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EUROPEAN GREEN DEAL – RESEARCH DIRECTIONS. A SYSTEMATIC LITERATURE REVIEW

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ABSTRACT: The article provided a classification of scientific research relating to European Green Deal (EGD) issues to assess their compatibility with areas identified in the EGD strategy document and identify emerging future research directions. A systematic literature review was based on bibliometric analysis and focused on articles in Scopus and Web of Science databases. The systematic literature review aimed to identify, integrate and evaluate research on the selected topic based on clearly defined criteria. Research query included (TITLE-ABS-KEY ("EU" OR europ*) AND TITLE-ABS-KEY ("green deal")) in the case of Scopus and TS = ("EU" OR europ*) AND "green deal") in the case of Web of Science. In total, 641 publication records were qualified for analysis. The bibliometric analysis allowed identifying eight thematic clusters and linking them to the eight areas of the European Green Deal strategy. The bibliometric analysis enabled the identification of eight thematic areas of international research undertaken in relation to the European Green Deal. These cover a variety of topics from social sciences, engineering, agriculture, sciences and natural sciences. Clusters included: Energy, circular economy, industry, building, mobility, food, biodiversity and pollution.

KEYWORDS: European Green Deal, energy, smart and sustainable mobility, circular economy, biodiversity, food, pollution

Introduction

The ongoing degradation of the environment and new environmental threats caused by human activity drive many international, national and local organisations to undertake large-scale initiatives counteracting environmental damages. Such action requires an integrated approach to solving shared problems affecting all communities regardless of location, wealth or level of socio-economic development. There is a global consensus that social and economic development depends on the sustainable management of our planet's natural resources (United Nations, 2015).

The European Environment Agency (EEA) highlighted 12 main problems of particular European concern. Among these significant environmental issues, the EEA emphasised the following:

1. Climate change, caused by rising CO_2 levels in the atmosphere, already exceeding pre-industrial times by 50%. Between 1990 and 2018, greenhouse gas emissions were reduced by 23%, while the economy grew by 61%.
2. Stratospheric ozone depletion, caused by the release of the chemicals known as chloro- and bromofluorocarbons, used as refrigerants, industrial cleaners, foaming agents and fire extinguishers.
3. The loss of biodiversity in European ecosystems having more than 2 500 habitat types and some 215 000 species, of which 90% are invertebrates, and almost every European country faced with endemic species (found nowhere else).
4. Major accidents that cause serious environmental damage.
5. Acidification resulting from the combustion of fossil fuels and sulphur and nitrogen dioxide emissions into the atmosphere where the gases are converted into acids and, after deposition, leading to a series of undesired changes in terrestrial and aquatic ecosystems.
6. Tropospheric ozone and other photochemical oxidants exceed Air Quality Guidelines for ozone in many European regions.
7. The management of freshwater resources, resulting in water losses due to distribution systems, water pollution and deterioration of aquatic habitats, severely hampering the water use for human consumption and wildlife.
8. Forest degradation, resulting from air pollution and seriously threatening the sustainability of forest resources in Central and Eastern regions and from fire in Southern Europe.
9. Threats to coastal zones and their management in connection with human activities creating physical modifications of the coastline and

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emissions of contaminants which have led to the deterioration of habitats and water quality.
10. Waste production and management caused by the steady increase in the quantity of waste and its toxic components.
11. Urban stress, such as environmental stress due to poor air quality, excessive noise and traffic congestion.
12. Chemical risk connected with excessive chemical loading. More than 10 million chemical compounds have been identified, of which about 100 000 are produced commercially (European Environment Agency, 2020; Communication…, 2019).

In response to the growing problems, the European Union has taken strategic actions to eliminate or reduce the negative impact of human activity on the environment in the long-term perspective. The 2020 European Green Deal (EGD) strategy implements the European Union's strategy, making the EU climate neutral by 2050 and indicating directions of economic development without increasing the consumption of natural resources. The Green Deal is an integral part of the strategy developed by the current Commission to implement the UN 2030 Agenda for Sustainable Development and the Sustainable Development Goals (United Nations, 2015). The European Green Deal strategy is one of the European Commission's six priorities for 2019–2024, also including a Europe fit for the digital age, an economy that works for people, a stronger Europe in the world, promoting our European way of life and a new push for European democracy (The European Commission, 2022). The European Green Deal is a form of a roadmap showing the way to a sustainable economy in Europe. The strategy implementation intends to ensure resource efficiency in a circular economy, protect biodiversity and reduce pollution (Rowan & Galanakis, 2020).

The main objective of the European Green Deal strategy is connected with the reduction of net greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels and achieving climate neutrality in 2050 (Communication…, 2019). The transition towards a climate-neutral economy is one of the most significant challenges faced by our generation and those that will follow (Amoroso et al., 2021; Montanarella & Panagos, 2021).

The main goal of the European Green Deal strategy is to place sustainability and human well-being at the centre of economic policy and as a fundamental dimension of all policy decisions and the resulting actions. Achieving the goal of climate neutrality will only be possible with the participation of all stakeholders from different sectors, such as construction, biodiversity, energy, transport, agriculture and food. Fields of European Green Deal strategy interest are presented in Figure 1.

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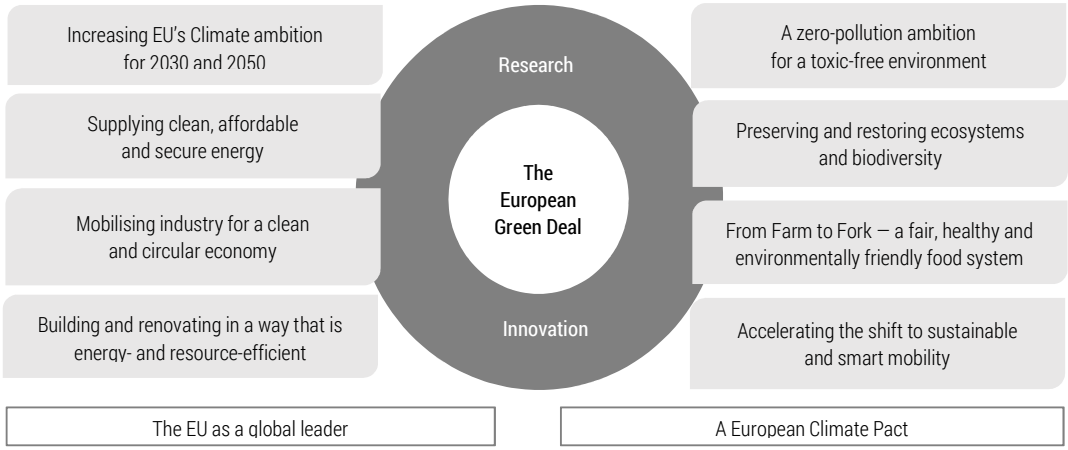

Figure 1. The European Green Deal

Source: Communication..., 2019.

Specific action plans are provided for implementation within the areas indicated in Figure 1. For example, the area of clean, affordable and secure energy plans the implementation of the Renovation Wave Initiative for the building sector and the offshore wind energy strategy. The industrial strategy for a clean and circular economy will encompass the circular economy action plan. Greening the Common Agricultural Policy will be based on the Farm to Fork Strategy, assuming a significant reduction in the use and risk of chemical pesticides, fertilisers and antibiotics. A detailed content description of the EGD areas based on keywords from the strategic document is presented in Table 1.

A comprehensive analysis of the scope of the EGD strategy areas has shown that the implementation of the European Green Deal strategy will require: (i) dialogue, solidarity and involvement of all stakeholders; (ii) revision and reformulation of the legal framework for action relating to all identified areas; (iii) application of innovation and new technological solutions and, in particular, digital technologies; and (iv) widespread application of the circular economy and sustainable development principles. Successful implementation of the European Green Deal strategy, according to Pe'er et al. (2020), will also require political courage to overcome resistance to change and the introduction of many political, economic and social measures (Brodny & Tutak, 2020; Montanarella & Panagos, 2021), and financial commitment (Brodny & Tutak, 2020; Chiaramonti & Maniatis, 2020; Brauers & Oei, 2020).

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Table 1. Description of European Green Deal fields activities and scope

European Green Deal fields	Keywords describing EGD fields
Supplying clean, affordable and secure energy	decarbonising the energy, energy efficiency, renewable sources, clean energy, offshore wind production, decarbonisation at the lowest possible cost, smart integration, decarbonised gases, energy-related methane emissions. household renovation, innovative technologies and infrastructure, such as smart grids, hydrogen networks or carbon capture, storage and utilisation, energy storage
Mobilising industry for a clean and circular economy	circular economy, sustainable model of inclusive growth, green and the digital transformation of industry, energy-intensive industries modernisation, circular economy, reducing and reusing materials before recycling them, new business models, prevention against environmentally harmful products, producer responsibility, resource-intensive sectors modernisation, reusable or recyclable packaging, biodegradable and bio-based plastics, single use plastics, reusable, durable and repairable products on the market, tackle false green claims, product passport, green public purchasing, sustainable product policy, over-packaging and waste generation, market for secondary raw materials and by-products, cooperation across value chains, separate waste collection, waste shipments and illegal exports, diversifying supply from both primary and secondary sources, climate and resource frontrunners, breakthrough technologies such us include clean hydrogen, fuel cells and other alternative fuels, energy storage, and carbon capture, storage and utilisation, clean steel breakthrough technologies, zero-carbon steel making, collaboration with industry, safe, circular and sustainable battery value chain, growing market of electric vehicles, Digital technologies such us artificial intelligence, 5G, cloud and edge computing and the internet of things, distance monitoring of pollution, transparency on the environmental impact, incentivise people to return unwanted devices
Building and renovating in an energy- and resource-efficient way	renovation of public and private buildings, construction sector, energy performance of buildings, construction products regulation, circular economy, digitalisation, building stock, platform bringing together the buildings and construction sector, architects and engineers and local authorities, innovative financing schemes, renovation of social housing, schools and hospitals
Accelerating the shift to sustainable and smart mobility	multimodal transport, efficiency of the transport system, inland freight, rail and inland waterways, combined transport, rail and waterborne transport, short-sea shipping, single European sky, aviation emissions, Automated and connected multimodal mobility, smart traffic management systems, digitalisation, sustainable mobility, congestion and pollution, Connected Europe Facility funding instruments, energy taxation, emissions trading to the maritime sector, effective road pricing, sustainable alternative transport fuels, public recharging, refuelling points, long-distance travel, less polluting in cities, urban congestion, public transport, CO_2 emission performance standards, emissions of pollutants by aeroplanes and airport operations.
From Farm to Fork: designing a fair, healthy and environmentally-friendly food system	food value chain, sustainable food, climate change, protect the environment and preserve biodiversity, common agricultural policy, common fisheries policy, precision agriculture, organic farming, agro-ecology, agro-forestry animal welfare standards, eco-schemes performance, managing and storing carbon in the soil, nutrient management to improve water quality and reduce emissions, sustainable seafood, low-carbon food, reduce use and risk of chemical pesticides, fertilisers and antibiotics, organic farming, harvests protection from pests and diseases, circular economy, food waste management, combat food fraud, new innovative food and feed products, such as seafood based on algae, sustainable food consumption, affordable healthy food, healthy and sustainable diets, digital means for better food information, source of food, nutritional value, environmental footprint

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European Green Deal fields	Keywords describing EGD fields
Preserving and restoring ecosystems and biodiversity	halt biodiversity loss, biodiversity strategy, protected biodiversity-rich land, protected sea areas, Natura 2000 network, cross-border cooperation, restore damaged ecosystems, green European cities, increase biodiversity in urban spaces, nature restoration plan, natural capital, common fisheries policy, sensitive areas, well-managed marine protected areas, forest ecosystems, reforestation, afforestation, restoration of degraded forests, increase absorption of CO_2, circular bio-economy, EU forest strategy, effective afforestation, forest fires, bio-economy, forests sustainably, a sustainable "blue economy", oceans, aquatic and marine resources, nature-based solutions including healthy and resilient seas and oceans, maritime space sustainably management
A zero-pollution ambition for a toxic-free environment	toxic-free environment, monitor, report, prevent and remedy pollution from the air, water, soil, and consumer products, zero pollution action plan for air, water and soil, natural functions of ground and surface water, biodiversity in lakes, rivers, wetlands and estuaries, limit damage from floods, excess nutrients, urban runoff, micro plastics, chemicals, including pharmaceuticals, combined effects of different pollutants, air quality plans, cleaner air, local communities, air quality standards, pollution from large industrial installations, prevention of industrial accidents, chemicals strategy for sustainability, sustainable alternatives, "one substance – one assessment", transparency, endocrine disruptors, hazardous chemicals in products

Source: author's work based on Communication..., 2019.

The effects of the Strategy will impact every area of human activities. For example, the activities proposed under the European Green Deal strategy will significantly impact the EU economy and labour market. In particular, the development of sustainable and job-intensive activities is expected in the areas of low-emission technologies (Jäger-Waldau et al., 2020).

Ambitious goals of the European Green Deal strategy will be possible to achieve by developing new technologies, sustainable solutions and breakthrough innovations. This requires a tremendous amount of intellectual effort and financial support to the research and innovation system. The Green Deal strategy is linked to Horizon Europe in supporting public and private investment through the financial support of research and innovation in transport technologies, including batteries, clean hydrogen, low-carbon steel making, circular bio-based sectors and the built environment (Communication..., 2019).

Implementation of the European Green Deal strategy will require significant structural changes towards the intensive use of low-carbon technologies that are already available and yet emerging and not currently available on the market (Amoroso et al., 2021). According to the International Energy Agency (IEA), half of the global reductions in energy-related CO_2 emissions by 2050 will have to come from technologies that are currently in the demonstration or prototype phase (IEA, 2021). This will require an intensification of research and development activities. According to the results of a joint study carried out by the European Commission's Joint Research Centre (JRC), which is the

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EC's science and knowledge service, and the Organisation for Economic Co-operation and Development (OECD), Scientific R&D is one of the top ten sectors in terms of R&D intensity sector. The following sectors in terms of R&D intensity are pharmaceuticals, publishing & broadcasting, IT services, computers & electronics, other manufacturers, electrical equipment, transport equipment and machinery (Amoroso et al., 2021).

Many authors express their hope and indicate the need to start a broad discussion on an effective EU climate policy (Brodny & Tutak, 2020). The scientific discussion is all the more desirable as EGD is a horizontal and sectoral strategy requiring action at the level of global, European, regional, national, and local levels in a diverse context (Ciot, 2021).

Identifying the state of scientific research relating to the European Green Deal strategy is a key element enabling, on the one hand, the assessment of the current scope of research and, on the other, the identification of potentially new emerging research directions. This article aims to provide a classification of scientific research relating to EGD issues, assess their compatibility with the areas identified in the EGD strategy document, and identify emerging research directions. It seems important to stimulate a science-based discussion around the European Green Deal strategy. The next part of the article describes the research methodology, the research results and the discussion of the findings.

Research Methods

A bibliometric analysis method was used to review the literature on the European Green Deal. Authors often use this method, particularly at the initial stage of interest in a particular research topic. With many publications available, it enables the identification, synthesis, analysis and critical evaluation of their content (Bornmann & Haunschild, 2017; Keathley-Herring et al., 2016; Szymczak et al., 2018). Quantitative techniques allow identifying the current state and development trends in a given research area. The obtained results provide knowledge about the main research directions in a given area, research trends and changes in the number of publications in a specific period. They also enable the construction of rankings of the most productive authors, journals, research units, and countries in a given research area (Niñerola et al., 2019; Szum, 2021). The bibliometric analysis targeted well-established research areas in the literature (Glińska & Siemieniako, 2018; Gudanowska, 2017; Halicka, 2017; Winkowska et al., 2019; Leończuk et al., 2019; Ejdys et al., 2019) and those emerging (Siderska & Jadaan, 2018; Szpilko, 2014; Tomaszewska & Florea, 2018; Nazarko et al., 2009).

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The operationalisation of the process used in this article with the bibliometric analysis method is presented in Figure 2.

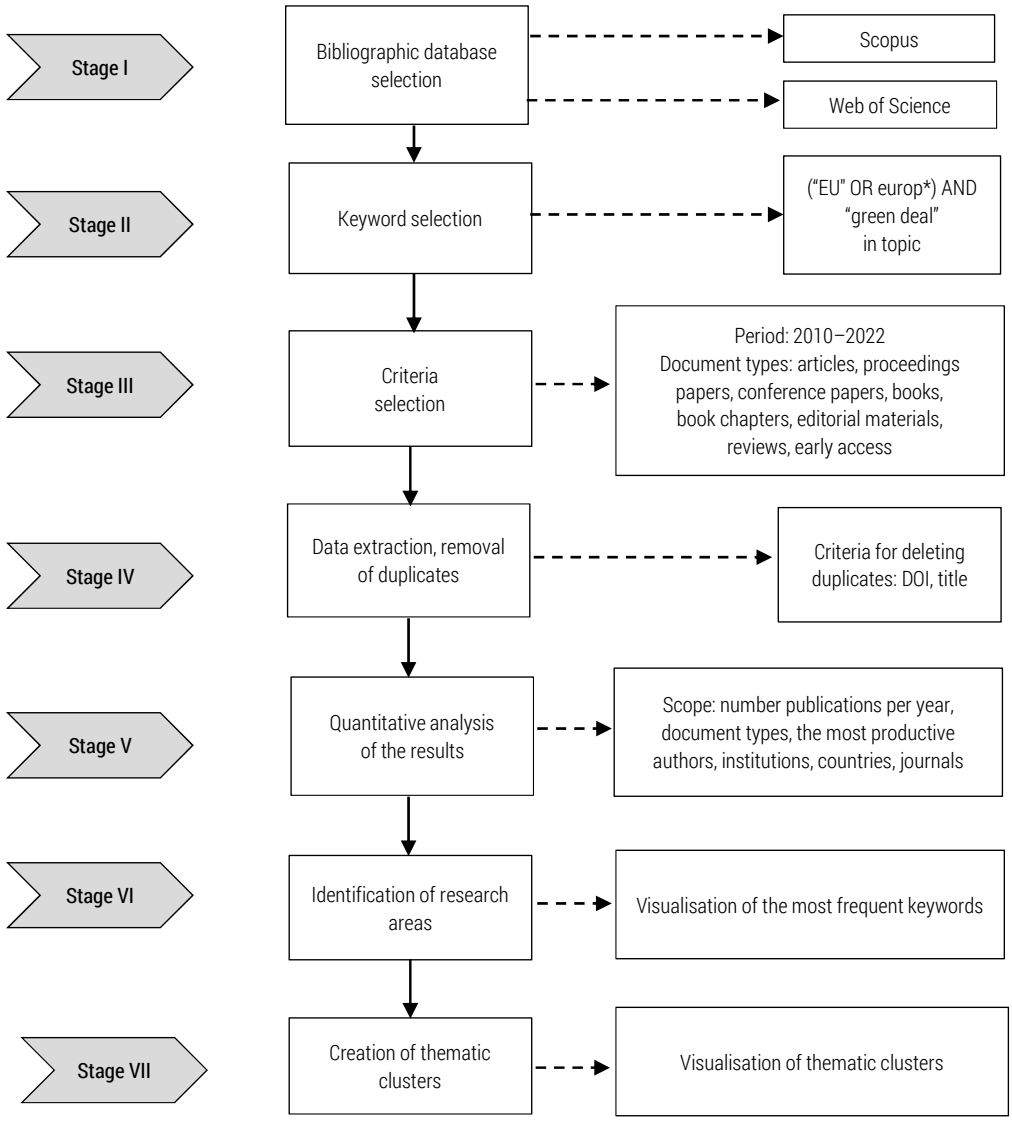

Figure 2. Methodology of bibliometric analysis

Source: author's work.

The methodology according to which the research process was conducted consists of seven phases, including the selection of bibliographic databases (I), the selection of keywords (II) and criteria limiting the search for publica-

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tions (III), data extraction and selection (IV) and the analysis of the set of publications (V). The final two phases consisted of identifying research areas (VI) and then defining thematic clusters (VII) (Figure 2).

The first stage of the study selected Scopus and Web of Science bibliographic databases presenting a wide spectrum of scientific publications. The choice of databases was dictated by their availability and thematic breadth within all scientific disciplines. The bibliometric analysis initially included publications containing the phrase "European Green Deal". The initial search in the first sample included publications containing the indicated phrase in the entire range of documents, while the second sample – in titles, abstracts and keywords. Selected restriction criteria were then applied. Materials published between 2010 and 2022 were searched. Articles, conference proceedings, books, book chapters, reviews, editorials and early access were qualified for further analysis. Other publication types (retracted publications, conference reviews, notes, letters) were discarded. The results of the initial search are shown in Table 2.

A search for the phrase "European Green Deal" across the range of papers in the first sample generated 2718 records in Scopus and 308 records in Web of Science. The initial analysis of the results showed that many publications were irrelevant to the study area. Therefore, in the second attempt, the search was limited only to publications containing the indicated phrase in the titles, abstracts and keywords. After searching for the phrase in titles, abstracts and keywords, 390 records were obtained in Scopus and 306 in Web of Science. After adopting limiting criteria, 376 and 302 records were obtained. The search results are presented in Table 2.

Table 2. Preliminary search results

Stage	Scopus	Web of Science
First search		
Research query	ALL ("european green deal")	ALL="european green deal"
Number of articles before inclusion criteria	2718	308
Number of articles after inclusion criteria	2665	304
Second search		
Research query	TITLE-ABS-KEY ("european green deal")	TS="european green deal"
Number of articles before inclusion criteria	390	306
Number of articles after inclusion criteria	376	302

Source: author's work based on Scopus and Web of Science databases.

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The preliminary analysis of the collected records in the first and second search attempts provided vital information from the study's point of view. It was noted that the record of the phrase "European Green Deal" also appears in the form of the following alternative phrases: EU Green Deal, European New Green Deal, European Union Green Deal, European Unions (EU) Green Deal, Europe's Green Deal, European "Green New Deal", European Union's Green Deal, Green Deal of the European Union, New Green Deal. Therefore, the authors reformulated the phrase by dividing it into two parts, the first one concerning the word "European" in the form of notation: "EU" OR europ* and the second: "green deal".

Table 3. Principal search results

Stage	Scopus	Web of Science
Research query	(TITLE-ABS-KEY ("EU" OR europ*) AND TITLE-ABS-KEY ("green deal")	TS = ("EU" OR europ*) AND "green deal")
Number of articles before inclusion criteria	605	475
Number of articles after inclusion criteria	579	469

Source: author's work based on the Scopus and Web of Science databases.

A search for the modified phrase generated 605 records in Scopus and 475 in Web of Science. Finally, after applying the accepted limitation on document type, 579 and 469 records were obtained, respectively (Table 3). Files containing the full description of the records in *csv format were downloaded from each database. A single aggregated file containing 1048 records was then created. After removing duplicates, a set of 641 records was qualified for further analysis.

Based on the obtained data set, analyses were made concerning the number of publications in a specific period, the most productive authors, organisations, countries and journals. The most recognisable, i.e., the most frequently cited articles, were also identified. The most frequently occurring keywords were also detected, and a map reflecting the co-occurrence of keywords related to the European Green Deal was prepared in the VOSviewer software (version 1.6.18). To eliminate different types of terms with the same meaning (e.g., EU, European Union) or irrelevant to the study (e.g., article, state, research, time), a thesaurus file was additionally prepared (Gudanowska, 2017; van Eck & Waltman, 2018). Then, based on keyword analysis and an in-depth review of the publication collection, thematic clusters depicting the main and emerging research directions were identified.

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Results of the Research

The first stage of the research included an analysis of interest in the subject over the years, identification of the dominant types of publications and their affiliation with the main subject areas in the Scopus and Web of Science databases.

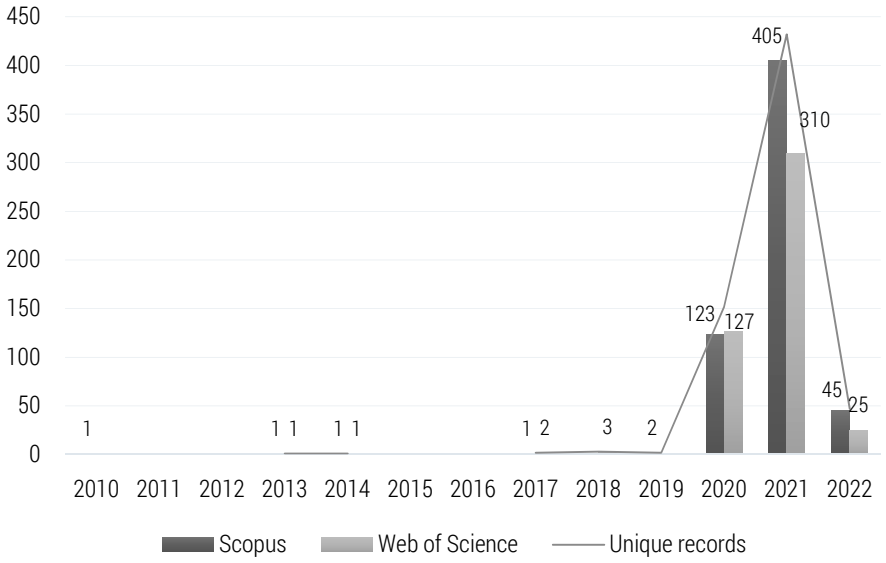

Figure 3. Number of publications in the field of European Green Deal in Scopus and Web of Science databases (indexed from January 2010 to January 2022)

Source: author's work based on the Scopus and Web of Science databases.

For both databases, numerous European Green Deal (EGD) publications appeared between 2020 and 2021 (Figure 3). In earlier years, references to EGD were sporadic and rather "emerging thematic". The total number of citations for publications indexed in the Scopus database was 1966, while in Web of Science – 1802. The number of uncited publications was 271 and 208, respectively.

Both in Scopus (77.5%) and Web of Science (83%) databases, most publications were articles and conference papers (10.7%, 8.7%, respectively). Reviews, editorials and book chapters constituted a small part. The structure of publications by document type is presented in Figure 4.

The majority of publications in Scopus and Web of Science databases are assigned to the areas of Environmental Sciences and Energy (Energy Fuels), comprising 40.1% and 37.0% in the former and 29.0% and 22.4% in the lat-

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ter. A significant proportion of publications in Scopus are also assigned to the areas Social Sciences (34.5%) and Engineering (25.4%), while in Web of Science, to Environmental Studies (22.2%), Green Sustainable Science Technology (21.1%). However, the naming of areas differs in Scopus and Web of Science databases.

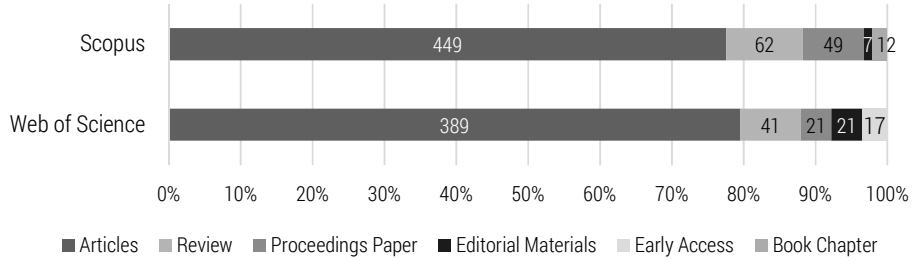

Figure 4. Type of documents of publications in the field of European Green Deal in Scopus and Web of Science databases (indexed from January 2010 to January 2022)

Source: author's work based on the Scopus and Web of Science databases.

The author with the highest number (ten) of publications was Blumberga, and the most cited articles were "Economic growth in contrast to GHG emission reduction measures in Green Deal context" from 2021 and "GHG Performance Evaluation in Green Deal Context" from 2020 (in WoS with three citations each). Next, Brodny, Smol, Tutak and Zorpas had six publications each. Brodny and Tutak had the highest average number of citations per publication in each database due to joint publishing. Their most cited publication (43 citations in WoS) was "Analyzing Similarities between the European Union Countries in Terms of the Structure and Volume of Energy Production from Renewable Energy Sources", published in Energies from 2020. Zorpas' most cited article (55 citations in WoS) was "Strategy development in the framework of waste management" from 2020, published in Science of the Total Environment. A detailed list of the most productive authors is presented in Table 4.

The highest number of publications were from Italy (119 publications), Poland (92) and Germany (78). Considering the authors' affiliation, the highest number of publications were from the European Commission's Joint Research Centre (31), Wageningen University & Research (17) and Riga Technical University (15). The ranking of ten most productive units had four units from Poland: the Polish Academy of Sciences (11), the Mineral and Energy Economy Research Institute of the Polish Academy of Sciences (11), the Silesian University of Technology (8), and the Warsaw University of Life Sciences (8). Publications from the Silesian University of Technology were the most highly cited (13.8 in Scopus, 16.3 in WoS). In comparison with other

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organisations in the ranking, it had by far the highest average number of citations in Scopus and Web of Science databases.

In the ranking of the most productive journals, Sustainability (Switzerland) ranked first (63 publications). This was followed by Energies (57) and Politics and Governance (12). However, the journal Science of the Total Environment achieved the highest average number of citations in each database (22 in Scopus, 16.4 in WoS).

Table 4. Most productive authors, organisations, countries and journals

No.	Item	NP	[%]	Average citation count	
				Scopus	Web of Science
Authors					
1	Blumberga, D.	10	1.6	1.2	1.1
2	Brodny, J.	6	0.9	18.2	16.3
3	Smol, M.	6	0.9	6.5	6.0
4	Tutak, M.	6	0.9	18.2	16.3
5	Zorpas, A. A.	6	0.9	17.0	15.2
6	Simionescu, M.	5	0.8	2.8	3.0
7	Sánchez-Bayón, A.	5	0.8	1.8	1.4
8	Jager-Waldau A.	5	0.8	0.5	10.0
9	Dupont, C.	4	0.6	5.3	6.0
10	Fragkos, P.	4	0.6	3.3	2.5
11	Prussi, M.	4	0.6	4.8	6.5
12	Scarlat, N.	4	0.6	4.8	6.5
13	Streimikiene, D.	4	0.6	2.0	1.5
14	Taylor, N.	4	0.6	13.8	10.5
15	Voukkali, I.	4	0.6	8.0	8.5
Countries					
16	Italy	119	18.6	5.3	5.1
17	Poland	92	14.4	3.0	2.7
18	Germany	78	12.2	4.5	4.3
19	Spain	69	10.8	3.8	3.3
20	Netherlands	50	7.8	3.7	3.6
21	United Kingdom	48	7.5	4.1	7.7
22	Belgium	48	7.5	5.0	3.0

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No.	Item	NP	[%]	Average citation count	
				Scopus	Web of Science
23	Greece	35	5.5	5.8	5.7
24	France	32	5.0	4.0	2.8
25	Austria	28	4.4	7.7	7.5
Organisations					
26	European Commission's Joint Research Centre	31	4.8	10.1	8.8
27	Wageningen University & Research	17	2.7	4.1	4.9
28	Riga Technical University	15	2.3	1.5	1.5
29	INRAE – National Research Institute for Agriculture, Food and Environment	12	1.9	4.4	3.8
30	Polish Academy of Sciences	11	1.7	4.2	3.8
31	Mineral and Energy Economy Research Institute of the Polish Academy of Sciences	11	1.7	3.7	3.7
32	Technical University of Berlin	9	1.4	5.6	6.0
33	European Commission	9	1.4	6.6	8.2
34	Silesian University of Technology	8	1.2	13.8	16.3
35	Warsaw University of Life Sciences	8	1.2	1.4	1.4
Journals					
36	Sustainability (Switzerland)	63	9.8	3.7	3.2
37	Energies	57	8.9	4.4	4.0
38	Politics and Governance	12	1.9	2.5	1.3
39	Environmental and Climate Technologies	10	1.6	0.8	0.7
40	Energy Policy	10	1.6	5.7	7.6
41	Science of the Total Environment	8	1.2	22	16.4
42	Energy	7	1.1	4.9	3.1
43	Applied Sciences	6	0.9	1.7	1.2
44	Energy and Buildings	6	0.9	9.7	7.8
45	Journal of Cleaner Production	6	0.9	5.8	5.2

Note: NP – number of publications, [%] – the percentage of the total number of publications (641), N/A – not applicable.

Source: author's work based on the Scopus and Web of Science databases.

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The total number of citations of publications on the European Green Deal was 1791 for WoS and 1963 for Scopus. The top ten publications included two articles published in Science of the Total Environment and one each in People and Nature, Energy Research & Social Science, Land Use Policy, Energies, Applied Energy, Energy Policy, Renewable & Sustainable Energy Reviews and Energy and Buildings. The eight most cited publications were from 2020.

Table 5. The most cited articles on the European Green Deal area

Authors	Article title	Journal	Number of citations	
			Scopus	Web of Science
(Pe'er et al., 2020)	Action needed for the EU Common Agricultural Policy to address sustainability challenges	People and Nature	85	83
(Rowan & Galanakis, 2020)	Unlocking challenges and opportunities presented by COVID-19 pandemic for cross-cutting disruption in agri-food and green deal innovations: Quo Vadis?	Science of the Total Environment	71	57
(Zorpas, 2020)	Strategy development in the framework of waste management	Science of the Total Environment	68	55
(Kern et al., 2017)	Policy packaging or policy patching? The development of complex energy efficiency policy mixes	Energy Research & Social Science	N/A	120
(Montanarella & Panagos, 2021)	The relevance of sustainable soil management within the European Green Deal	Land Use Policy	54	43
(Brodny & Tutak, 2020)	Analyzing Similarities between the European Union Countries in Terms of the Structure and Volume of Energy Production from Renewable Energy Sources	Energies	44	43
(Chiaramonti & Maniatis, 2020)	Security of supply, strategic storage and Covid19: Which lessons learnt for renewable and recycled carbon fuels, and their future role in decarbonizing transport?	Applied Energy	45	36
(Brauers & Oei, 2020)	The political economy of coal in Poland: Drivers and barriers for a shift away from fossil fuels	Energy Policy	39	37
(Jäger-Waldau et al., 2020)	How photovoltaics can contribute to GHG emission reductions of 55% in the EU by 2030	Renewable & Sustainable Energy Reviews	43	32
(Pohoryles et al., 2020)	Energy performance of existing residential buildings in Europe: A novel approach combining energy with seismic retrofitting	Energy and Buildings	35	30

Note: N/A – not applicable.

Source: author's work based on the Scopus and Web of Science databases.

The most cited publication (85 in Scopus, 83 in WoS) was the article by Pe'er et al. (2020), "Action needed for the EU Common Agricultural Policy to address sustainability challenges". This was followed by the articles "Unlocking challenges and opportunities presented by COVID-19 pandemic for

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cross-cutting disruption in agri-food and green deal innovations: Quo Vadis?" by Rowan and Galanakis (2020) and "Strategy development in the framework of waste management" by Zorpas (2020). The total number of citations was slightly lower than the first publication (71 and 68 in Scopus; 57 and 55 in WoS). Both articles were published in the journal Science of the Total Environment (Table 5).

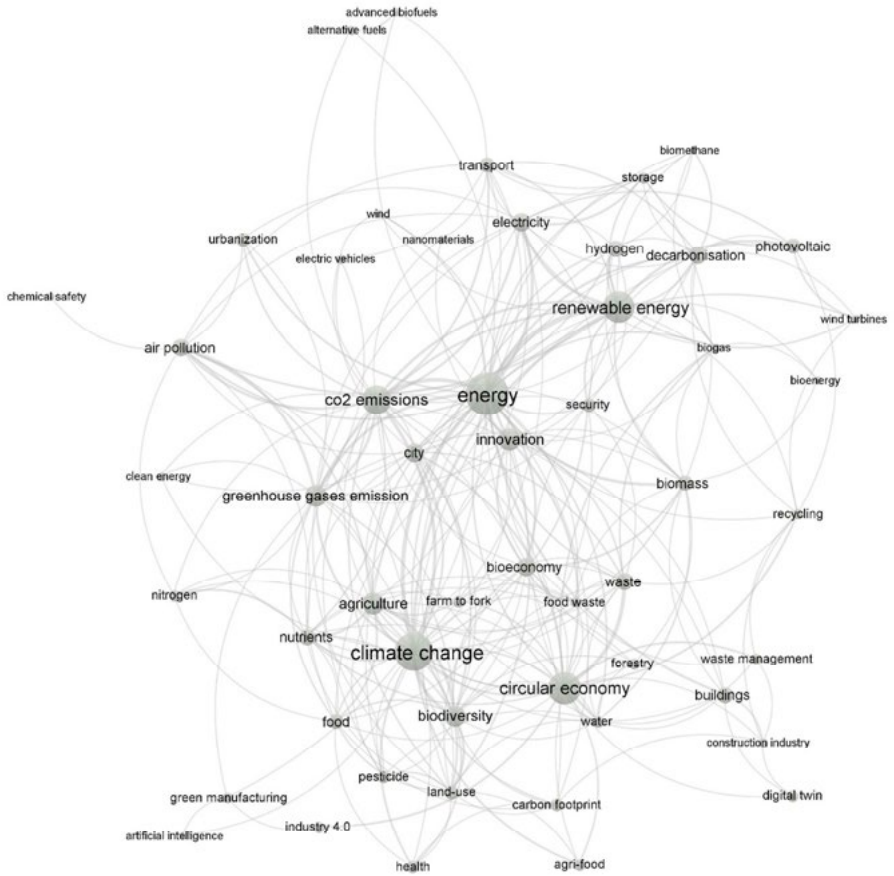

Figure 5. Keyword co-occurrence map on the European Green Deal area

Source: author's work using VOSviewer software.

The most frequent keywords related to the topic of the European Green Deal were also extracted as part of the bibliometric analysis. The VOSviewer software was used during the analysis. The generated set contained a total of 310 words or phrases, which appeared at least three times in the keywords included in 641 analysed articles. The set included words with the same meaning as abbreviations or repetitions (e.g., land use, land-use) and words

directly unrelated to the analysis subject (e.g., article, analysis). A thesaurus file was prepared and used to organise the set of words. Keywords used in the search (e.g., EGD, European Green Deal) were excluded from the collection. The notation of terms and abbreviations with the same meaning was also standardised, and terms irrelevant to the analyses conducted were removed. The final set contained 53 keywords. The most frequent terms and the links between them are presented in Figure 5.

Among the most frequent keywords related to the European Green Deal were terms related to energy (energy had 98 occurrences of the word in the set, renewable energy – 49), climate (climate change – 79), air pollution (CO_2 emission – 41, greenhouse gas emission – 24), closed-loop economy (54) and agriculture (23). The larger the circle in Figure 6, the greater the number of occurrences for a given keyword. It should be noted that these terms also show the most links to other terms. It is also worth noting the frequent occurrence of the word innovation (23) and its linkage being weaker than previously mentioned words and mainly centred on energy-related issues.

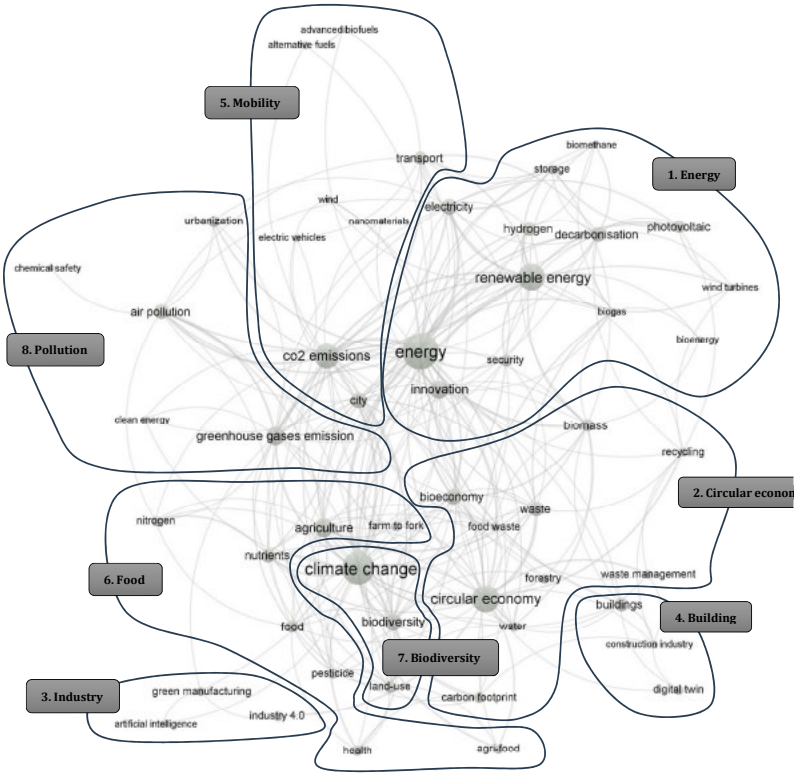

Figure 6. Thematic clusters on the European Green Deal

Source: elaborated by the authors using the VOSviewer software.

An in-depth analysis of the most frequently occurring keywords made it possible to identify eight thematic clusters and link them to eight assumptions (elements) underpinning the European Green Deal (Figure 6, Table 6).

Table 6. Subareas of the European Green Deal research

Cluster number	Cluster name	Words	Transformative policies of European Green Deal	
1	Energy	energy, renewable energy, bioenergy, biogas, biomethane, decarbonisation, electricity, hydrogen, photovoltaic, innovation, security, storage, wind turbines	2. Supplying clean, affordable and secure energy	1. Increasing the EU's climate ambition for 2030 and 2050
2	Circular Economy	bioeconomy, circular economy, food waste, recycling, waste, waste management, biomass, forestry, water, carbon footprint	3. Mobilising industry for a clean and circular economy	
3	Industry	artificial intelligence, green manufacturing, industry 4.0		
4	Building	buildings, construction industry, digital twin	4. Building and renovating in an energy- and resource-efficient way	
5	Mobility	advance biofuels, alternative fuels, electric vehicles, city, nanomaterials, transport, CO_2 emissions, wind	5. Accelerating the shift to sustainable and smart mobility	
6	Food	agriculture, agri-food, farm to fork, food, health, nitrogen, nutrients, pesticide	6. From Farm to Fork: designing a fair, healthy and environmentally-friendly food system	
7	Biodiversity	biodiversity, climate change, land-use	7. Preserving and restoring ecosystems and biodiversity	
8	Pollution	air pollution, chemical safety, clean energy, greenhouse gases emission, urbanisation	8. A zero-pollution ambition for a toxic-free environment	

Source: author's work.

The first cluster, "Energy", refers primarily to technological solutions enabling the efficient and secure supply and storage of energy from renewable sources (e.g., renewable energy, bioenergy, biogas, biomethane, decarbonisation, electricity, hydrogen, photovoltaic, security, storage, and wind turbines). This cluster is closely linked to the European Green Deal's transformational policy for providing clean, affordable and secure energy. The second cluster, "Circular Economy", is focused on leaving products in the economy for as long as possible and minimising waste generation. It includes such keywords as bioeconomy, food waste, recycling, waste, waste management, biomass, forestry, water, and carbon footprint. The third cluster, "Industry", is represented by such keywords as artificial intelligence, green manufacturing, and Industry 4.0. It simultaneously focuses on Industry 4.0 based on artificial intelligence and environmentally-friendly manufacturing. It seems to be an emerg-

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ing research area, so far poorly recognised in the literature. Both the "Circular Economy" and "Industry" clusters are closely linked to the EGD policy on mobilising industry to move towards a clean, circular economy. The fourth cluster, "Building", covers issues related to construction and the use of virtual technologies. It includes such keywords as buildings, construction industry, and digital twin. Like the "Industry" cluster, this research area can also be considered emerging. This cluster is closely connected to the EGD focus on building and renovating in an energy- and resource-efficient way. The fifth cluster, "Mobility", is related to the development of innovative vehicles and fuels to enable mobility while reducing CO_2 emissions. It is associated with such keywords as advanced biofuels, alternative fuels, electric vehicles, city, nanomaterials, transport, CO_2 emissions, and wind. This cluster is closely associated with the European Green Deal's transformational policy on the transition to sustainable and intelligent mobility. The sixth cluster, "Food", is centred on the production of fresh health-friendly food. It is represented by keywords agriculture, agri-food, farm to fork, food, health, nitrogen, nutrients, and pesticides. Within EGD, the themes relate to the premise of designing a fair, healthy and environmentally-friendly food system. The penultimate cluster was named "Biodiversity" as the themes within it related to the preservation of biodiversity (biodiversity, climate change, land-use). It strongly focuses on the protection and restoration of ecosystems and biodiversity, which are also the object of the EGD transformation policy. The last cluster, "Pollution", contains keywords on various pollutants and especially air pollution (greenhouse gases emission, air pollution, chemical safety, clean energy, and urbanisation). It is closely related to the zero-pollution aim and the toxin-free environment enshrined in the EGD. It is important to mention that all the listed clusters directly or indirectly relate to the achievement of the EU climate targets for 2030 and 2050.

Discussion of the Results

The bibliometric analysis enabled the identification of eight thematic areas of international research undertaken in relation to the European Green Deal. These cover a variety of topics from social sciences, engineering, agriculture, sciences and natural sciences.

Negative climate change, associated with the high carbon intensity of the hydrocarbon-burning economy and growing public awareness, has prompted the search for green energy sources (Brodny et al., 2020). EGD targets will require introducing countless renewable energy sources at an unprecedented speed (Kougias et al., 2021). There is, therefore, a strong emphasis in publications on finding solutions to generate energy efficiently and safely

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from renewable sources. Biomass (Tzelepi et al., 2020) and biogas (Brémond et al., 2021) are energy sources that can meet the growing demand for clean, long-life energy sources. Many authors are also conducting research relating to solar energy – photovoltaic installations (Jäger-Waldau et al., 2020; Sweetnam et al., 2013) and wind energy (Hrnčić et al., 2021).

Despite global growth in renewable energy consumption, global energy-related carbon emissions are increasing, and there are still significant differences in the share of renewable energy consumption in national energy portfolios. These issues require further efforts at the policy level, especially in countries that rely heavily on energy imports. These countries could improve their lack of energy independence by using renewable energy sources (RES) (Marra & Colantonio, 2021). There are numerous publications in the literature on the comparison of EU countries by the structure of energy production, including from RES, useful for the development of energy and climate policies of EU countries (Brodny et al., 2021; Brodny & Tutak, 2020; Hafner & Raimondi, 2021; Kochanek, 2021; Tutak et al., 2021; Włodarczyk et al., 2021). There are also a number of articles available on aspects of strategic energy management planning in the European Union (Bouzarovski et al., 2021; Hafner & Raimondi, 2021; Nikas et al., 2021; Skjærseth, 2021), as well as in individual countries, e.g., reducing coal-fired generation in Poland (Brauers & Oei, 2020). The publications also provide a comprehensive discussion of the changes to the European Union's climate and energy law introduced by the Climate and Energy Policy Framework 2030 (Kulovesi & Oberthür, 2020).

In the European Green Deal context, the bioeconomy is also high on the policy agenda. The bioeconomy includes several related concepts (e.g., the bio-based economy, the green economy and the circular economy), between which there are clear synergies (Kardung et al., 2021). The circular economy has a significant place in EGD-related research. It assumes a shift from a take–make–dispose linear model to a circular model where waste, if produced, becomes a valuable resource (Smol et al., 2020). This theme in the literature is directed towards waste management, particularly recycling (Goel et al., 2021; Vardopoulos et al., 2021) and biomass production (Loizia et al., 2021). The shift towards a more sustainable society is intertwined with the economy's production, use and disposal of plastics. Emissions generated by plastic production, plastic waste, littering and leakage in nature, insufficient recycling are just some of the challenges of a circular economy (di Bartolo et al., 2021). The literature presents approaches to develop, implement, monitor and improve strategies in the framework of waste management at the local or central level (Zorpas, 2020). Publications also address the issue of carbon footprint (Attia et al., 2021) and water footprint (Trubetskaya et al., 2021).

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An emerging topic that is directly related to the circular economy is Industry 4.0. The shift of European production systems towards carbon neutrality requires a wider range of "green" industrial policies that should collectively address environmental sustainability, structural change and equitable economic performance in Europe (Pianta & Lucchese, 2020). In the literature related to EGD, the focus is on the industrial application of artificial intelligence and technological solutions focused on green manufacturing, including energy efficiency (Walther & Weigold, 2021).

The current European building stock is ageing and requires significant renovation efforts to improve its energy performance and meet climate and environmental challenges (Gangolells et al., 2020). In the European Union, buildings are responsible for 40% of energy consumption and 36% of greenhouse gas (GHG) emissions resulting from their construction, use, renovation and demolition (Bonoli et al., 2021). As a key EGD action, more building renovations are required to ensure that the EU's energy-saving and decarbonisation targets are met (Pohoryles et al., 2020). Building-related topics in relation to EGD are an emerging area. Research focuses on energy-efficient construction (Buckley et al., 2021; Figueiredo et al., 2020; Ibañez Iralde et al., 2021; Napoli et al., 2020) and the use of virtual technologies. An example of the use of virtual technologies is the application of the digital twin to assess the sustainability of an educational building. This approach allows real-time control of a wide range of sustainability criteria from the user's point of view. The building adapts to the students' daily activities through continuous interaction with sensory resources monitoring indoor comfort and air quality conditions, as well as energy needs linked to renewable energy production. The digital twin approach can be used to support sustainability-related decision-making throughout the building life cycle (Tagliabue et al., 2021).

Mobility is also a research topic inextricably linked to the European Green Deal. The transport sector, particularly road transport, is one of the most significant segments of national economies in the EU, dependent on fossil fuels (Savickis et al., 2020). It is also a major cause of global climate change. While overall EU carbon emissions are decreasing, transport-related emissions are higher than in 1990 (Haas & Sander, 2020). Road transport is responsible for about 73% of total transport GHG emissions, as more than 308.3 million road vehicles in Europe rely on conventional fuels, such as diesel and petrol, for more than 90% of their emissions. In contrast, there are low-carbon alternative fuels that can reduce GHG emissions from road transport. The literature indicates that biofuels will make a significant contribution to meeting EU targets, with a gradual shift to advanced raw materials (Chiaramonti et al., 2021; Chiaramonti & Maniatis, 2020; Panoutsou et al., 2021).

Digital technologies that transform traditional mobility concepts are also used to reduce transport emissions. Innovative mobility services are emerg-

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ing, including online platforms for car-sharing, bicycles and cars, freight transport (Tsakalidis et al., 2020). The electrification of transport and the move towards public acceptance of electric cars is also playing a key role in research (Omahne et al., 2021). In the European Union, approximately 80% of the urban population is exposed to air pollution above levels recommended by the World Health Organization (WHO). Air pollution is considered a major threat to public health, causing a 7% increase in overall mortality for every 10 $\mu g/m^3$ increase in annual average PM2.5 (Iriti et al., 2020). Therefore, research and innovation on pollution are extremely important. Related to the EGD topic are many publications on air pollution issues and greenhouse gas emissions (Ćetković et al., 2021; Dolge & Blumberga, 2021; Paprocki, 2021; Prussi et al., 2021; Zlaugotne et al., 2020), as well as on chemical safety and related risk assessment (Dulio et al., 2020).

Sustainable food systems play an essential role in policy and research agendas (Vanham & Leip, 2020). Research topics on food within the EGD are primarily focused on issues of healthy food production on agricultural land. By 2030, at least 25% of agricultural land in the EU should be farmed organically (Purnhagen et al., 2021). Sustainable agriculture is a global challenge, and, therefore, research and innovation are needed to ensure sustainable food production on agricultural land, biodiversity conservation and climate change mitigation. The literature also raises issues related to the pursuit of pesticide-free crop greening. The European Union and global sustainability policies emphasise the need to replace pesticides with safe, efficient and cost-effective alternatives to ensure sustainable food production. However, research and development on alternatives to pesticides is delayed and needs to be expanded (Taning et al., 2021). Research is also addressing the impact of the COVID-19 pandemic on the EU agri-food sector (Barcaccia et al., 2020; Rowan & Galanakis, 2020). It is important to stress that research and innovation are key factors in accelerating the transition towards sustainable, healthy and inclusive food systems, from primary production to consumption (Riccaboni et al., 2021).

Topics related to biodiversity conservation and climate change in the EGD literature are primarily considered in the context of the strategic actions and challenges facing the European Union in this regard (Hermoso et al., 2022; Montanarella & Panagos, 2021; Dupont et al., 2020) as well as individual countries, such as Greece (Kougioumoutzis et al., 2021). The challenge facing the European Union is to transform an ambitious climate agenda into effective legal and economic instruments. The EGD is an outstanding opportunity, but to be implemented successfully, it needs to be firmly grounded in the constitutional framework of the EU legal order, in particular the concepts of solidarity, sustainable development and a high level of environmental protection (Sikora, 2020).

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Conclusions

The study mostly focused on the identification of current and future directions for research relating to the issues of the European Green Deal. The European Green Deal strategy, adopted by the European Commission in 2019, requires simultaneous action in many areas, including research and application of the proposed solutions. Achieving the ambitious goal of climate neutrality in 2050 will depend on the level of achievement of sub-targets relating to the 8 EGD areas: energy, circular economy, industry, building, mobility, food, biodiversity and pollution.

Within the area of energy, research to date has focused in particular on the study of green energy sources and renewable energy sources. An important area of research is energy efficiency and security of energy production from renewable sources. All categories of renewable energy: biomass, biogas, solar energy and wind energy are of interest to researchers.

The circular economy has a significant place in EGD-related research. Research relating to the circular economy addresses waste management, in particular plastic waste. The challenge for a circular economy is to build effective recycling systems and avoid littering and leakage in nature. The literature points to the need to develop strategies at local, regional and central level focused on waste management.

The concept of Industry 4.0 as an object of scientific research now seems to be crucial also in relation to the circular economy. Many researchers point to the need for a green industrial policy, based on artificial intelligence and environmental technological solutions.

An emerging area of research is the area of construction mainly in the context of improving the energy efficiency of buildings responsible for 40% of energy consumption. Research in this area is focused on: on energy-efficient construction and use of virtual technologies which allow real-time control of a wide range of sustainability criteria from the user's point of view. Digital twin are indicated in the research as methods and decision-making tools enabling the application of digital replica showing potential and actual physical assets use (not only for educational purposes).

The transport sector, particularly road transport, is another research area relating to the EGD strategy. Research in this area focuses in particular on low-carbon alternative fuels and advanced raw materials. A challenge from both a scientific and a practical point of view are the research involved in the electrification of transport and innovative mobility services such as online platforms for car-sharing, bicycles and cars, freight transport.

Due to the lack of significant results in improving the state of air pollution, mainly in urban areas, research and innovation on pollution are

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extremely important. The main research themes concern greenhouse gas emissions, chemical safety and risk assessment.

Sustainable food systems play an essential role in policy and research agendas mainly in the context of problems generated by pesticides. Research in the area related to sustainable food focuses mainly on the search for pesticide-free crop greening, development on alternatives to pesticides and accelerating the transition towards sustainable, healthy and inclusive food systems as well.

The conducted research allowed drawing scientific and practical conclusions and identifying horizontal research directions, including digitalisation and innovations. The two identified study areas overlap with other areas identified in the EGD. From the practical point of view, the conducted analyses and studies related to EGD (including the one presented in this article) provide insights into important problems that require wider consideration and development of solutions in this area. The currently available research results can help inform decisions related to legislation and the allocation of funding in future research and innovation framework programmes.

The research results obtained have also identified key and emerging areas where further research and in-depth analysis should be carried out. These are necessary if the objectives set out in the European Green Deal are to be achieved. This will only be possible by combining knowledge from research with its practical application.

The identification of priority research directions relating to the EGD strategy can provide a basis for scholars, governments and businesses to set their own development strategies and directions for action in the long term. The indicated research directions have a huge application potential.

The research findings indicate directions for future research. After the period of planning the implementation of the EGD strategy and the implementation of specific actions, it will be necessary to measure the effectiveness and efficiency of the initiatives undertaken, which will undoubtedly be a new research direction. Research on the development of new forms and methods of social participation and involvement of various stakeholder groups for common and important goals will continue to be relevant.

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The contribution of the authors

Conceptualisation, D.S. and J.E.; literature review, D.S. and J.E.; methodology, D.S.; formal analysis, D.S.; data collection, D.S.; writing, D.S. and J.E.; conclusions and discussion D.S. and J.E. Both authors have read and agreed to the published version of the manuscript.

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