for Business, Energy and Industrial Strategy; BRIICS, Brazil, Russia Federation, India, Indonesia, China and South Africa; CCEMG, Common Correlated Effects Mean Group; CCC, Committee on Climate Change; CNIPA, China National Intellectual Property Administration; CSIRO, Commonwealth Scientific and Industrial Research Organization; DEA, data envelopment analysis; DEN, National energy Council of Indonesia; DFE, Dynamic Fixed Effect; DfT, Department for Transport; DJK-ESDM, Ministry of Energy and Mineral Resources of Indonesia; DK-SE, Driscoll and Kraay estimators; DARDL, dynamic autoregressive distributed lag simulation; DOLS, Dynamic Ordinary Least Squares; ENSG, Electricity Networks Strategy Group; FA-TOPSIS, factor analysis-based technique for order-preference by similarity to the ideal solution technique; FMOLS, Fully Modified Ordinary Least Squares; GMM, generalized method of moments; HOMER, Hybrid Optimization Model for Electric Renewables; IEA, International Energy Agency; IV-GMM, instrumental variable-

generalized method of moments; KEPCO, Korea electric power corporation; KMA, Korea meteorological agency; KOSIS, Korean statistical information service; KPX, Korea power exchange; K-water, Korea Water Resources Corporation; MCDM, multiple-criteria decision making; MG, Mean Group; MMQR, method of moments quantile regression; LEAP, Long-range Energy Alternative Planning; PMG, Pooled Mean Group; PLN, Perusahaan Listrik Negara (State Electricity Company of Indonesia); PSS-System, Patent Search and Analysis System; TEAM-UK, Transport Energy Air Pollution Model for the UK; TESE, technological, economic, sociological, and environmental; TSSolver, Time Sequential Solver (linear programming tool); UKTM, UK TIMES energy system model; UN COMTRADE, United Nations Commodity Trade Statistics; WEC, Water-energy-carbon WDI, World Development Indicators

[a]China, the United Kingdom, Italy, Germany, Japan, Indonesia, South Korea, India, France, and the United States.
[b]Canada, Mexico, US, Argentina, Brazil, Chile, Colombia, Ecuador, Peru, Trinidad & Tobago, Venezuela, Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Netherlands, North Macedonia, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom, Azerbaijan, Belarus, Kazakhstan, Russian Federation, Turkmenistan, Uzbekistan, Iran, Iraq, Israel, Kuwait, Oman, Qatar, Saudi Arabia, United Arab Emirates, Algeria, Egypt, Morocco, South Africa, Australia, Bangladesh, China, India, Indonesia, Japan, Malaysia, New Zealand, Pakistan, Philippines, Singapore, South Korea, Sri Lanka, Thailand, Vietnam
[c]Algeria, Argentina, Australia, Austria, Bangladesh, Belgium, Benin, Botswana, Brazil, Cambodia, Cameroon, Canada, China, Colombia, Congo, Dem. Rep., Congo, Rep., Cote d'Ivoire, Croatia, Czech Republic, Denmark, Egypt, Eritrea, Ethiopia, Finland, France, Gabon, Germany, Ghana, Greece, Haiti, Hungary, India, Indonesia, Ireland, Italy, Jamaica, Japan, Kenya, Libya, Luxembourg, Malaysia, Mauritius, Mexico, Mongolia, Mozambique, Myanmar, Nepal, Netherlands, Nigeria, Norway, Pakistan, Paraguay, Peru, Philippines, Poland, Portugal , Russian Federation, Senegal, Singapore, South Africa, South Korea, Spain, Sudan, Sweden, Switzerland, Tanzania, Thailand, Togo, Tunisia, United Kingdom, United States, Vietnam, Zimbabwe
[d]Beijing, Anhui, Chongqing, Fujian, Gansu, Guangdong, Guangxi, Guizhou, Hainan, Hebei, Heilongjiang, Henan, Hubei, Hunan, Inner Mongolia, Jiangsu, Jiangxi, Jilin, Liaoning, Ningxia ,Qinghai, Shaanxi, Shandong, Shanghai, Shanxi, Sichuan, Tianjin, Xinjiang, Yunnan, Zhejiang
[e]Argentina, Australia, Austria, Bangladesh, Belgium, Brazil, Bulgaria, Canada, Chile, China, Chinese Taipei, Colombia, Croatia, Czech Republic, Denmark, Ecuador, Finland, France, Germany, Greece, Hungary, Iceland, India, Indonesia, Iran, Ireland, Israel, Italy, Japan, Kazakhstan, Korea, Lithuania, Luxembourg, Malaysia, Mexico, Netherlands, New Zealand, Norway, Pakistan, Peru,

Philippines, Poland, Portugal, Romania, Russian Federation, Slovak Republic, Slovenia, Spain, Sri Lanka, Sweden, Switzerland, Thailand, Turkey, Ukraine, United Kingdom, United States, Venezuela, Vietnam

[f]Afghanistan, Albania, Algeria, Andorra, Angola, Antigua and Barbuda, Argentina, Armenia, Aruba, Australia, Austria, Azerbaijan, Bahamas, Bahrain, Bangladesh, Barbados, Belarus, Belgium, Belize, Benin, Bermuda, Bhutan, Bolivia (Plurinational State of), Bosnia Herzegovina, Botswana, Brazil, Brunei Darussalam, Bulgaria, Burkina Faso, Burundi, Cabo Verde, Cambodia, Cameroon, Canada, Cayman Isds, Central African Rep., Chad, Chile, China, China, Hong Kong SAR, China, Macao SAR, Christmas Isds, Colombia, Comoros, Congo, Cook Isds, Costa Rica, Côte d'Ivoire, Croatia, Cuba, Curaçao, Cyprus, Czechia, Dem. People's Rep. of Korea, Dem. Rep. of the Congo, Denmark, Djibouti, Dominica, Dominican Rep., Ecuador, Egypt, El Salvador, Equatorial Guinea, Estonia, Eswatini, Ethiopia, Faeroe Isds, Falkland Isds (Malvinas), Fiji, Finland, France, French Polynesia, Gabon, Gambia, Georgia, Germany, Ghana, Gibraltar, Greece, Greenland, Grenada, Guam, Guatemala, Guinea, Guinea-Bissau, Guyana, Haiti, Honduras, Hungary, Iceland, India, Indonesia, Iran, Iraq, Ireland, Israel, Italy, Jamaica, Japan, Jordan, Kazakhstan, Kenya, Kiribati, Kuwait, Kyrgyzstan, Lao People's Dem. Rep., Latvia, Lebanon, Lesotho, Liberia, Libya, Lithuania, Luxembourg, Madagascar, Malawi, Malaysia, Maldives, Mali, Malta, Marshall Isds, Mauritania, Mauritius, Mayotte, Mexico, Mongolia, Montenegro, Montserrat, Morocco, Mozambique, Myanmar, Namibia, Nauru, Nepal, Netherlands, New Caledonia, New Zealand, Nicaragua, Niger, Nigeria, North Macedonia, Norway, Oman, Pakistan, Palau, Panama, Papua New Guinea, Paraguay, Peru, Philippines, Poland, Portugal, Qatar, Rep. of Korea, Rep. of Moldova, Romania, Russian Federation, Rwanda, Saint Barthélemy, Saint Helena, Saint Kitts and Nevis, Saint Lucia, Saint Maarten, Saint Pierre and Miquelon, Saint Vincent and the Grenadines, Samoa, San Marino, Sao Tome and Principe, Saudi Arabia, Senegal, Serbia, Seychelles, Sierra Leone, Singapore, Slovakia, Slovenia, Solomon Isds, Somalia, South Africa, Spain, Sri Lanka, State of Palestine, Sudan, Suriname, Sweden, Switzerland, Syria, Tajikistan, Thailand, Timor-Leste, Togo, Tonga, Trinidad and Tobago, Tunisia, Turkey, Turkmenistan, Turks and Caicos Isds, Uganda, Ukraine, United Arab Emirates, United Kingdom, United Rep. of Tanzania, Uruguay, USA, Uzbekistan, Vanuatu, Venezuela, Viet Nam, Wallis and Futuna Isds, Yemen, Zambia, Zimbabwe

[g]United States of America (USA), China, Germany, France, and Norway.

Results of individual studies

The focus of the interventions and the measured outcomes varied. Two studies [25,31] did not specify the geographic areas that their analysis focused on. Fourteen studies employed econometric-empirical modelling and 10[13,17,19,21-26,28] of them used CO_2 emissions as their dependent variable, which was the focus of their analysis. Amongst these studies the independent variables used in the modelling varied substantially (Table 2). Only two independent variables, namely the use of renewable energies and economic growth was used in all studies. Therefore, a direct comparison of the studies' findings and PRs is not feasible.

Only two studies[14,33] defined PRs as primary outcomes. The PRs made by the studies often expanded beyond the scope of this systematic review, hence only the PRs relevant to climate change mitigation and/or reaching net zero targets were extracted, in line with the eligibility criteria. The full PRs can be found in Table S2. Themes of the PRs included fiscal measures, technology integration, environmental awareness, international collaborations etc. The majority of the studies presented their PRs in a separate section right after the discussion section, either following or preceding the conclusions section.

Table 2. Econometric studies modelling details.

Study	Model independent variables	Model depended variable
Qadeer et al. 2023[35]	GDP (economic growth), trade openness, population	carbon emissions, methane emissions, nitrous emissions
Zhao et al. 2023[18]	renewable energy consumption, economic development, industry	carbon lock-in

	structure, international trade, and urbanization	
	industry lock-in, institution lock-in, technology lock-in, and society lock-in	integrated international carbon lock-in index
Raihan et al. 2023[19]	economic growth, renewable energy use, urbanization, industrialization, tourism, agricultural productivity, and forest area	CO_2 emissions
Jahanger et al. 2023[17]	economic growth (GDP), consumption of renewable energy, technology, variable manufacturing sector, energy efficiency	greenhouse gas emissions (GHGs) measured in kilograms (Kt) of CO_2 equivalent
Sun et al. 2023[13]	Electric vehicles, GDP, population, urbanization, renewable energy consumption	CO_2 emissions
Raihan et al. 2022[21]	economic growth, renewable energy use, urbanization, industrialization, tourism, agricultural productivity, and forest area	CO_2 emissions
Raihan et al. 2022[22]	economic growth, renewable energy use, and technological innovation	CO_2 emissions
Raihan et al. 2022[23]	economic growth, renewable energy use, urbanization, industrialization, technological innovation, and forest area	CO_2 emissions
Horobet et al. 2022[25]	Share of electricity generation that comes from fossil fuels (coal, oil and gas combined); nuclear power; solar power, wind power; biofuels; hydropower, GDP. trade openness	Per capita greenhouse-gas emissions produced in the generation of electricity (measured in million tonnes of CO_2 equivalent); Carbon intensity of electricity production
Raihan et al. 2022[24]	economic growth, renewable energy use, and agricultural land expansion	CO_2 emissions
Obobisa et al. 2022[26]	financial development, renewable energy consumption, fossil fuel energy consumption, economic growth, and economic growth square.	CO_2 emissions

Cheng et al. 2021[27]	Renewable energy technology innovation, industrial structure, energy consumption structure, and urbanization rate	carbon intensity (ratio of total CO_2 emissions to real GRP)
Cheng et al. 2019[28]	renewable energy supply, development of environment-related technologies, GDP, exports of goods and services, foreign direct investment and domestic credit to private sector	CO_2 emission per capita
Hossain et al. 2023[20]	GDP, eco-innovation, nuclear energy consumption, fossil fuel consumption and renewable energy consumption	impact on Load Capacity Factor (Load Capacity Factor (LCF) =Biocapacity per capita/Ecological footprint per capita)

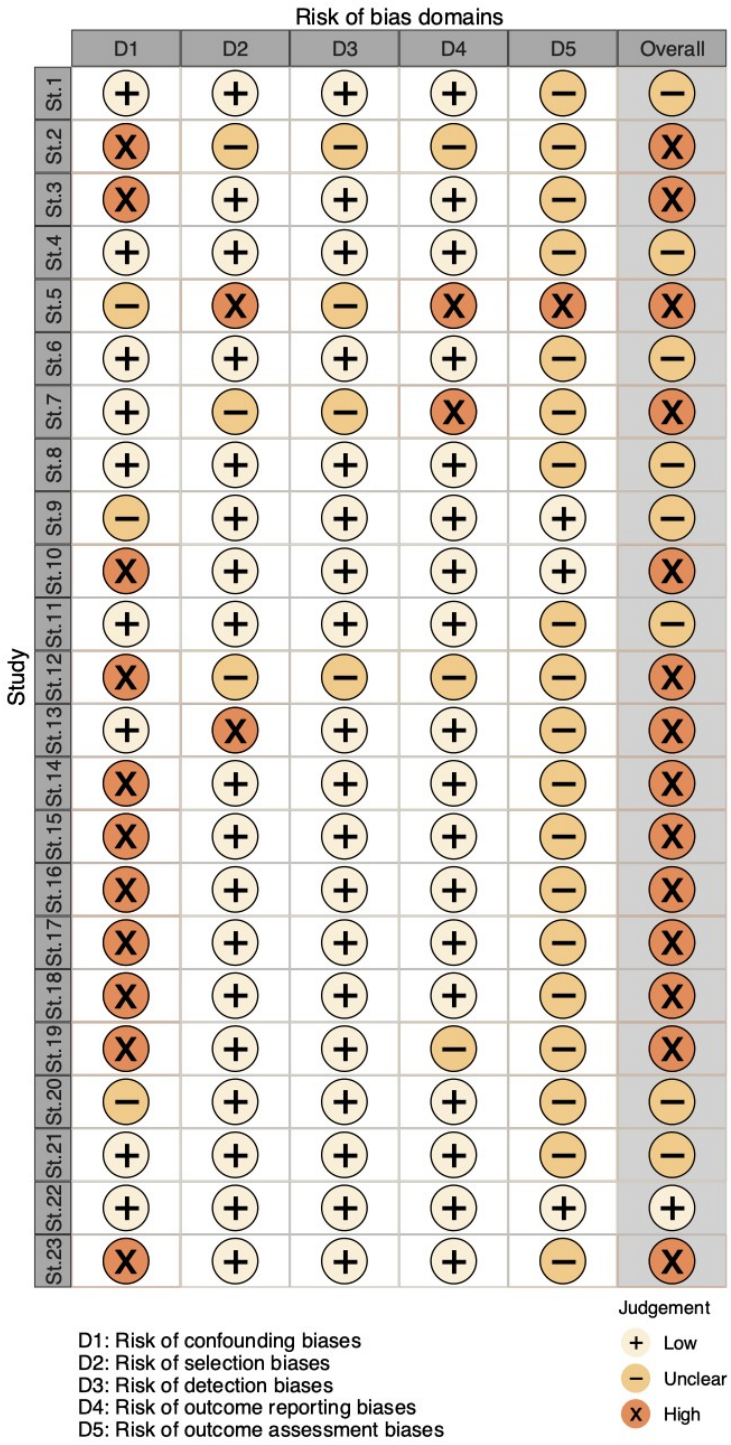
Quality appraisal

Two quality appraisal tools were used in this systematic review, CEECAT and ECR-P, each focusing on different aspects of the studies. The results of the CEECAT assessment are illustrated in Figure 2. Out of the seven domains (criterions) of the tool only five were used, as criterions three and four are designed for study types that were not identified nor included in our systematic review (observational and experimental). The highest bias was identified in criterion 1 of the tool, concerning risk arising from confounding biases. Fourteen studies[15-17,19,21-28,31,35] were found to be of overall high RoB, eight[13,14,20,29,30,32-34] exhibiting some concerns and only one study[18] was assessed to be of low RoB. The results for each individual study for each criterion are illustrated in Figure 3.

Figure 2. Collaboration for Environmental Evidence critical appraisal tool (CEECAT) summary of results. The three ratings are illustrated by percentage.

The domain on confounding biases was identified with the highest potential for risk across the studies (11 out of 23). Nine out of these 11 studies used econometric methods as described in the previous section. The omission or addition of variables in the models that seemingly had very similar research objectives raises significant questions on the existence of confounding parameters and their potential effects on the modelling results. The inconsistent configuration of the models (Table 2) and the lack of supporting justification is reflected in the CEECAT assessment results.

Figure 3. Collaboration for Environmental Evidence critical appraisal tool individual study results. (-) indicates high risk of bias, (+) indicates low RoB and (-) indicates some concerns.



St.1, Calvillo and Turner 2020[33]; St.2, Cheng and Yao 2021[27]; St.3, Cheng et al., 2019[28]; St.4, Gilmore et al., 2023[14]; St.5, Govindarajan et al., 2021[31]; St.6, Handayani et al., 2019[30]; St.7, Horobet et al., 2022[25]; St.8, Hossain et al., 2023[20]; St.9, Ifaei et al., 2022[32]; St.10, Jahanger et al., 2023[17]; St.11, Logan et al., 2020[34]; St.12, Obobisa et al., 2022[26];St.13, Qadeer et al., 2023[35];St.14, Raihan and Tuspekova 2022a[19]; St.15, Raihan and Tuspekova 2022b[21]; St.16, Raihan et al.,

2022a[22]; St.17, Raihan et al., 2022b[23]; St.18, Raihan et al., 2023[24]; St.19, Song and Chen 2023[15]; St.20, Sun and Dong 2022[13]; St.21, Sun et al., 2023[29]; St.22, Zhao C. et al., 2023[16]; St.23, Zhao L. et al., 2023[18]

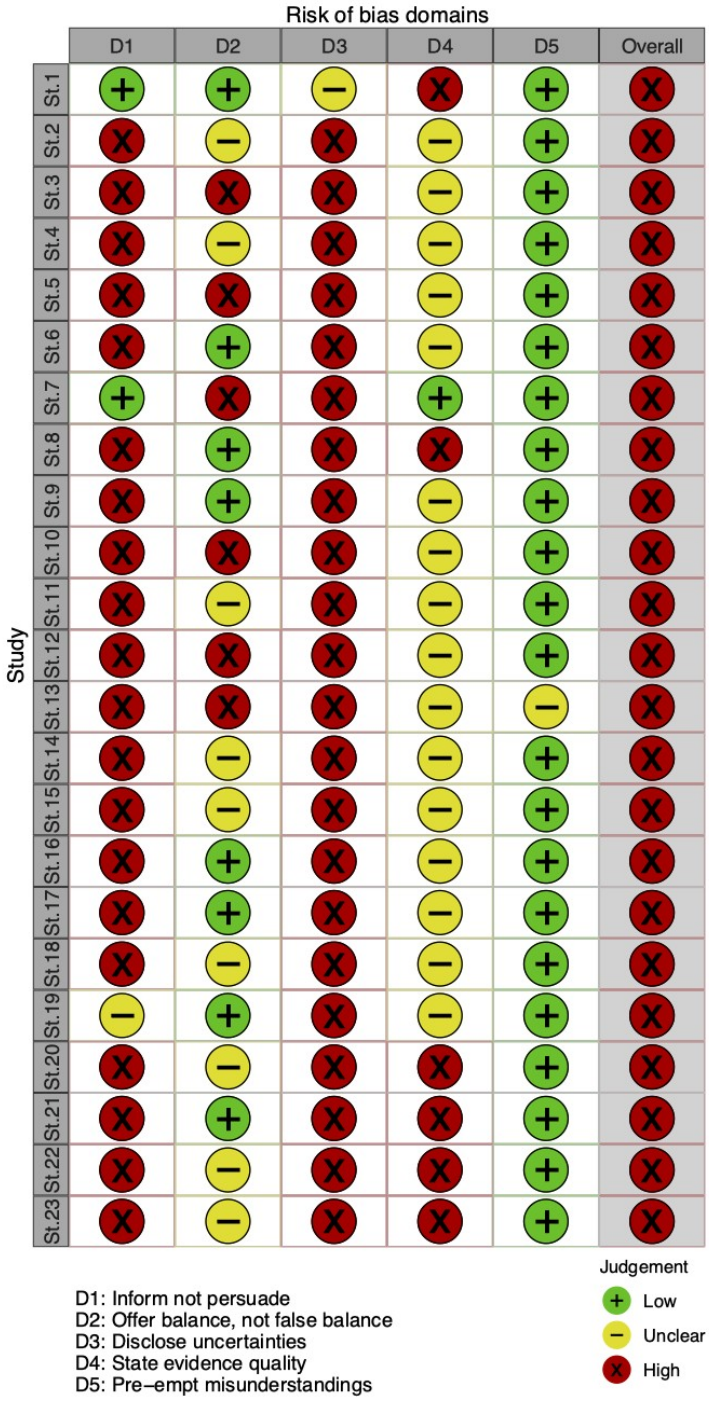
Five domains were examined within the ECR-P critical appraisal tool. ECR-P was specifically designed for assessing the communication and the quality of scientific-based PRs. This systematic review is the first one this tool has been used in, following extensive piloting and validation. The summary of the assessment is illustrated in Figure 4, while the assessment for individual studies is presented in Figure 5.

Figure 4. Evidence Communication Rules for Policy (ECR-P) critical appraisal tool summary of results. The three ratings are illustrated by percentage.

ECR-P is assessment executed for each domain in two different levels: the study level and the PRs level. The results of each level are combined for each domain and an overall assessment is provided across all domains. In order to achieve the highest transparency and to draw conclusion around the drivers of quality, the assessment results for each lever per domain are also provided. Figure S1 and Figure S2 present the summary assessment for

study level and PRs level, respectively, while Figure S3 and Figure S4 present the individual study assessment results.

Figure 5. Evidence Communication Rules for Policy (ECR-P) critical appraisal tool individual study results. (-) indicates high risk of bias, (+) indicates low RoB and (-) indicates some concerns.



Inform not persuade

Eighty-seven percent of the studies (20 out of 24) were rated as high risk of bias in this domain. This is the second worst rated domain in the tool. It should be noted that only 11 out of the 20 studies were assessed for high risk in both study level and PRs level (Figures S3, S4). At the study level, the areas that drove the high-risk results were concerned with the studies not reporting the limitations of their analysis and lacking a clear connection between their findings and conclusions.

Similarly, in the PRs level, these two areas were also identified as problematic since studies did not report the limitations of their PRs, and did not clearly connect their PRs to the findings of their research. From the studies that did report PRs limitations, the majority (10 out of 11) related the reported study limitations to both findings and PRs. Only one study[34] addressed specifically the PRs limitations and recognizing that they are contingent on factors that were not part of their analysis (Figure S4).

Almost half of the studies (48%) provided some PRs relevant to their findings but also put forward PRs that were not scientifically based. For example, it was observed that a lot of studies had PRs on promoting environmental consciousness as a way of increasing the use of green energies that would lead to reducing carbon emissions [18,19,21-24]. Although, these PRs might ‘make sense’ in the context of tackling climate change, they were not connected to the studies’ scientific analysis and findings.

In the PRs level, a third area was identified as problematic. Six studies were found to have used emotive language in communicating their PRs,

indicating advocacy rather than simply scientific reporting. Examples of emotive language included: "*Climate-minded policymakers should implement unprecedented reforms and wean their citizens off fossil fuels...*"[26], " *...the use of obsolete, polluting technologies must be forbidden*."[19], "*Alternatives that are more ecologically friendly should be used in place of obsolete and incompetent technology*"[35].

On the other hand, studies overall did very well on clearly reporting their aims and objectives for both research outcomes and PRs, proposing ways to tackle the reported study limitations in future research, avoiding the use of emotive language in their findings and conclusions, and using accessible language in their PRs.

Offer balance, but not false balance

In this domain 35% and 39% of the studies were rated of low RoB and some concerns, respectively (Figure 5). On the study level, only two studies[25,31] were rated of high RoB. Both these studies included a lot of different geographical areas (163 countries and 45 cities) but didn't specify them or report how and why they were chosen for their analysis. In this domain and level, the use a reporting guideline was inquired. To the best of our knowledge a discipline specific reporting guideline does not exist for this field, therefore, this area was not assessed.

The PRs level in this domain focuses on two areas, whether the authors acknowledge the inherent complexity of PRs and thus consider their potential multiple implications and whether they have an overview of the current policies that are in place (or a lack thereof) for the issues they are

researching. Indeed, most studies offered multiple PRs and in different policy areas but only one study[35] considered the potential negative implication of their PRs. Nineteen studies exhibited knowledge of current policies but only 9 of them considered the implications of not changing the *status quo* (Figure S4). High risk of bias was attributed to the four studies that did not mention the current policy status.

Disclose uncertainties

This was the domain that was rated with the highest risk of bias across all studies. Indeed, 96% were rated as of high RoB and 4% as exhibiting some concerns (Figure 5). The study level focuses on reporting uncertainties in study findings and proposing ways to reduce them in the future. Most studies (20 of 23) did indeed report uncertainties but only one[33] suggested a way to alleviate them.

In the PRs level, studies overwhelmingly did not address uncertainties. Only one study discussed uncertainties but only briefly and partially, stating "*Therefore, we see this analysis as necessary first step for further research on the full implications of the EV rollout in the energy system and the wider economy.*"[33]. It should be noted that the study did not propose a way forward in addressing uncertainties in the future in any specific way.

State evidence quality

Most of the studies (70%) raised only some concerns of bias in this domain. There is a clear mismatch between the rating of the study level and the PRs level (Figures S3, S4). In the study level, 17 studies appear to have used high quality data inputs, but only a small subsection of them actively

discussed their quality. Only three studies went into detail about how data collection processes ensured data quality[31], how data production was relevant for their analysis[34], or acknowledged poor quality for a subset of their data[14]. On the other hand, six studies reported to have used data of questionable quality, mainly coming from commercial companies reports, with no consideration around their quality or around the obvious potential competing interests' issues. This led to these six studies having a high RoB rating in the study level. No specific metrics for data quality were used by any studies.

On the PRs level the focus was on whether the studies considered the quality of the study findings, that formulated the evidence base for the PRs. Only one study actively discussed this issue stating "*Our study, like any other research, has limitations. They are caused by the data used and the availability of data, the time period under consideration, and the variables included in the models. All of these constraints can be addressed in future research, as well as the impact of specific policies on electricity-generated pollution*."[25] Not considering evidence quality for PRs led to nineteen studies been rated as of high RoB in the PRs level of this domain.

Pre-empt misunderstandings

This domain focused on inoculating against misinformation. This was the domain that was rated best across all studies for both study level and PRs level. Only one study[35] was found to raise some bias concerns while the rest 22 were rated as of low RoB. On the study level the quality of the communication was assessed on whether studies tried to pre-emptively

address potential misunderstandings about the study findings and conclusions and ultimately if any ambiguity was identified. In the PRs level, in addition to assessing the clarity of the PRs themselves, the targeted policy makers also needed to be defined. Both areas were rated of low RoB across all studies.

Overall risk of bias rating

All studies were rated as of overall high RoB within the ECR-P critical appraisal tool. The studies did better in some domains than others, but in the synthesis of the domains all studies were rated with high RoB in at least one of them, thus resulting in an overall high RoB rating. These results indicate poor quality of PRs formulation and communication. The flow of the ratings through the five domains is illustrated in Figure 6. The two worst rated domains were domain one: inform not persuade, and domain 3: disclose uncertainties.

The critical appraisal process revealed that there were specific questions of the ECR-P tool that all studies felt short in addressing. The question that had the most negative responses was 3.2 "*Were uncertainties of the policy recommendations reported?*", with 22 negative responses; followed by the conditional question 3.1.1 (If Y/PY to 3.1) "*Did the study propose ways to reduce uncertainties in the future?*", with 19 negative responses; and question 4.2 "*Was the quality of the study findings, that formulated the evidence base for the policy recommendations, considered?*", also with 19 negative responses.

Figure 6. Evidence Communication Rules for Policy (ECR-P) critical appraisal tool individual study rating flow.

The domain that was rated best across all studies was domain 5: Pre-empt Misunderstandings. The three studies that were best rated were by Calvillo and Turner 2020[33], Horobet et al. 2022[25], and Song and Chen 2023[15]. The study that was rated best across levels and domains was by Calvillo and Turner 2020[33], rated with low RoB in three domains (1, 2 and 5), one domain with some concerns (3) and one with high RoB (4). The study focused on the rollout of electric vehicles in the UK. Interestingly, it was one of the two studies which had PRs as their main research outcome (the other being the study by Gilmore et al. 2023[14]), and it was the only study that addressed uncertainties in their PRs. Calvillo and Turner 2020[33] were only rated badly in domain 4. Regarding the study level, although they used secondary evidence as inputs for their energy system modelling from commercial companies (including Scotish Power and Bloomberg new energy finance) they did not consider the quality of their data sources. The issue was

propagated in the PRs section. On the other hand, Song and Chen 2023[15] were also rated badly in only one domain, but this time it was domain 3 as the study did not address uncertainties in their findings nor their PRs. This was the only case study included in the systematic review. Horobet et al. 2022[25] was the only other study (apart from Calvillo and Turner 2020[33]) that was rated with low RoB in three separate domains (1, 4 and 5). Calvillo and Turner 2020[33] and Horobet et al. 2022[25] were the only two studies that rated low RoB in the PRs level in domain 1, providing high quality communication across the areas addressed in this domain (see supplementary file 2).

Table 3. Risk of bias ratings for Collaboration for Environmental Evidence critical appraisal tool (CEECAT) and Evidence Communication Rules for Policy (ECR-P) critical appraisal tool. Green cells denote agreement between overall rating between the two tools. Purple denotes agreement between the overall rating of CEECAT the level rating for ECP-R. 'medium' rating stands for 'some concerns' for ECP-R.

	Risk of Bias rating			
	CEECAT	**ECP-R**		
Study	Overall	Study level	PR level	Overall
Calvillo and Turner 2020[33]	medium	high	high	high
Cheng and Yao 2021[27]	high	high	high	high
Cheng et al. 2019[28]	high	high	high	high
Gilmore et al. 2023[14]	medium	high	high	high
Govindarajan et al. 2021[31]	high	high	high	high
Handayani et al. 2019[30]	medium	medium	high	high
Horobet et al. 2022[25]	high	high	high	high
Hossain et al. 2023[20]	medium	high	high	high
Ifaei et al. 2022[32]	medium	high	high	high
Jahanger et al. 2023[17]	high	medium	high	high
Logan et al. 2020[34]	medium	medium	high	high
Obobisa et al. 2022[26]	high	high	high	high

Qadeer et al. 2023[35]	high	medium	high	high
Raihan and Tuspekova 2022a[24]	high	high	high	high
Raihan and Tuspekova 2022b[21]	high	high	high	high
Raihan et al. 2022a[23]	high	high	high	high
Raihan et al. 2022b[22]	high	high	high	high
Raihan et al. 2023[19]	high	high	high	high
Song and Chen 2023[15]	high	high	high	high
Sun and Dong 2022[29]	medium	high	high	high
Sun et al. 2023[13]	medium	high	high	high
Zhao C. et al. 2023[18]	low	high	high	high
Zhao L. et al. 2023[16]	high	high	high	high

There was sufficient agreement between the overall ratings between the two critical appraisal tools. The ratings were the same for 14 out of the 23 studies and, as expected, the agreement was much stronger for the studies that rated badly in the CEECAT. Agreement between the tools is presented in Table 3.

Discussion

Twenty-three studies were included in this methodological systematic review. Evidence communication for policy making was examined via ECR-P, a novel critical appraisal tool which was implemented for the first time. All studies provided PRs to tackle climate change, achieve decarbonization, or both. The themes of the PRs varied from fiscal measures to the promotion of environmental consciousness. To our knowledge this is the first systematic review to focus on the communication of scientific-based PRs in any scientific field. Access to relevant research evidence of good quality at the right time have been found to be the most important factors influencing the

uptake of evidence in policy making[1]. Other important factors are collaboration-, relationship- and skills-building with policymakers.

One of the most important findings of this systematic review is the complete lack of studies in engineering or experimental environmental science that put forward PRs for tackling climate change. Reflecting on how topical the issues around climate change are and the sharp increase of peer-review paper publication in every scientific field it is astonishing that no such research exists. Our exhaustive searches in four different databases did not identify any such studies. This finding suggests that including PRs in these fields is still far from being the norm.

The majority of the studies presented their PRs clearly in a separate section, which would make it easy for policy makers to quickly identify them. In addition, studies often provided specific practical PRs rather than sticking to generic statements. This was reflected in domain 5 focusing of pre-empting misunderstandings, which is further discussed below.

Regarding internal validity according to CEECAT, the studies were overall found to be of medium to low quality. This somewhat poor quality was also reflected in the PRs as well. The focus of the two tools, CEECAT and ECR-P, is not the same. CEECAT focuses on the internal validity of the study examining study design and conduct while ECP-P focuses more on the external validity (transportability, applicability), reporting and communication. Although it could be expected that if one side of the study would be of low quality then other parts would be of low quality as well, this is not always the case. This counter intuitive status is addressed by most

existing critical appraisal tools, where each part of the study is examined first separately and then a holistic decision is made on the quality rating by looking at all the individual assessments[39,40].

The validity and usefulness of the novel ECR-P critical appraisal tool was piloted and verified in this methodological systematic review. The tool was used to address every aspect of the studies connected to the PRs as well as the scientific findings that they were based on. The structure of the tool was further used to guide the narrative analysis and discussion of the findings.

According to the ratings of ECR-P critical appraisal tool, the PRs of all studies were found to be of low quality. The domains that were rated worst were those addressing the authors skills to inform, not persuade and to disclose uncertainties, especially when it came down to uncertainties around the PRs. There was also a clear trend that studies rated much better in the study level than in the PRs level. This observation might be attributed to the fact that most authors are more accustomed to reporting study findings and conclusions than PRs. A lack of know-how in formulating and communicating PRs might explain this disparity. In addition, there are no reporting guidelines for this scientific field nor for scientific-based PRs. In many disciplines, reporting guidelines are used to ensure a study's good reporting standard. Increasingly more scientific journals require a documented use of such a reporting guideline as a prerequisite for accepting a manuscript for peer-review (e.g. PRISMA guideline for reporting systematic reviews[11], CONSORT guidelines for reporting parallel group

randomised trials[41], CHEERS guidance for Health Economic Evaluations[42], COREQ criteria for reporting qualitative research[43] etc.).

The review process identified that often studies started with very specific and in many cases practical PRs (e.g. fiscal measures) but ended up rounding up the PRs section with a sort of a ‘wish list’ of recommendations that would be considered common ground in the climate change fight realm but were not connected to their analysis. It is not clear if the authors felt compelled to include these PRs so that they conform to the current climate. Nevertheless, putting forward non-scientific-based PRs reduces the overall trustworthiness of the studies. Furthermore, it was identified that there was a shortcoming in discussing the study and PRs limitations. Limitations are connected to the methodology limitations, data input limitations and analysis limitations. These finally affect and ‘limit’ the study’s outputs. Openness regarding limitations speaks to the trustworthiness of the study.[2]

Only one study[35] considered the potential negative implication of their PRs thus offering a balanced communication. Policies are inherently multifactorial and can have multiple effects. A consideration of multiple outcomes of the policy recommendation shows that the researchers acknowledge the complexity of policies. Moreover, the implementation of PRs might have both positive and negative implications. A study should exhibit that these have been taken into consideration. In many policy areas, it might be the case that a policy is already in place for the issue the study is focusing on. Knowledge of the current policy, or of the absence of one is essential for putting forward future policy implementation.

Uncertainties in PRs were overwhelmingly not considered, while almost none of the studies considered how uncertainties in study findings could be addressed by future research. Disclosing uncertainties in study findings speaks to the trustworthiness of the research evidence. In simpler terms researchers should acknowledge what they don't know. Uncertainties largely relate to the difference between the research findings and the 'true values' and help us understand the degree of confidence in the study findings.

Although, it could be expected that emotive language would be avoided in scientific literature, it was identified that more than a quarter of the studies (26%) did exactly that. Emotive language is the wording that is used in order to elicit an undue emotional response in the reader. Undue, refers to trying to evoke an emotion based on unsubstantiated statements. Emotive language can be used to persuade readers which goes directly against the 'inform not persuade' rule for evidence communication.[2] The use of emotive language in PRs could be ever more problematic as researchers might be tempted to use 'stronger' language in order to persuade potential policy makers. Considering evidence quality was another precarious area, evidence quality was not actively discussed by the majority of the studies for neither the study findings nor the PRs. Standardized metrics of data quality were not used by any of the studies.

Overall, it appeared that there was less effort put in the PRs section and less rigorous scientific methods applied in formulating PRs. The fact that the study[33] identified as the one with the PRs section of the best quality had PRs

as a main research objective, reinforces the conclusion that PRs have been treated more as an afterthought by most studies.

Five [19,21-24] of the included studies in the systematic review, shared at least the lead author. All studies were rated of high RoB and presented very similar issues rating badly in both domains 1 and 3. The inclusion of studies by the same authors might have skewed our results and is recognized as a limitation of this systematic review.

Pre-empting misunderstandings was rated best for all studies. This was not because studies actively tried to address issues but because they used practical examples thus minimising clarity problems that might arise. Clear and unambiguous reporting of study findings, conclusions and PRs is essential and is often the topic of critique within the peer-review process. Anticipating and pre-emptively inoculating against misunderstandings, misinformation or even disinformation is key. On the other hand, transparent reporting of study limitations and uncertainties, which is championed by ECR-P, might be maliciously used by others to cast doubt. Nevertheless, this should not deter researchers from reporting them. The first step in pre-emptying misunderstandings in PRs is to correctly identify the audience, their needs and expectations. PRs should be clear and unambiguous, tailored to the needs of the policymakers.

Conclusions - implications for practice, policy, and future research

There is widespread consensus that science and evidence should underpin policies. Nevertheless, there are still significant barriers to the knowledge exchange between scientists and policy makers. Formulating and providing

scientific-based PRs a part of peer-reviewed papers can help tackle some of these issues. These PRs can only be useful if they are based on standards of the highest quality for conducting and communicating research. Although there is a rise in the number of papers that put forward PRs there is still a clear need to raise awareness around their usefulness.

The current status of PRs was found to be of poor quality. There was a distinct superiority of communication quality of study findings and conclusions over the communication quality of PRs. Authors should use the same scientific rigour in the development and communication of their PRs as in any other section of their studies, meticulously building the trustworthiness of their scientific outputs. In many disciplines the use of reporting guidelines is the norm, denoting the structure and the minimum information that a paper should report to allow readers to make independent judgements and draw conclusions. There is a clear need of reporting guidelines for scientific-based PRs. The findings of this systematic review have provided insights on the current status of PRs and identified areas where authors should be more attentive when communicating their PRs. These findings in conjunction with our novel critical appraisal tool can be used a basis for a reporting guideline that will promote research integrity.

Improving the quality of reporting and communication has been shown to affect the impact in policy making and decision making in general[44]. Further research in other scientific fields is needed in order to deepen our understanding on the quality of PRs and to have a more holistic appreciation of current challenges and ways forward.

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