sustainability

Systematic Review

Traceability Models and Traceability Systems to Accelerate the Transition to a Circular Economy: A Systematic Review

Silvina Santana [1,2,3,*] and Agostinho Ribeiro [1,2]

[1] Department of Economics, Management, Industrial Engineering and Tourism, University of Aveiro, Campus de Santiago, 3810-193 Aveiro, Portugal; agostinho.ribeiro@ua.pt
[2] Institute of Electronics and Informatics Engineering of Aveiro, University of Aveiro, Campus de Santiago, 3810-193 Aveiro, Portugal
[3] Research Unit on Governance, Competitiveness and Public Policies, University of Aveiro, Campus de Santiago, 3810-193 Aveiro, Portugal
* Correspondence: silvina.santana@ua.pt; Tel.: +351-234-370-840

Abstract: Research and implementation efforts and investment in the circular economy are rising sharply. With the high stakes associated with achievements in the field, an increasing emphasis on evaluation, transparency and accountability are to be expected. All require high-quality data, methodologies and tools that are able to improve results and to assess and document the implementation processes and outcomes. A challenging key issue in the implementation of a circular economy is ensuring coordination, control and transparency within a network of parties. Traceability models and systems are vital pillars of such an endeavor, but a preliminary search of the available literature revealed a rather unstable and fragmented research field and practice. The objective of this systematic review was to examine those studies discussing traceability models and traceability systems while connecting traceability capacities and outputs to implement the principles of the circular economy. The literature databases were searched on 6 January 2020, with an update for the entire year of 2020. Overall, 49 studies were included. By addressing eight specific research questions, we found that a link between traceability and the circular economy is yet to be established. Sound research and practice documentation are required to establish evidence regarding this connection, including methodologies that are able to support the design and implementation of business- and lifecycle-oriented, value-based traceability models and traceability systems, along with thorough evaluation methods and tools incorporating economic, social and environmental perspectives.

Keywords: traceability model; traceability system; circular economy; systematic review; requirements; standard; ontology; technology

Citation: Santana, S.; Ribeiro, A. Traceability Models and Traceability Systems to Accelerate the Transition to a Circular Economy: A Systematic Review. *Sustainability* **2022**, *14*, 5469. https://doi.org/10.3390/su14095469

Academic Editor: Claudio Sassanelli

Received: 2 April 2022
Accepted: 29 April 2022
Published: 2 May 2022

1. Introduction

The circular economy (CE) has been proposed as an approach to an economic system aimed at making the most of the resources we use and minimizing waste [1,2]. The transition to a circular economy has gained prominence on the agendas of policymakers, researchers and practitioners [3–6] since it is expected to guide society toward the efficient use of resources and to the dissociation of economic growth from environmental impacts [4,7].

However, closing the loop and achieving circularity while assuring social wealth, productivity and economic growth may prove challenging [8,9]. Given the expected and unprecedented requirements in collaboration, communication, coordination and control [10,11] within a network of involved parties, tracking and tracing capabilities will be in high demand.

Traceability has been defined as the ability to identify and trace the history, distribution, location and application of products, parts, materials and services [12]. A traceability system (TS) would record and allow us to follow the trail of production, as products, parts, materials and services originate from suppliers and are processed and ultimately distributed as final products and services [13]. A TS should support both tracking and tracing [14] and span the boundaries of a single entity, allowing for both internal and external traceability [15]. To be able to trace and identify an item in any system, a traceable resource unit [16,17], or similar concept, must be defined.

The dimensions, components and capabilities of a traceability model (TM) and TS are determined by contextual and industry-specific issues, regulatory recommendations and enforcement, along with the many needs and expectations of different stakeholders. The recent ISO standard, BS 8001 [18], is the first to address the understanding and implementation of a CE at an organizational level. The principles needed to achieve a CE are systems-oriented thinking, stewardship, transparency, collaboration, innovation and value optimization, and while the standard does integrate them into business process development, organizations are given full responsibility for choosing CE performance indicators, both internally and for communicating progress to stakeholders [19]. Moreover, the link between a CE, sustainability, social risks and ethical responsibility needs clarification and specific guidance is missing regarding the quantitative assessment of CE performance [19]. The Ellen MacArthur Foundation has already developed indicators that assess the performance of a company or a product in the context of a CE [20]. More recently, a dashboard for selecting core indicators for the quantitative assessment of CE strategies for organizations and product systems was proposed [19]. Indicators can be used to guide and enable the work of different participants, for example, as decision-making tools in design and procurement, internal and external reports, business evaluation and rating, policy development and research [20–22].

In realistic terms, it is not feasible to develop advanced TSs that are intended to span organizational and sectoral boundaries in increasingly data- and information-driven and highly knowledge-intensive contexts without using information and communication technologies. Technology is necessary for the identification and characterization of products and processes, along with the capture, analysis, storage and transmission of data and information, as well as for the overall integration and validation of the system [23].

On the one hand, TSs are fundamental, as are TMs that are able to guide and support their development, deployment and evolution. On the other hand, consistency in terms of approach is a key prerequisite for quality in research and implementation efforts and of the subsequent results, particularly those involving system modeling and integration, commanding the use of ontologies able to capture and ensure a common understanding and an explicit formal specification of the terms used in a domain and the relationships among them [24].

Previous work on TMs, TSs and a CE revealed a rather amorphous field of research, even with regard to the shared understanding of key concepts within the same industry, where several definitions of traceability and its classifications, coming from organizations, legislation and research literature, may be found [25]. One review [26] focuses on the origins, principles, advantages and disadvantages, modeling and implementation of a CE at different levels, without addressing traceability or tracking. A recent systematic review on supply chain management in global supply chains (GSC) [27] addresses GSC configurations, governance mechanisms and the dimensions of sustainability outcomes, but not traceability. A strand of research on the life-cycle assessment (LCA) component of products [28] highlights the pressing need for a socio-economic LCA methodology, including indicators, allowing to complement the more traditional vision of the production, use and disposal of products.

A limited search of available literature revealed that there are currently no systematic reviews on TMs or TSs that are able to support a circular, life-cycle perspective of product design, use and disposal toward a transition to a CE. Therefore, a systematic review (SR) was deemed necessary to identify and review those proposals and implementations of TMs and TSs that would promote and support the transition to a CE.

2. Research Questions

We set a primary question (PQ) and eight secondary questions (SQ) to guide the development of this SR (Figure 1).

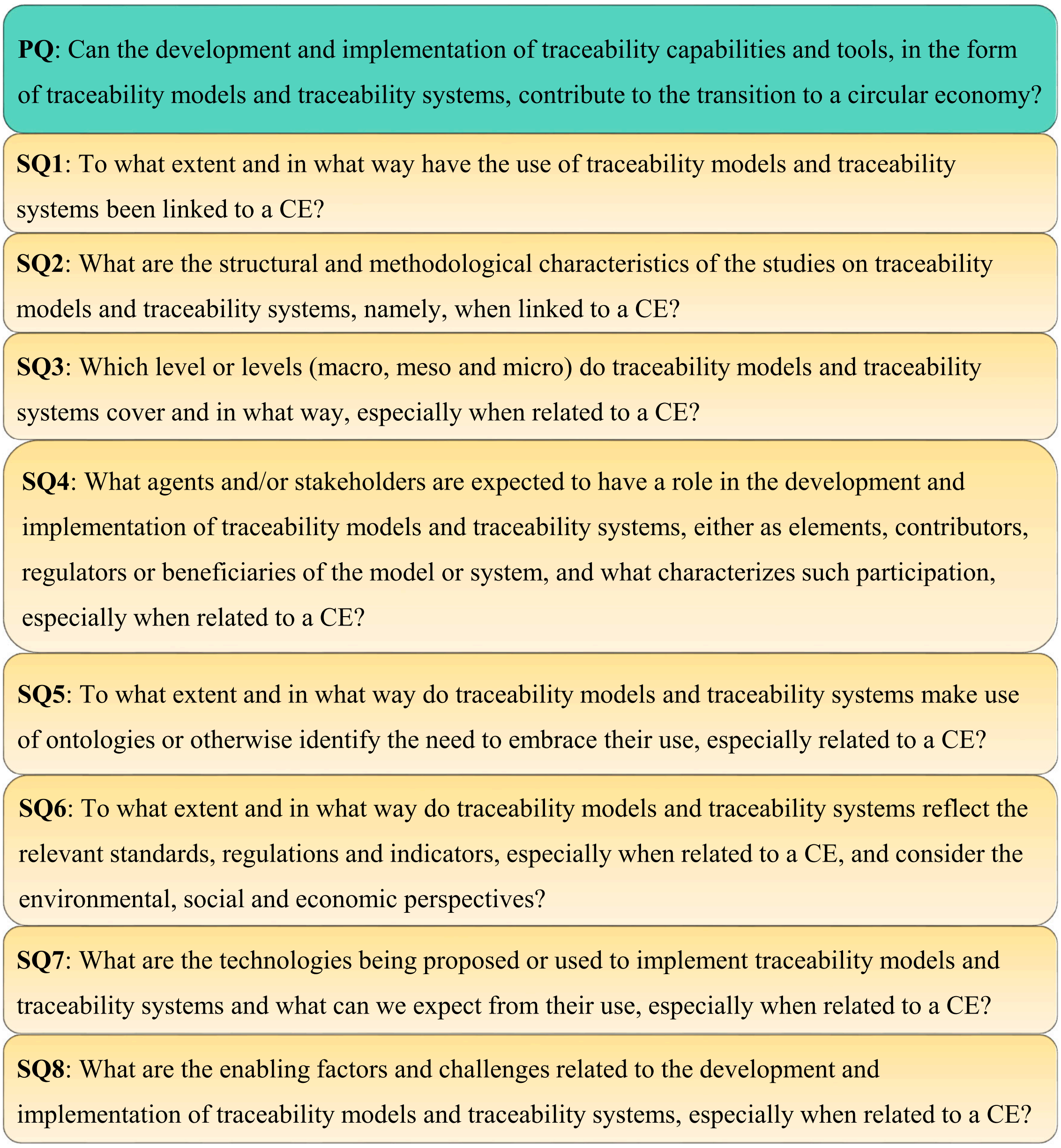


Figure 1. The primary question (PQ) and secondary questions (SQ) of the SR.

3. Eligibility Criteria

The SR included studies where the population consists of traceable entities (e.g., specifications, products, packaging, processes). Traceable entities could be expressed differently depending on the context addressed, the objective sought and the disciplinary perspective of the study.

The SR encompassed studies proposing or assessing TMs and studies conceptualizing, discussing the implementation, or assessing the TSs or components of TSs: (1) broadly presented as a means to support the implementation of the principles of a CE; (2) narrowly presented as a means to improve those issues revolving around the modeling, registration, retrieval, and general management of data and information on traceable entities, with an explicit or implicit mention of a contribution to the principles of a CE. Comparators would consist of other traditional approaches, including frameworks or technological advances that proposed to improve aspects such as collaboration, coordination and transparency in supply chains, intra- or inter-organizations, or performance, such as in safety, quality, sustainability, or circularity-related initiatives, but where traceability may not be considered as essential to the aspects being addressed as outcomes of the intervention.

The SR included studies on TMs and TSs independent of the implementation industry/context, namely: (1) studies addressing the micro, the meso- and the macro-levels [29], along with studies dealing with different layers and different variable types; (2) studies identifying contextual drivers of and barriers to the implementation of TMs and TSs, especially when discussing an impact on the implementation of a CE.

Outcomes sought included: (1) contributions to the implementation of a CE, either as declared by the authors or identified by the reviewers, based on the relevant literature [18–20]; (2) contributions to the characteristics of data and information on traceable entities—e.g., accuracy, objectivity, relevance, accessibility, richness, timeliness, authorship, verifiability, scalability.

Furthermore, the SR included all types of studies, namely, quantitative and qualitative research, conceptual and empirical studies; it set no time or industry limitations; it also considered publications made in English, Portuguese, Spanish, Italian and French. Moreover, the SR excluded those literature reviews, systematic reviews and studies that did not meet research and professional standards. Finally, the review did not include basic research on technology and process innovation that was disconnected from industry applications.

4. Methods

A population, intervention, comparator, context and outcome (PICCO) framework was used to develop and combine subject headings and keywords, to help with screening and selecting the studies and analyzing, synthesizing and reporting the results. A protocol that was compliant with PRISMA-P (Preferred Reporting Items for Systematic Reviews and Meta-Analysis Protocols) was developed a priori [30]. PRISMA was used to report the SR [31].

A three-step search strategy was followed, aiming to find both published and unpublished studies (Figure 2). Three queries were finally established for the SR, allowing us to capture studies addressing the primary themes (the circular economy, track and trace, traceability tools, traceability methods) and extending the search to concepts closely related or tantamount to CEs that were in use before the current surge of interest in this topic (reduce, reuse, recycle, circularity, upcycling), as well as to the field of ontologies, when related to the circular economy and industrial symbiosis (see Appendix A for the full queries).

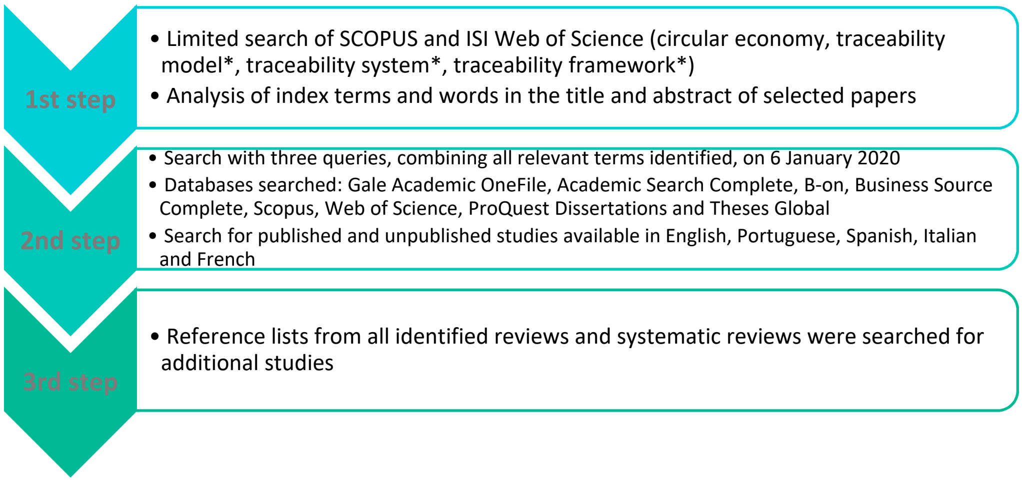


Figure 2. Three-step search strategy used in the SR.

The selection process evolved in two phases. In the screening phase, the titles and abstracts of all identified studies were screened by two reviewers. In the eligibility phase, the retained studies were assessed by two reviewers through full-text reading. A discussion was conducted to resolve disagreements. Rayyan QCRI [32] was used to help manage the review process.

Data of significance to the primary and the secondary questions and the study methods were collated by two independent reviewers. The extraction forms were validated by the review team prior to utilization, to ensure acceptability and study validity.

It was anticipated that a significant part of the included studies would be descriptive and qualitative in nature and that those studies reporting on results from implementations would be based on observational data. Therefore, the direct applicability of standardized tools for the assessment of methodological validity of studies considered for inclusion in systematic reviews and meta-syntheses was expected to be low; consequently, a custom-made framework based on a multi-dimensional concept of quality in research was used to examine the quality of any studies under consideration.

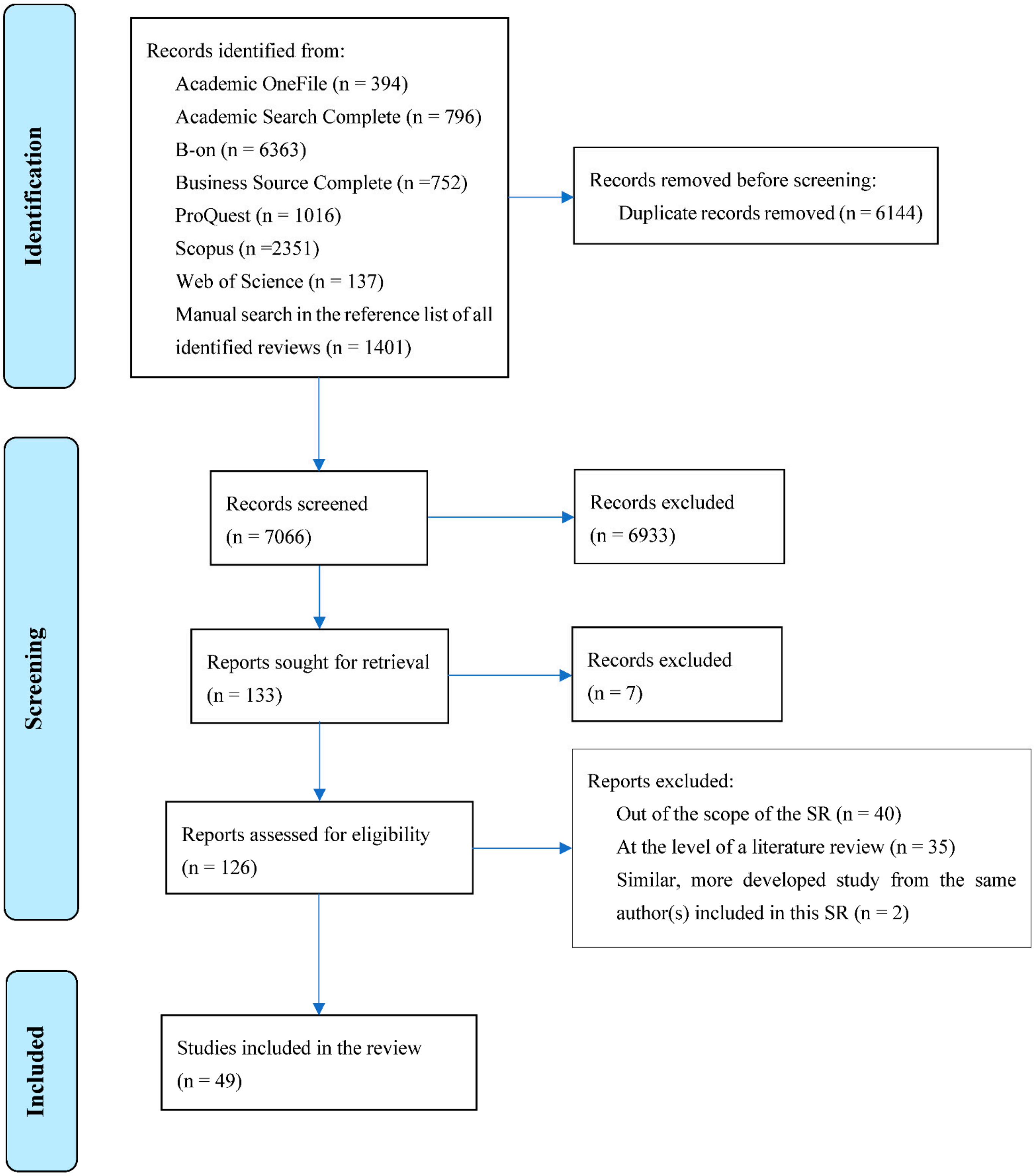
A narrative synthesis oriented to answering the primary and the secondary questions of the SR was carried out. In the face of the high volume of data extracted, additional consensual categories within the group of reviewers, not previewed in the protocol, were introduced to help synthesize and take meaning from the results. In this phase, no filtering of the primary studies involving the application of additional exclusion criteria was conducted.

5. Results

5.1. Study Selection

The results of the search and selection processes are presented in Figure 3. A total of 13,210 potentially relevant articles were identified in the literature search, which was conducted on 6 January 2020. Of those, 6144 were duplicates. From the remaining 7066 records, 6933 were excluded after the title and abstract assessments. Subsequently, 84 were excluded after full-text analysis as they did not meet the inclusion criteria, or did not comply with the quality requirements. The remaining 49 studies entered the data collection phase. By the time we began drafting the report, a search update had been conducted for the entire year of 2020 and three additional studies were brought to the discussion.

The complete extraction tables are available from the authors.


Identification
Records identified from:
Academic OneFile (n = 394)
Academic Search Complete (n = 796)
B-on (n = 6363)
Business Source Complete (n =752)
ProQuest (n = 1016)
Scopus (n =2351)
Web of Science (n = 137)
Manual search in the reference list of all identified reviews (n = 1401)
Records removed before screening:
Duplicate records removed (n = 6144)
Screening
Records screened (n = 7066)
Records excluded (n = 6933)
Reports sought for retrieval (n = 133)
Records excluded (n = 7)
Reports assessed for eligibility (n = 126)
Reports excluded:
Out of the scope of the SR (n = 40)
At the level of a literature review (n = 35)
Similar, more developed study from the same author(s) included in this SR (n = 2)
Included
Studies included in the review (n = 49)

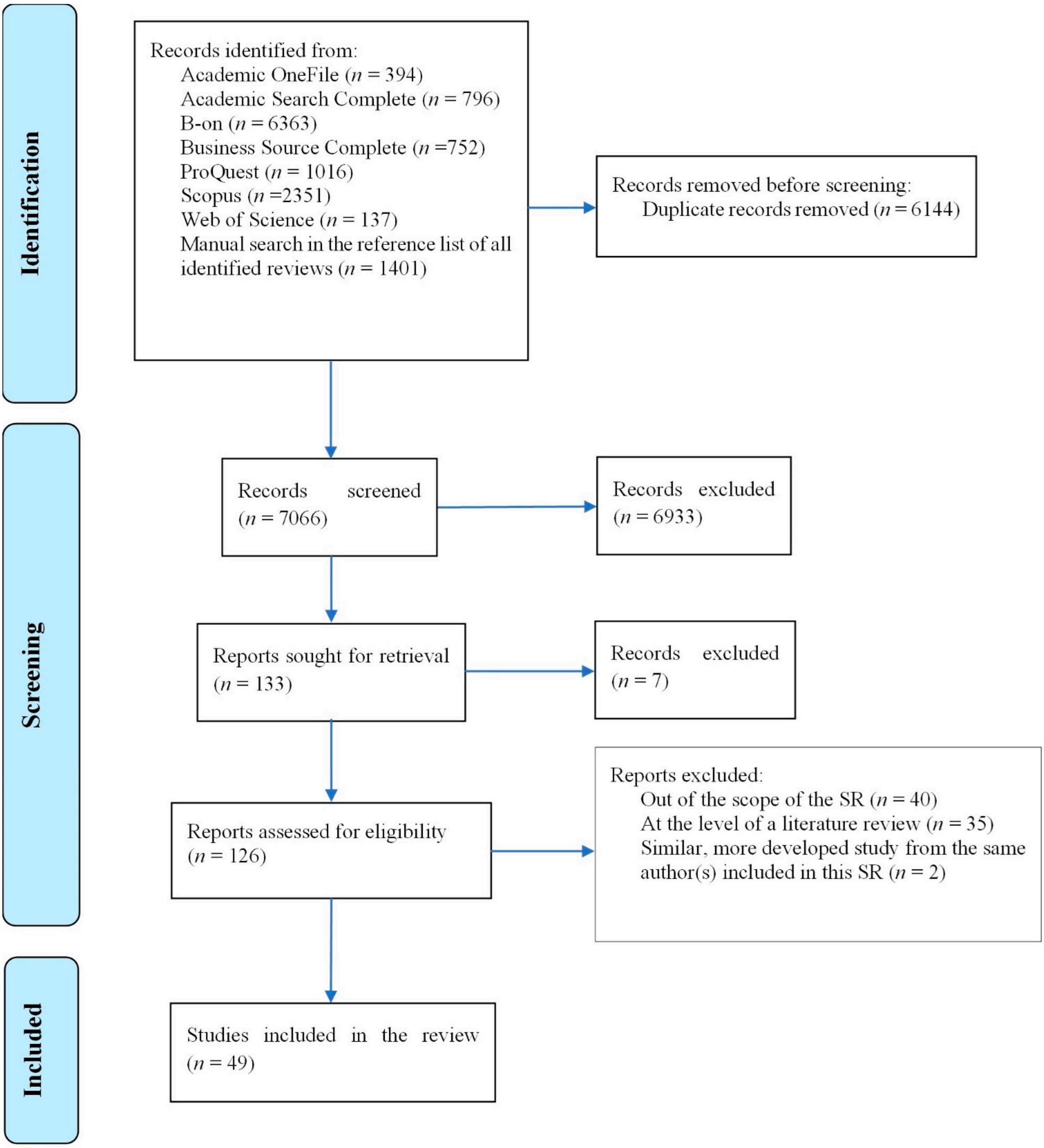


Figure 3. PRISMA flow diagram of the study selection and inclusion processes.

5.2. General Characteristics of the Included Studies

Description data on the general characteristics of all the included studies and study numbers within the SR are presented in Table 1. Dates of publication ranged from 2003 to 2020 and all studies were published in English. When assessed according to the affiliation(s) of the first author, thirty studies were conducted in Europe, fifteen in Asia, four in the US, and one in Oceania. Twenty-three studies declared a source of funding, namely: nine were funded, at least in part, by a European Union (EU) entity or program; eighteen were funded by a national public body, complemented in some cases by other support. Table 1 and Figure 4 provide information on the study characteristics, including author(s), title, country of study and source of funding.

Table 1. Study characteristics.

Study	Author(s)	Title	Affiliation(s) of the First Author	Source of Funding
Tian, 2017 [33]	Feng Tian	A supply chain traceability system for food safety, based on HACCP, blockchain and Internet of Things	Department of Information Systems and Operations, Vienna University of Economics and Business, Vienna, Austria	None declared.
Wang et al., 2018 [34]	Jun Wang, Hung-Lin Chi, Wenchi Shou, Heap-Yih Chong and Xiangyu Wang	A coordinated approach for supply-chain tracking in the liquefied natural gas industry	Australasian Joint Research Centre for Building Information Modelling, School of Design and the Built Environment, Curtin University, Perth	Australia.
Parreño-Marchante et al., 2014 [35]	Alfredo Parreño-Marchante, Alejandro Alvarez-Melcon, Mira Trebar, Piero Filippin	Advanced traceability system in aquaculture supply chain	Universidad Politécnica de Cartagena, Cartagena, Spain	European Union.
Terzi et al., 2007 [36]	Sergio Terzi, Hervé Panetto, Gérard Morel, Marco Garetti	A holonic metamodel for product traceability in product lifecycle management	University of Bergamo, Department of Industrial Engineering, Italy	None declared.
Ruiz-Garcia et al., 2010 [37]	Ruiz-Garcia, L., Steinberger, G., and Rothmund, M.	A model and prototype implementation for tracking and tracing agricultural batch products along the food chain	Laboratorio de Propiedades Físicas y Tecnologías Avanzadas en Agroalimentación, Universidad Politécnica de Madrid, Madrid, Spain	Spain. Germany.
Anquetil et al., 2010 [38]	Nicolas Anquetil, Uirá Kulesza, Ralf Mitschke, Ana Moreira, Jean-Claude Royer, Andreas Rummler, André Sousa	A model-driven traceability framework for software product lines	ASCOLA, EMN-INRIA, Nantes, France	European Union.
Tian, 2016 [39]	Feng Tian	An agri-food supply chain traceability system for China based on RFID and blockchain technology	Department of Information Systems and Operations, Vienna University of Economics and Business, Vienna, Austria	None declared.
Chen, 2017 [40]	Rui-Yang Chen	An intelligent value stream-based approach to collaboration of a food traceability cyber-physical system by fog computing	Department of Business Administration, Aletheia University, Taiwan	None declared.
[41](Hsu, Chen, & Wang, 2008)Hsu et al., 2008 [41]	Yu-Chia Hsu, An-Pin Chen, Chun-Hung Wang	An RFID-enabled traceability system for the supply chain of live fish	Institute of Information Management, National Chiao Tung University, Taiwan Mackay Medicine, Nursing and Management College, Taiwan	None declared.
Bevilacqua et al., 2009 [42]	M. Bevilacqua, F.E. Ciarapica, G. Giacchetta	Business process reengineering of a supply chain and a traceability system: a case study	Dipartimento di Energetica, Università Politecnica delle Marche, Ancona, Italy	None declared.

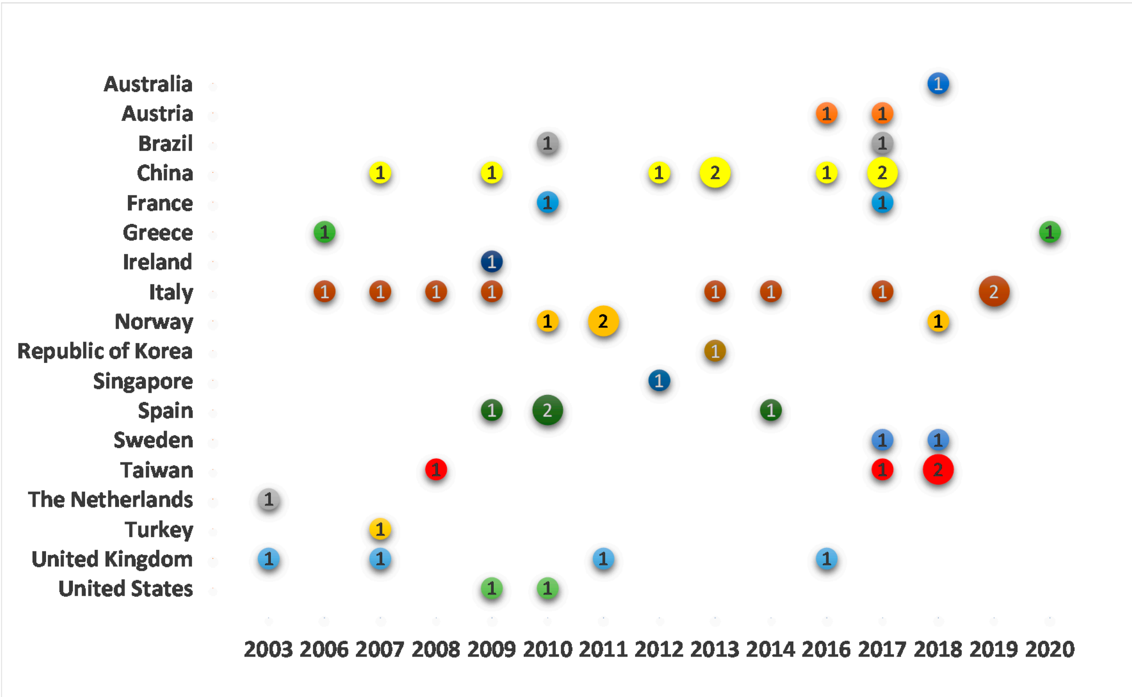
Conti and Orcioni, 2019 [43]	Massimo Conti and Simone Orcioni	Cloud-based sustainable management of electrical and electronic equipment from production to end-of-life	Department of Information Engineering, Universita Politecnica delle Marche, Ancona, Italy	European Union.
Karlsen et al., 2011 [44]	K.M. Karlsen, C.F. Sørensen, F. Forås, P. Olsen	Critical criteria when implementing electronic chain traceability in a fish supply chain	Norwegian Institute of Fisheries and Aquaculture Research (Nofima), Tromsø, Norway	Norway.
Kumar et al., 2017 [45]	Vijay Kumar, Carina Hallqvist and Daniel Ekwall	Developing a framework for traceability implementation in the textile supply chain	University of Borås, Allégatan 1, 503 32 Borås, Sweden ENSAIT/GEMTEX, Roubaix, France Université Lille 1 Sciences et Technologies, Villeneuve-d'Ascq, France College of Textile and Clothing Engineering, Soochow University, Suzhou, China	European Union.
Ngai et al., 2007 [46]	E. W. T. Ngai, T. C. E. Cheng, Kee-hung Lai, P. Y. F. Chai, Y. S. Choi, R. K. Y. Sin	Development of an RFID-based traceability system: experiences and lessons learned from an aircraft engineering company	The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong SAR, PR China	Hong Kong, China.
Feng et al., 2013 [47]	Jianying Feng, Zetian Fu, Zaiqiong Wang, Mark Xu, Xiaoshuan Zhang	Development and evaluation of an RFID-based traceability system for cattle/beef quality safety in China	College of Engineering, China Agricultural University, Beijing 100083, PR China	China.
Bezerra et al., 2017 [48]	Alan C. Bezerra, Heliton Pandorfi, Rafael M. Gama, Francisco F. R. De Carvalho, Cristiane Guiselini	Development of a traceability model applied to goat and sheep meat production	Universidade Federal Rural de Pernambuco—Unidade Acadêmica de Serra Talhada/ Serra Talhada—PE, Brasil	None declared.
Kang and Lee, 2013 [49]	Yong-Shin Kang, Yong-Han Lee	Development of generic RFID traceability services	u-SCM Research Center, Dongguk University—Seoul, Republic of Korea	Republic of Korea.
Bertolini et al., 2006 [50]	Massimo Bertolini, Maurizio Bevilacqua, Roberto Massini	FMECA approach to product traceability in the food industry	Dipartimento di Ingegneria Industriale, Universita` degli Studi di Parma, Italy	None declared.
Pizzuti et al., 2014 [51]	Teresa Pizzuti, Giovanni Mirabelli, Miguel Angel Sanz-Bobi, Fernando Goméz-Gonzaléz	Food Track and Trace ontology for helping the food traceability control	Dipartimento di Ingegneria Meccanica, Energetica e Gestionale, Università della Calabria, Italy	None declared.
Thakur and Hurburgh, 2009 [52]	Maitri Thakur, Charles R. Hurburgh	Framework for implementing traceability system in the bulk grain supply chain	Department of Agricultural and Biosystems Engineering, Iowa State University, United States	None declared.
Lavelli, 2013 [53]	V. Lavelli	High-warranty traceability system in the poultry meat supply chain: a medium-sized enterprise case study	DeFENS e Department of Food, Environmental and Nutritional Sciences, Università degli Studi di Milano, Milano, Italy	None declared.

Muñoz-Gea et al., 2010 [54]	Juan Pedro Muñoz-Gea, Josemaria Malgosa-Sanahuja, Pilar Manzanares-Lopez, Juan Carlos Sanchez-Aarnoutse	Implementation of traceability using a distributed RFID-based mechanism	Department of Information Technologies and Communications, Polytechnic University of Cartagena, Cartagena, Spain	Spain.
Tu et al., 2018a [55]	Mengru Tu, Ming K. Lim, Ming-Fang Yang	IoT-based production logistics and supply chain system—Part 1: modeling IoT-based manufacturing supply chain	Department of Transportation Science, National Taiwan Ocean University, Keelung, Taiwan	None declared.
Tu et al., 2018b [56]	Mengru Tu, Ming Lim, Ming-Fang Yang	IoT-based production logistics and supply chain system—Part 2: IoT-based cyber-physical system: a framework and evaluation	Department of Transportation Science, National Taiwan Ocean University, Keelung, Taiwan	None declared.
Li et al., 2017 [57]	Zhi Li, Guo Liu, Layne Liu Xinjun Lai, Gangyan Xu	IoT-based tracking and tracing platform for prepackaged food supply chain	Guangdong Provincial Key Lab of Computer Integrated Manufacturing System, Guangdong University of Technology, Guangzhou, China	China.
Thakur et al., 2011 [58]	Maitri Thakur, Carl-Fredrik Sørensen, Finn Olav Bjørnson, Eskil Forås, Charles R. Hurburgh	Managing food traceability information using EPCIS framework	Aquaculture Technology, SINTEF Fisheries and Aquaculture, Trondheim, Norway	Unclear, it seems to be the European Union and Japan.
Jansen-Vullers et al., 2003 [59]	M.H. Jansen-Vullers, C.A. van Dorp, A.J.M. Beulens	Managing traceability information in manufacture	Department of Technology Management, Eindhoven University of Technology (TU/e), Eindhoven, The Netherlands	None declared.
Pizzuti et al., 2017 [60]	Teresa Pizzuti, Giovanni Mirabelli, Giovanni Grasso, Giulia Paldino	MESCO (meat supply chain ontology): an ontology for supporting traceability in the meat supply chain	Dipartimento di Ingegneria Meccanica, Energetica e Gestionale, Università della Calabria, Italy	None declared.
Hu et al., 2013 [61]	Jinyou Hu, Xu Zhang, Liliana Mihaela Moga, Mihaela Neculita	Modeling and implementation of the vegetable supply chain traceability system	College of Engineering, China Agricultural University, Beijing 100083, PR China	Unclear, at least partially by the European Union.
Thakur and Donnelly, 2010 [62]	Maitri Thakur, Kathryn A.-M. Donnelly	Modeling traceability information in soybean value chains	Department of Agricultural and Biosystems Engineering, Iowa State University, Ames, IA 50011, United States Department of Industrial and Manufacturing Systems Engineering, Iowa State University, Ames, IA 50011, United States	Unclear.
Xu et al., 2009 [63]	D. F. Xu, Q. Li, H.-B. Jun, J. Browne, Y. L. Chen, D. Kiritsis	Modeling for product information tracking and feedback via wireless	Department of Automation, Tsinghua University, Beijing, China	Unclear.

		technology in closed-loop supply chains	CIMRU, National University of Ireland, Galway, Ireland	
Bechini et al., 2008 [64]	Alessio Bechini, Mario G.C.A. Cimino, Francesco Marcelloni, Andrea Tomasi	Patterns and technologies for enabling supply chain traceability through collaborative e-business	Dipartimento di Ingegneria dell'Informazione: Elettronica, Informatica, Telecomunicazioni, University of Pisa, Pisa, Italy	Italy.
Olsen and Aschan, 2010 [65]	Petter Olsen and Michael Aschan	Reference method for analyzing material flow, information flow and information loss in food supply chains	Nofima Market,Muninbakken,Breivik, Tromsø, Norway	European Union.
Sundberg et al., 2018 [66]	Peter Sundberg, Sven Hermansson, Claes Tullin, Marcus Öhman	Traceability of bulk biomass: Application of radio frequency identification technology on a bulk pellet flow	RISE Research Institutes of Sweden, Department of Energy and Circular Economy, Borås, Sweden Energy Engineering, Division of Energy Science, Luleå University of Technology, Luleå, Sweden	Sweden.
da Silva et al., 2010 [67]	Daniel Lins da Silva, Pedro Luiz Pizzigatti Corrêa, Leandro Halle Najm	Requirements analysis for a traceability system for the management of the wood supply chain in the Amazon forest	Electrical Engineering Digital Systems, Engineering School of USP, Brazil	None declared.
Zhang et al., 2012 [68]	Yingfeng Zhang, Pingyu Jiang, George Huang, Ting Qu, Guanghui Zhou, Jun Hong	RFID-enabled real-time manufacturing information tracking infrastructure for extended enterprises	Key Laboratory of Contemporary Design and Integrated Manufacturing Technology, Ministry of Education, Northwestern Polytechnical University, Xi'an, China State Key Laboratory for Manufacturing Systems Engineering, School of Mechanical Engineering, Xi'an Jiaotong University, Xi'an, China	China.
Kelepouris et al., 2007 [69]	Thomas Kelepouris, Katerina Pramatari and Georgios Doukidis	RFID-enabled traceability in the food supply chain	Auto-ID Lab, Institute for Manufacturing, University of Cambridge, Cambridge, UK.	None declared.
Shi et al., 2012 [70]	Jie Shi, Yingjiu Li, Wei He, Darren Sim	SecTTS: a secure track and trace system for RFID-enabled supply chains	School of Information Systems, Singapore Management University, Stamford Road, Singapore.	Singapore.
Olsen and Borit [71]	Petter Olsen, Melania Borit	The components of a food traceability system	Nofima, Muninbakken 9–13, Breivika, Tromsø, Norway.	European Union. Norway.
Wong and Wong, 2016 [72]	Eugene Y. C. Wong and W. H. Wong	The development of a reusable luggage tag with the Internet of Things for mobile tracking and environmental sustainability	Department of Supply Chain and Information Management, Hang Seng Management College, Hong Kong (China).	Hong Kong, China.
Parlikad et al., 2003 [73]	Ajith Kumar Parlikad, Duncan McFarlane, Elgar Fleisch, Sandra Gross	The role of product identity in end-of-life decisionmaking	AUTO-ID Centre Institute for Manufacturing, University of Cambridge, Cambridge, United Kingdom	None declared.

Segura-Velandia et al., 2016 [74]	Diana M. Segura-Velandia, Navjot Kaur, William G. Whittow, Paul P.Conway, Andrew A.West	Toward the industrial Internet of Things: Crankshaft monitoring, traceability and tracking using RFID	Wolfson School of Mechanical and Manufacturing Engineering and Loughborough University, England, UK.	Unclear.
Ouertani et al., 2011 [75]	M.Z. Ouertani, S. Baïna, L. Gzara, G. Morel	Traceability and management of dispersed product knowledge during design and manufacturing	Department of Engineering, University of Cambridge, UK.	None declared.
Folinas et al., 2006 [76]	Dimitris Folinas, Ioannis Manikas and Basil Manos	Traceability data management for food chains	Department of Applied Informatics, University of Macedonia, Thessaloniki, Greece.	None declared.
UNECE, 2016 [77]	Markus Pikart and Andrew Baxter	Traceability for sustainable trade—a framework to design traceability systems for cross-border trade	United Nations Economic Commission for Europe (UNECE).	None declared.
Ergen et al., 2007 [78]	Esin Ergen, Burcu Akinci, Rafael Sacks	Tracking and locating components in a precast storage yard utilizing radio frequency identification technology and GPS	Department of Civil Engineering, Istanbul Technical University, Istanbul, Turkey.	Unclear.
Martínez-Sala et al., 2009 [79]	Alejandro S. Martínez-Sala, Esteban Egea-Lopez, Felipe Garcia-Sanchez, Joan Garcıa-Haro	Tracking of returnable packaging and transport units with active RFID in the grocery supply chain	Polytechnic University of Cartagena (UPCT), Cuartel Antigones, Cartagena, Spain.	Spain.
Papetti et al., 2019 [80]	Alessandra Papetti, Marco Marconi, Marta Rossi, Michele Germani	Web-based platform for eco-sustainable supply chain management	Department of Industrial Engineering and Mathematical Sciences, Università Politecnica delle Marche, Ancona, Italy.	Unclear.
Plakas et al., 2020 [81]	G. Plakas, S. T. Ponis, K. Agalianos, E. Aretoulaki	Reverse logistics of end-of-life plastics using industrial IoT and LPWAN technologies—a proposed solution for the bottled water industry	School of Mechanical Engineering, National Technical University Athens, Athens, Greece	European Union. Greece.

Affiliation(s) of the first author



Source of funding

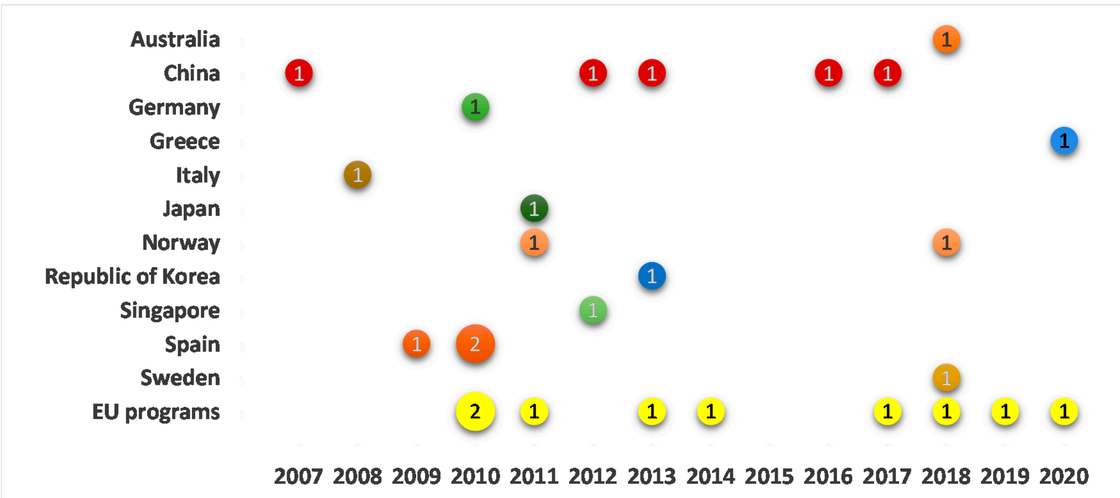


Figure 4. A view showing the country of study and source of funding of all the included studies, arranged by year.

5.3. Methodological Options of the Included Studies

Only five of the included studies stated the research questions explicitly, and always in a very generic way. Eighteen studies described a methodology, research design/methods or approach outline. For many of the other studies, it was possible to elicit steps or phases from the way in which the authors described their work. Only in three studies was there a clear mention of recognizable research methods covering the entire study: design research [55], "design research method, case study, emulation experiment method, and cost-benefit analysis" [56] (p. 96), and trials [66].

Regarding the main areas of research, as declared by the authors or collected by the reviewers from the study introduction/background, it was possible to classify the studies according to eleven main themes (Table 2).

Table 2. Main areas of research of all included studies.

Study	Traceability, Tracking, and Related Concepts	Supply Chain Management and Integration	Environmental and Lifecycle Management	Technology	Information Modeling, SW Development, Systems Architecture, Distributed and Cloud Computing	Processes and Processes' Representation	Requirements	International Initiatives, Regulations and Standards	Intertwine of Physical and Computational Elements	Ontologies	Security
[33]				X				X			
[34]		X		X							
[35]	X			X				X			
[36]	X		X		X		X	X	X		
[37]	X				X						
[38]	X				X						
[39]				X							
[40]	X					X		X	X		
[41]	X			X							
[42]	X					X					
[43]			X	X							
[44]	X						X	X			
[45]	X				X		X				
[46]				X							
[47]				X							
[48]	X										
[49]	X			X	X		X	X			
[50]	X										
[51]	X									X	
[52]	X				X	X	X				
[53]	X							X			
[54]				X	X			X			
[55]		X		X	X	X		X		X	
[56]		X		X	X			X	X		
[57]	X			X	X						
[58]					X			X			
[59]	X					X	X				
[60]										X	
[61]	X				X						
[62]	X										
[63]	X		X		X						
[64]	X				X						
[65]	X					X					
[66]				X	X						
[67]	X				X						
[68]				X							
[69]	X			X			X	X			
[70]	X							X			X

[71]	X				
[72]			X		X
[73]		X			
[74]	X		X		
[75]		X			X
[76]	X				
[77]	X				
[78]			X		
[79]			X	X	
[80]	X	X			
[81]		X	X		

Note: X = main areas discussed in the study introduction/background.

Twenty studies were classified as reporting on traceability models (TMs) or modeling traceability and thirty-one were classified as reporting on traceability systems (TSs) or the components of traceability systems (Table 3). Two studies [38,48] were classified as belonging to both groups, based on the information available in the studies.

Table 3. Classification of the included studies.

Group of Studies	Study Number
Studies reporting on traceability models or modeling traceability	[36,38,45,48,51,52,55,58–60,62–65,67,69,73,75–77]
Studies reporting on traceability systems or the components of traceability systems	[33–35,37–44,46–50,53,54,56,57,61,66,68,70–72,74,78–81]

Stages documented in the studies on traceability systems included conceptual work, design proposals, technology development, implementation and evaluation; in a number of cases, this is evaluated through simulation (Table 4).

Table 4. Developmental stages reported by the studies on traceability systems.

Study	Conceptual	Design	Technology Development	Implementation	Evaluation
[33]	X				
[34]		X	X	Feasibility study	Feasibility study
[35]				X	Feasibility study
[36]	X	X		Simulation	
[37]		X	X	Prototype	Test of prototype
[38]	X	X	X	Instantiation	
[39]	X				
[40]	X	X	X	Experiment	Experiment
[41]		X	X	X	
[42]		X			
[43]		X	X	X	
[44]				X	Feasibility study
[45]		X			
[46]		X	X	X	
[47]		X	X	X	X
[48]		X	X		
[49]		X	X	X	Evaluation through simulation
[50]					X

[51]	X	X			Suggestion for validation
[52]		X			
[53]	X	X			Evaluation through simulation
[54]		X	X		
[55]	X	X		Proof of concept	
[56]		X		Prototype in laboratory	Prototype in laboratory
[57]		X	X	X	
[58]	X	X			Proposal for model evaluation
[59]	X	X			
[60]	X	X	X	X	Test of an ontology
[61]		X	X	X	X
[62]	X	X	X		
[63]		X	X	Case study	Case study
[64]	X	X	X	Prototype	
[65]	X	X		Suggestion for proof of concept	
[66]				X	Feasibility study
[67]	X	X			
[68]	X	X	X		
[69]	X				
[70]	X	X	X	X	Test of prototype
[71]	X				
[72]		X	X		Feasibility study
[73]	X				
[74]				X	Feasibility study
[75]	X	X	X	Case study	Tools validation
[76]	X				
[77]	X				
[78]		X	X	X	X
[79]		X	X		
[80]		X	X	X	X
[81]	X				

Note: X = developmental stages documented in a study; further detail is provided when available.

5.4. Traceable Entities

Most of the studies did not define, were unclear, or were rather vague in the way that they reported on traceable entities (Table 5). Within the group of studies reporting on TMs, only two studies clearly identified traceable artifacts (in SW product lines) [38] and product knowledge during design and manufacturing phases [75] as the entities to be traced, and only four studies accounted for the different granularity or different nature of the entity to be tracked/traced along the production process [59] or supply chain [45,62,64]. Within the group of studies reporting on TSs, only eight studies explicitly approached the concept, and two studies went further by accounting for different granularity or the different natures of the entities to be tracked/traced along the supply chain [44] or the production process [50].

Table 5. Traceable entities/units, as addressed by the included studies.

Traceable Entities/Units within the Group of Studies Reporting on Traceability Models or Modeling Traceability	Study Specifics Where Appropriate (Study Number: Page Where Needed)
Undefined or unclear about traceable entity/unit	[36,51,52,63,65,67,76]
Not defined, but "object" was consistently used when modeling and a clear instantiation was provided in the running examples	Dehumidifiers and associated critical parts [55]
	Meat products and packaged products [60]
Generic terms used	traceable items [69]
	traceable unit [58]
	product [73]
	traceable assets [77]
Inconsistent use of terms	[48]
Clearly identified	traceable artifacts (in SW product lines) [38]
	product knowledge during the design and manufacturing phases [75]
Different granularity or different nature of the entity to be tracked/raced	Along the production process [59]
	Along the supply chain [45,62,64]
Traceable Entities/Units within the Group of Studies Reporting on Traceability Systems or Components of Traceability Systems	**Study Specifics Where Appropriate (Study Number:Page Where Needed)**
Undefined or unclear about traceable entity/unit	[33,39,42,48,49,54,57,61,68,70,80,81]
Not defined, but clear the entity being tracked/traced from the text	[41,43,46,50,52,56,66,72,74,78,79,81]
Identified	Tracking objects (steel columns and beams from a real construction project; a vehicle during shipping and delivery; construction materials in site logistics) [34]
	"traceable unit" (batch of fish in cages and polystyrene boxes) [35] (pp. 102–103)
	"TRU, just called a batch in the system" [37] (p. 116)
	traceable artifacts [38]
	"various traceable objects with smart devices" [40] (p. 130)
	Traceable materials [53]
	Traceable resource unit (TRU) (a trade unit, a logistic unit or a production unit) [71]
	Traceable unit as a function [47]
Different granularity or different nature of the entity to be tracked/traced	Along the supply chain [44]
	Along the production process [50]

5.5. Interventions as Proposals on Traceability Models and Traceability Systems

5.5.1. Studies on Traceability Models or Modeling Traceability

Content and Dimensions of the Interventions

From the twenty studies in this group, five developed some sort of data/information model, eight modeled traceability infrastructures, frameworks, or frameworks with tracking capabilities, three developed modeling methodologies or models for information analysis and management in supply chains, two developed ontologies for supporting traceability, one was dedicated to modeling closed-loop product information tracking and feedback, and one discussed a methodology for managing the relevant aspects specific to traceability (Table 6).

Table 6. Intervention within studies reporting on traceability models or modeling traceability.

Intervention	Description (Study Number: Page Where Needed)
Developed some sort of **data/information model**	"… a reference metamodel" where a "product holon" is defined", mainly focused on defining the information part for ensuring product traceability and using the UML (unified modeling language) formalism as the modeling methodology [36] (p. 2)
	"… a metamodel for a repository of traceability links" in software product lines, using MOF 2.0 (meta-object facility) [38] (p. 2)
	A basic "general traceability model applied to goat and sheep meat production" [48] (p. 1064)
	A reference model allowing the exploration of the "model-part of the bill of lots and/or batches", the "model-part of operations and variables" and "the integration of these two model-parts" [59] (pp. 405–408)
	An "Auto-ID Enabled Product Information Model" for end-of-life decision making [73] (p. 17)
Modeled **traceability infrastructures or frameworks or frameworks with tracking capabilities**	A framework for traceability implementation based on traceability requirements and utilizing IDEF-0 (integrated computer-aided manufacturing (ICAM) definition Part 0) model to show its implementation at an actor level, illustrating the integration of the different supply chain actors using a unified modeling language (UML) sequential diagram and the extensible markup language (XML) [45]
	A framework for traceability implementation in the bulk grain supply chain, based on the usage requirements of the traceability system from each actor involved, an IDEF-0 model for developing and implementing an internal traceability system at a grain elevator and electronic data interchange (EDI) and XML (extensible markup language) for information interchange [52]
	A unified modeling framework with a hierarchical-modeling approach (ontology-modeling layer, process-modeling layer and object-modeling layer) to support the modeling and design of IoT systems for product logistics supply chain systems (PLSCS), to reduce system modeling and design complexity while achieving high system reusability and maintainability and allowing to track both product and parts [55]
	Basic modeling of service-oriented architecture, including requirements analysis, for a wood supply chain [67]
	An information infrastructure for RFID-enabled traceability that would provide an interface based on web-services technology for integration with the global EPC network and that would be cost-effective for an SME supply chain [69]
	A "traceability framework that would support the tracing and sharing of product knowledge throughout the product development phase of its lifecycle, i.e. product design and product manufacturing", and that addresses the contextual, the conceptual, the logical, the physical, the out-of-context and the functioning system levels [75] (p. 547)
	A generic framework for traceability data management for food chains, based on requirements elicitation and "the implementation of XML (extensible markup language) technology" [76] (p. 622)
	A framework to design traceability systems for cross border trade, encompassing a number of components, namely, "policy claim, entry point, entry point conditions, exit point, exit point conditions, transformation rules and audit agency" [77] (pp. 9–10)
Developed **modeling methodologies** or **models for information analysis and management** in supply chains	A methodology for modeling traceability information using the EPCIS framework and UML statecharts, where a state-transition model with emphasis on identifying both traceability transitions and food safety and quality data is developed [58]
	A model for information capture at various stages in the soybean chain [62]
	A process-mapping reference method for analyzing material flow, information flow and information loss in food supply chains [65]

Modeled **closed-loop product information tracking and feedback**	A model based on a 3-level approach to the closed-loop supply chain (CLSC) aimed at modeling the system level, the process level and the information and data level, considering the beginning of life (BoL), the middle of life (MoL) and the end of life (EoL) of a product and modeling for product information tracking and feedback via wireless technology (closed-loop product information (CLPI) tracking and feedback (TAF)) [63]
Developed **ontologies** for supporting traceability	MESCO (meat supply chain ontology), specific to the meat supply chain [60]
	Food Track and Trace ontology, generic to food supply chain [51]
Discussed a **methodology for managing relevant aspects specific to traceability**	Methodologies such as traceability semantics, scalability, information management, lot identification, integration, business process interoperability and standards for inter-enterprise business collaboration [64]

All the studies in this group mentioned actors in the process or stakeholders of the overall effort and intended results, most of the time giving scant detail (Table 7).

Table 7. Actors or stakeholders mentioned when developing traceability models or modeling traceability.

Actors	**Study Number**
Small and medium enterprises	[36]
Software analysts, architects, developers	[38]
"actors"	[64]
"users"	[65]
Parties intervening in a supply chain	[51,52,69]
Parties intervening in a supply chain, including the consumer	[45,55,58–60,62,63,67,76]
Those active in a product life cycle	[73]
Those active in the product development cycle of a company	[75]
Regulatory, monitoring and enforcement entities, namely: internal policies, regulation and accreditation entities, governmental agencies	[45]
The Observatory, which was responsible for the management of the traceability system and the recall activities	[51]
Public authorities	[59]
Government, regulatory and audit agencies and inspectors	[67,77]

None of the studies in this group addressed the costs of the intervention or measures of workload, such as the time required to deploy the intervention.

Requirements

Nine of the studies in this group addressed the requirements and criteria for design and implementation while developing their proposals, most of the time giving scant detail: user requirements and basic requirements [36], framework requirements [38], traceability requirements using use-case diagrams [45,52], industry-related basic requirements from case studies such as the registration of lot numbers consumed by production and the registration of process variables on batch level [59], legal requirements [60], (non-functional) requirements that are loosely defined [67], criteria for the implementation of chain traceability [69], and information model requirements [73]. A study considered that basic chain traceability requirements were directly covered by EPCIS Events [58], another followed the TraceFood Framework developed during another project [62].

Standards and Regulations

Only nine of the twenty studies in this group reported having brought international and global initiatives and systems, regulations and standards to their research (Table 8).

Table 8. International initiatives, regulations and standards mentioned or used when developing traceability models or modeling traceability.

International and Global Initiatives and Systems, Regulations and Standards	Study Number
EPCglobal standards, broadly mentioned	[69]
GS1 standards, broadly mentioned	[58]
EPC (electronic product code) standards	[64]
EPCIS (electronic product code information services) standards	[58]
IEC 62264	[36]
ISO standards such as STEP (ISO 10303), Mandate (ISO 15531), PLCS (ISO 10303-239)	[36]
ISO 9001:2000 and ISO 9000	[64]
Food-related initiatives such as the EC Directive 178/2002, Codex Alimentarius Classification of Food and Animal Feeds, Eurocode2 Food Coding System, CIAA Food Categorization, USDA National Nutrient Database for Standard Reference	[51]
XML (extensible markup language)	[36,45,63]
ebXML (electronic business XML)	[64]
PML (physical markup language)	[36]
OWL (ontology web language)	[51,60]
UML (unified modeling language)	[62]

Ontologies

The development of new ontologies for the food traceability domain was focal in two studies, the Food Track and Trace ontology (FTTO) [51], and the MESCO ontology [60]. A study developed an IoT-aware ontology concept model (IoTCM) and a "prototypical ontology" (OBLTP) as part of IoT system modeling [55] (p. 73). Another study employed the Bunge–Wand–Weber (BWW) ontology to formalize a holon [75]. Two studies acknowledged the need for more research in this area, given that the lack of standardized semantics or a common framework to share information is one of the major barriers to sharing information [45] and that generic ontologies are not directly usable in the traceability domain, because they do not contain domain-specific concept definitions [64]. The use of appropriate ontologies to permit automated reasoning [63] and for achieving effective universal data exchange [58] was also discussed.

Technologies

Methods and tools for information and knowledge modeling, classification, standardization, processes and business modeling, software and systems development, connection and identification, and communication and interoperability lead the discussion on **technologies** adopted in most of the twenty studies in this group (Table 9; the detailed extraction table is available from the authors).

Table 9. Methods and tools used when developing traceability models or modeling traceability.

Methods and Tools	Study Number
MOF 2.0 (meta object facility)	[38]
Eclipse modeling framework (EMF)	[38]
Aspect-oriented software development (AOSD)	[38]
Web ontology language (OWL)	[51]

Pellet reasoner	[51]
Protégé	[51,60]
Ontology-based database access (OBDA)	[51]
UML	[36,38,45,52,55,58,62,64,65,75]
EPC and EPCglobal technologies	[36,58,64,69,76]
IDEF-0 (integrated computer-aided manufacturing (ICAM) definition Part 0)	[45,52]
Bill of Lots (BoL), Bill of Materials (BoM)	[59]
Gozinto graphs	[59]
Petri Net	[55,65]
Business process modeling and notation (BPMN)	[51]
Service-oriented architecture (SOA)	[64]
RFID	[55,58,63,64,69,73,76]
IoT	[55]
Physical markup language (PML)	[36,64,73,76]
Extensible markup language (XML)	[36,45,52,62–64,76]
ebXML	[64]
Extensible style-sheet language (XSL)	[76]
Electronic data interchange (EDI)	[52,62]

5.5.2. Studies on Traceability Systems or the Components of Traceability Systems

Content and Dimensions of the Interventions

From the thirty-one studies in this group, eighteen proposed traceability or/and tracking systems, two discussed traceability services or the components of traceability systems, five made proposals where a traceability/tracking capability was a component/module of a larger system, four proposed methodologies by which to analyze, and sometimes improve, traceability systems or part of a system, one addressed critical criteria when implementing electronic chain traceability in a supply chain and another discussed the experiences and lessons learned from developing an RFID-based traceability system (Table 10).

Table 10. Intervention within studies reporting on traceability systems or components of traceability systems.

Intervention	Description (Study Number: Page Where Needed)
Proposed **traceability or/and tracking systems**	A supply chain traceability system for real-time food tracing based on HACCP (hazard analysis and critical control points), blockchain and the Internet of Things [33]
	"… a framework of a coordinated approach towards SCM in LNG construction that integrates different tracking technologies", including supply-chain tracking for general-material management, supply-chain tracking for project specific-material management and a supply chain control platform [34] (p. 2)
	A traceability system for the aquaculture supply chain, based on RFID readers, sensors and data input devices, a set of capture and query applications, a traceability repository that is used to store the relevant traceability data, and the set of web services that provide the product information to the customer [35]
	A system based on web service technologies for tracking and tracing agricultural batch products along the processing chain [37]
	A traceability framework for software product lines, composed of a trace repository containing all the specific data necessary to a certain use case for tracing activities (ATF Core), an open and flexible GUI platform (ATF Front-end) and ATF Plugins [38]

	An agri-food supply chain traceability system for China, based on RFID and blockchain technology [39]
	An intelligent value stream-based food traceability cyber-physical system by fog computing [40]
	An RFID-enabled traceability system for live fish supply chain [41]
	An RFID-based traceability system for cattle/beef quality safety in China, based on business processes modeling and users' requirements identification, modeling traceability information acquisition and transmission, design and implementation of the breeding management system, the slaughter and processing management system and the traceability information retrieval system [47]
	A traceability system for goat and sheep meat production, composed of a web server, with the database management system in structured query language (MySQL) and programming language in a hypertext preprocessor (PHP) [48]
	A high-warranty traceability system for the poultry meat supply chain [53]
	An IoT-based platform for the real-time tracking and tracing of the prepackaged food supply chain (five layers: perception layer, data layer, service layer, application layer, and users layer [57]
	A traceability system for the vegetable supply chain [61]
	A secure track and trace system for RFID-enabled supply chains, based on the EPCglobal network and where the EPCDS is semi-trusted and can be outsourced to the cloud to provide a more scalable and reliable service to users [70]
	An integrated cyber-physical system for the tracking of a reusable luggage tag, including RFID-related components, a database management system and a mobile app [72]
	An RFID system architecture for crankshaft monitoring, traceability and tracking detailing the system hardware and software architectures [74]
	An RFID- and GPS-based system for tracking and locating components in a precast storage yard [78]
	A system for tracking returnable packaging and transport units with active RFID in the grocery supply chain, including the RFID framework, the middleware framework and the control and customer framework [79]
Proposed **traceability services or the components of traceability systems**	A novel set of generic RFID traceability services (TS) with embedded algorithms that would allow multiple aggregations of products into containers and would work efficiently by invoking EPCISs in parallel [49]
	A "mechanism for automatically obtaining the supply network associated with a specific product using the EPCglobal Network" [54] (p. 480)
Proposals where a **traceability/tracking capability was a component/module of a larger system**	A cloud-based system for the management of the waste of electric and electronic equipment (WEEE) from production to end-of-life, including tracking the entire working life of an electronic appliance and tracing all the single components of the electronic products [43]
	An IoT-based production logistics and supply chain cyber-physical system, including tracking and tracing capabilities [56]
	An RFID-enabled real-time manufacturing information tracking infrastructure for extended enterprises to implement real-time visibility and interoperability during manufacturing execution, addressing information tracking and real-time traceability, visibility and interoperability [68]
	A web-based platform for eco-sustainable supply chain management, capable of simultaneously assessing the environmental impacts of production while effectively tracking products through the supply chain [80]

	A "technology solution aiming to provide tracking information at the disposed-of product unit instead of the transportation unit (bin) where most of the existing IoT applications seem to focus" [81] (p. 1683)
Proposed **methodologies to analyze, and sometimes improve, traceability systems** or part of it	The reengineering of a supply chain and introduction of a traceability system [42]
	Applying the FMECA approach to product traceability in the food industry, by using FMEA (Failure Mode and Effects Analysis) to identify the main causes for effectiveness or efficiency loss during a product's history information recovery and CA (Criticality Analysis) to assess the risk, in terms of occurrence and severity, involved in each failure mode previously recognized [50]
	Evaluating the applicability of radio frequency identification technology on a bulk pellet flow [66]
	A structure for describing and analyzing a traceability system [71]
addressed **critical criteria when implementing electronic chain traceability**	Critical criteria when implementing electronic chain traceability in a fish supply chain [44]
discussed **experiences and lessons learned**	Lessons from developing an RFID-based traceability system for an aircraft engineering company [46]

All the studies in this group mentioned **actors** in the process or **stakeholders** of the intended results, most of the time with scant detail (Table 11).

Table 11. Actors or stakeholders mentioned when developing traceability systems or components of traceability systems.

Actors	Study Number
Actors in a supply chain	[37,39,41,42,44,47,49,54,56,57,61,72,80]
Actors in a supply chain, including consumers or costumers	[40,53,79]
Researchers, members of the project, experts or consultants	[34,35,38,42,46,50,56,61]
Authorities that could include governments, regulators and certification bodies	[33,34,39]
The authors simply invoked a European Directive	[43]
Actors intervening directly in the study, namely, logistic operators in the company, consultants, researchers	[46]
Actors intervening directly in the study, namely, processers	[48]
Actors intervening directly in the study, namely, company actors, experts	[50]
Actors intervening directly in the study, namely, energy plant, supplier	[66]
Actors intervening directly in the study, namely, users in a company	[68]
Actors intervening directly in the study, namely, decision-makers and RFID designers	[74]
Actors intervening directly in the study, namely, manufacturers, workers, and clients	[78]
Actors implied; mentioned as "stakeholders"	[81]

Only six of the thirty-one studies identified some sort of **implementation costs**, namely, the cost per tag of passive and active RFID, and the cost of barcodes and GPS [34]; the cost of RFID tags, addressing two possible solutions for its reduction [47]; the cost of building an IoT-based CPS (cyber-physical system), including the cost of an RFID reader and tagging [56]; the cost of RFID tags and their use in combination with a QR code [57]; the cost of RFID tags and the cost of system maintenance, including the marginal cost, which was difficult to estimate [66]; the cost of implementing an RFID system, including hardware, middleware and service cost [74].

Only four studies in this group addressed the measures of **time required** to implement and/or test their solution. The duration of some specific activities for a feasibility study was reported without addressing the total time needed for the deployment of the system [34]. The time required to run the pilots in one study was reported but the duration of the umbrella project was unclear [35]; all related process activities were identified and the time to perform them was measured before and after the system implementation. Numerous key performance indicators (KPIs) were used to quantify the benefits obtained in term of time savings after the introduction of the new system in the selected processes. Another study indicated that the completion of their project and of their traceability system was planned within six months, then three months were taken up in the definition of processes and data, with four months to design and create the application [42]. The reduction/elimination of time gained from the implementation of an IoT system framework was discussed in one study; nevertheless, the time required to implement the model on a testbed platform was not provided [56].

Requirements

Eleven of the studies in this group addressed the **requirements and criteria** for design and implementation as: traceability system with "minimal requirements" [37] (p. 115), traceability framework requirements [38], functional requirements [40], users' requirements and "performance requirements for RCBTS" [47] (p. 317), essential RFID traceability requirements drawn from earlier studies and an industry survey [49], basic requirements of the international standard ISO 22005 [53], "some of the requirements of the DS" (Discovery Service) [54] (p. 481); users' requirements using use case diagrams [61], "eight requirements" proposed by others "for an EPCDS system" [70] (p. 575), high-level requirements, functional requirements, and technology-specific requirements for the RFID system [78]. One study addressed business and technical requirements over text [79].

Standards and Regulations

Fifteen of the thirty-one studies in this group reported having brought **international and global initiatives and systems, regulations and standards** to their research (see Table 12).

Table 12. International initiatives, regulations and standards mentioned or used when developing traceability systems or the components of traceability systems.

International and Global Initiatives and Systems, Regulations and Standards	Study Number: Page Where Needed
EPCglobal Architecture Framework	[35,49]
EAN.UCC system and Chinese EAN.UCC System	[61]
EPCglobal standards	[40]
EPCglobal network standards	[54,70]
GS1 standards	[35,42,44,54,61,71]
US Military standard, MIL-STD-1629A (1980)	[50]
Criticality number (CN) based on US MIL-STD-1629A	[50]
Global trade item code (GTIN)	[61]
GS1 serialized global trade identification number (SGTIN)	[71]
EPCIS (electronic product code information services)	[35,40,49,54]
UPC (universal product code) standard for barcodes	[80]
ISO/IEC15693-3	[47]
ISO 22005	[53,71]
ISO 12875/12877	[71]
European Commission, Commission Regulation (EC) No 2065/2001	[35]
European Commission, 2002. Regulation (EC) No 178/2002	[37,42,71]
European Committee for Standardization Workshop Agreement (CWA) 14660	[44]

United States: FDA Food Safety Modernization Act (2007)	[71]
Tracecore, a standard describing information exchanges between software systems	[44]
Open Geospatial Consortium (OGC) standards such as GML (geographic markup language)	[37]
WS*-standards	[54]
Extensible access control markup language (XACML)	[54]
Extensible markup language (XML)	[40,54]
Web service security (WSS) standard	[54]
IETF X.509v3 standards for digital certificates	[54]
Unified modeling language (UML)	[61]
MQ telemetry transport (MQTT) protocol	[81]
LoRaWAN communication protocol	[81]
User datagram protocol/internet protocol (UDP/IP)	[81]
Extended producer responsibility (EPR) mentioned as "a policy approach"	[81] (p. 1685)

Ontologies

None of the studies in this group either discussed or developed **ontologies**. One study mentioned that the "IoT-aware ontology model concept model" had been previously developed and published [56] (p. 18).

Technologies

In the face of the high volume and the diversity of data extracted, proposals on **methods and technologies** were systematized into five main topics, according to the objective sought and the implemented function (Table 13). Three of them are directly related to primary functions expected from a TS: methods and technologies aimed at the identification of traceable resources and the capture of related information, such as RFID devices, wireless sensor networks (WSNs) and their software (topic A); middleware technologies, e.g., database management systems and application servers, and middleware software, which is able to store and process traceability data and information (topic B); methods and technologies aimed at traceability data output, user access and human-system interaction (topic C). Two of the topics are related to support and parallel functions: methods and technologies aimed at advancing specific aspects related to TSs and services, such as performance, security, trust, interoperability, networking and communications, aggregation, efficient discovery services (topic D); methods and technologies aimed at deploying business-related services and features, built over traceability capabilities and technology (topic E). Detailed coverage of all the tools, techniques and technological options is not feasible; therefore, most of the salient aspects reported below should act as entry points for the detailed information presented in the complete extraction table (available from the authors on request) and the corresponding studies.

Table 13. Main topics of methods and technologies, according to the objective sought and the implemented function, in the group of studies addressing traceability systems or the components of traceability systems.

Study	Topic A	Topic B	Topic C	Topic D	Topic E
[33]	X	X	X	X	X
[34]	X		X		X
[35]	X	X	X	X	X
[37]		X	X		X
[38]	X	X	X	X	X

[39]	X	X		X	X
[40]	X	X	X	X	X
[41]	X	X	X		X
[42]					X
[43]	X	X	X		X
[44]					X
[46]	X	X	X		X
[47]	X	X	X		X
[48]		X	X		X
[49]	X	X	X	X	X
[50]					X
[53]					X
[54]	X	X	X	X	X
[56]	X	X	X	X	X
[57]	X	X	X	X	X
[61]	X	X	X		
[66]	X			X	
[68]	X			X	X
[70]		X	X	X	
[71]	X			X	
[72]	X	X	X		X
[74]	X				X
[78]	X		X		X
[79]	X	X	X	X	X
[80]	X	X	X	X	X
[81]	X			X	

Note: X = main topics in terms of methods and technologies as discussed in a study, according to the proposed typology.

Most studies addressed topic A in detail, with the overwhelming presence of RFID technologies. Roughly two-thirds of the studies addressed topic B and about two-thirds addressed topic C, sometimes giving very little detail. Systems based on the SQL language were the most commonly used as the main database management systems. Web services and APIs (application programming interfaces) were often mentioned and employed. User-system interaction, user access and data output were frequently mentioned but little in the way of detail was usually available regarding implementation, beyond brief mentions of the internet and web browsers. PDA (personal digital assistant) hardware was discussed in some studies.

Sixteen studies were deemed as addressing topic D, most of the time contributing to other topics as well, while introducing innovation in those aspects related to traceability systems and services. Most studies addressed business-related services and features built in over traceability capabilities and technology (topic E). Ten of the thirty-one studies in this group were deemed as addressing all the five topics, at different levels of detail.

5.6. Comparators

We went beyond the strict definition of a comparator and researched any mention of, or effort to compare with, other studies and products (Table 14). Roughly half of the studies did not compare with other studies or products.

Table 14. Mention of, or effort to compare to, other studies and products by studies reporting on traceability systems or components of traceability systems.

Comparator	**Study Number: Page Where Needed**
Not declared	[37,40,42,47–50,53,57,61,68,80]
Unclear	[35,44,71]
Not explicit	[33]
Alternatives mentioned or discussed but not detailly and rigorously compared—using barcode, passive RFID, active RFID, GPS tags or paper-based instructions, or a combination of some of them, in offsite fabrication and construction site logistics	[34]
Centralized traceability systems mentioned or discussed, but not in detail or rigorously compared	[39]
Traditional ways of managing production information in companies mentioned or discussed, but not in detail or rigorously compared	[41,46]
Technologies that are mentioned but not fully compared to the actual proposal	[72,74,78]
Studies and solutions from other identified but not adequately compared	[43,54]
Qualitative information provided regarding how their solutions performed when compared to other systems	[70,79,81]
All studies only deal with 1-to-1 traceability links	[38]
"… conducted emulation experiments to evaluate the performance and benefits of adopting an IoT-based CPS for PL management." and compared the performance between a model employing M2M (machine to machine) distributed intelligence and a model without such technology because IoT and M2M "tackle different problems facing a production enterprise"	[56] (p. 11)
"… performing three separate trials investigating the technological aspects where RFID tags were traced along a biomass fuel supply chain", but results from the three pilots performed cannot be compared between themselves and were not compared to usual practices in the industry	[66] (p. 150)

5.7. Context

5.7.1. Studies Reporting Traceability Models or Modeling Traceability

Information on the **industries** addressed and **levels and connections between the levels considered** are reported in Table 15.

Table 15. Industries addressed and the levels and connections between levels, as considered by studies reporting on traceability models or modeling traceability.

Industries Addressed	**Study Number**
Industry-independent solutions, even if most of them placed an emphasis on food-related industries and supply chains	[36,55,58,59,63–65,69,73,75]
Food: live goat and sheep sector	[48]
Food: the bulk grain supply chain in the United States	[52]
Food: the meat supply chain	[60]
Food: soybean value chains	[62]
Food: the general food supply chain	[51]
Food: fresh, non-processed food products supply chains	[76]
The software industry, in particular, software product line engineering	[38]
The textile and apparel sector, a very challenging industry with globally dispersed actors in the supply chain	[45]
The supply chain of wood from the Brazilian Amazon rainforest	[67]
Cross-border trade and environments	[77]

Levels and Connections Between Levels Addressed	Study Number
Single companies and supply chains	[45,48,52,60,62,64,76]
The supply chain level	[51,67,77]
Material and information flow in supply chains	[65,69]
Merging product and product information through the entire lifecycle of the product	[36]
Software product lines	[38]
A product supply chain monitored throughout its lifecycle with an emphasis on the information required to manage the end-of-life	[73]
Manufacturing processes, supply chain, goods and information flows	[58]
Manufacturing processes, bill-of-lots, bill-of-materials	[59]
Integrating product knowledge during design and manufacturing	[75]
Production logistics and supply chains in the real world and three layers when modeling (ontology, process, objects), in an information space composed of the object, business entity, location, time, process informatics	[55]
Three levels of a closed-loop supply chain (CLSC) (system, process, information and data) and considering beginning of life (BOL), middle of life (MOL) and end-of-life (EOL) of a product	[63]

Fourteen out of twenty studies emphasized enablers and motivators more directly related to their work, namely: standardization initiatives; regulations from governments; business- and market-related motivators; identifying and addressing the needs, expectations, motivations and limitations of diverse stakeholders; technological aspects (details on Table 16).

Sixteen in twenty studies discussed challenges more directly related to their work, namely: the many faces of heterogeneity; security and privacy issues [36]; standards; semantics inconsistencies; ontology-related issues; difficulties in identification and evaluation of existing conditions before the development of a traceability framework; limitations of modeling methods; technology limitations; issues related to business and markets; governmental intervention and regulatory bodies' mandates (details on Table 16).

Table 16. Enablers/motivators and challenges reported by studies on traceability models or modeling traceability.

Enablers and Motivators	Description	Study Number
Standards	Taking into account existing standardization initiatives	[36]
	The need for standardization of information exchange semantics	[45,64]
	The need for explicit semantics and contexts in the information content that is to be shared across product lifecycle management (PLM) applications	[75]
Regulations	Regulations from governments, formulating guidelines for various actors and for the minimum of required traceability	[45]

Business- and market-related motivators	The need to deal with increasing risks inherent to participation in global markets and supply chains	[45]
	The need to answer the market's need for safety and fight against counterfeiting products and parts	[55]
	Dynamically knowing the characteristics of raw materials, semi-finished and finished products	[59]
Stakeholders	Identifying and addressing the needs, expectations, motivations and limitations of diverse stakeholders, such as companies, governments, audit agencies and final consumers	[65,67,69,73,76,77]
Technological aspects	Aspects related to methods, software, or hardware, such as using clear categorization and modeling methods and a core traceability metamodel	[38]
	Building flexible core IoT design models	[55]
	Using a product-embedded information device (PEID) to realize the whole scenario for closed-loop product information (CLPI) tracking and feedback	[63]
	Using XML, SOAP and ebXML to achieve interoperability and data integration.	[64]
Challenges	**Description**	**Study Number**
Heterogeneity	Entailed in managing information coming from different systems	[36]
	Dealing with the number and complexity of artifacts and diversity of software processes	[38]
	Dealing with all stages of production	[52]
	Heterogeneity in field processes	[67]
	Adopting appropriate technology and maintaining the system at all levels of the supply chain	[45]
	The diversity of operations and properties each firm may use for a specific traceable resource unit	[69]
	The diversity of the participants involved	[55]
Security and privacy	Security and privacy issues	[36]
Standards	Lack of common standards in an industry	[51]
	Non-consideration of standards for information exchange at the level of the supply chain	[59]
	Not supporting certification systems, such as ISO and EMAS	[59]
Semantic inconsistencies	Semantic inconsistencies between diverse sources of information	[63]
	Lack of agreement on a concept's meaning and relationships between terms, worsened by current enterprise information systems	[51]
	Limitations of ontology-based approaches	[75]
	The need for new ontologies in some domains, including food traceability	[51]
Difficulties with the identification and evaluation	Before the development of a traceability framework	[65]
	Difficulties including information requirements for the whole product lifecycle	[63]

of existing conditions		
Limitations in modeling	Imitations of modeling methods, namely, the inability to model information process flows	[52]
	Lack of architecture design methods for IoT application development	[55]
	Lack of high level of abstractions to specify high-level IoT system behaviors and lack of common software architecture to account for different IoT environments and diverse software modules	[55]
	Difficulty in representing the dynamic behavior of IoT systems through a traditional process-modeling scheme	[55]
Technology limitations	Limitations such as difficulties in dealing with high volumes of information when tags are attached at item level	[69]
	The inability of available product data management or product life-cycle management systems to manage and use product knowledge generated in all phases of the product lifecycle	[75]
	Challenges in obtaining the required performance level at each specific domain covered by the traceability system	[64]
Business and markets issues	Issues especially when SMEs are involved, namely, a lack of workforce skills to implement and maintain a traceability system	[45,76]
	Confidentiality of business processes	[45]
	Narrow profit margins in some businesses	[76]
	Cost-effectiveness of traceability systems adoption	[69]
	The concept of transformation in bulk product traceability	[62]
	The information gap among entities due to unwillingness or inability to share information and fragmentation of supply chains	[76]
Governmental intervention and regulations	Governmental intervention and regulatory bodies' mandates	[77]

5.7.2. Studies Reporting on Traceability Systems or the Components of Traceability Systems

Information on the **industries** addressed and **levels and connections between levels considered** are reported in Table 17.

Table 17. Industries addressed and levels and connections between levels considered by studies reporting on the traceability systems or the components of traceability systems.

Industries Addressed	**Study Number: Page Where Needed**
Industry-independent solutions	[49,54,56,68,70]

The food sector in general, where consistency in terminology and standardization are in need	[71]
The whole food supply chain	[33,39,40]
The seafood sector, where many SMEs still work with paper-based systems	[35]
Live fish supply chains in Taiwan	[41]
A fresh fish supply chain	[44]
Agriculture food chain	[37]
Agro-food, in particular companies involved in the production of “fourth range vegetable products.”	[42] (p. 14)
The cattle/beef sector	[47]
The goat and sheep industry	[48]
The durum wheat past production process of an Italian company	[50]
The poultry meat industry	[53]
The prepackaged food sector	[57]
Vegetable supply chains in China	[61]
The grocery market with fresh fruit and vegetables	[79]
The software industry	[38]
The liquefied natural gas (LNG) industry, where poor coordination and fragmented practices harm productivity and performance	[34]
The electrical and electronic equipment (EEE) sector, where an integrated cloud-based WEEE management system with real-time tracking capabilities would make the EOL treatment of electronic equipment easier	[43]
An aircraft engineering company implementing an RFID-based traceability system	[46]
The energy industry, using pellets as fuel	[66]
Air travel sector and IoT for mobile tracking with reusable luggage tags	[72]
Automated manufacturers of automotive parts	[74]
The construction sector, where little research has been conducted on RFID technology for tracking components	[78]
The leather shoe sector, where specific rules, ontologies, and systems are needed to guarantee effective data sharing and collaboration between partners in the production network	[80]
Bottled water manufacturers	[81]
Levels and Connections Between Levels Addressed	**Study Number**
The supply chain	[33–35,37,39–42,47,57,66]
Single companies and the supply chains in which they are involved	[44,56,61,70,80]
Supply networks	[54]
Production chains	[43]
Overall real-time manufacturing information tracking infrastructure of extended enterprises	[68]
Company level	[46,53,72,78]
Internal processes of a company	[50]
Production lines	[74]
Processes, company and supply chain levels	[71]
Distribution cycle of fresh fruit and vegetables, including forward and backward paths	[79]
Software product lines	[38]
Levels unclear	[48,49,81]

Twenty-six out of thirty-one studies emphasized those **enablers and motivators** more directly related to their work, including: **business- and market-related** issues; **needs, expectations, the motivations and limitations of diverse stakeholders**; increasing pressure from **regulators**; global **standards**; **technological aspects**; **environment-related motivations**. One study presented a formalized, systematic analysis based on **critical criteria** when implementing traceability [44], while another identified **critical success factors** and described lessons learned in detail [46] (see details in Table 18).

Twenty-two out of thirty-one studies discussed **challenges** more directly related to their work, namely: **technology challenges and limitations**; **business- and market-related** issues; the **limitations of the models and methods** used; problems posed by **standards** (details in Table 18).

Table 18. Enablers/motivators and challenges reported by studies on traceability systems or the components of traceability systems.

Enablers and Motivators	Description	Study Number
Business- and market-related motivators	The need to assure food safety and trust in the sector	[33,39,42]
	The need to deal with the high agri-food loss ratio in China	[39]
	The need to assure proper management of large and complex LNG supply chains	[34]
	To meet increasing consumers' demand for food information	[35]
	To achieve higher value in the market	[35]
	Power position of a leading partner	[41]
	To detect anomalies in an internal traceability system	[50]
	To get feedback from consumers	[57]
	To improve service for the customer and build on their relationship with the company	[72]
	To decrease operational costs	[72]
	To foster collaborative relationships among supply chain actors aiming at a more sustainable supply chain	[80]
Needs, expectations, motivations and limitations of diverse stakeholders	Deploying user-friendly solutions	[37]
	Deploying user-friendly solutions, especially when SMEs are involved	[41]
	Addressing related EU (European Union) research funding opportunities	[35]
	Testing and evaluating before deploying	[66,74]
	Testing and evaluating before deploying, including cost and benefit analysis of a cyber-physical system	[56]
	Relatively low cost of an RFID system	[57,66,71,78]
Governments and regulations	Increasing pressure from regulators	[47,81]
	Enforcement from governments	[43]
Standards	Using global standards	[70]
	Limitations of existing standards	[49]
Technological aspects	Deploying web services and tools	[37,42,79]
	Optimizing the RFID system to the fuel and supply chain in question	[66]
	Using the value-stream mapping method in an IoT environment	[40]
	Using software simulation and lab emulation with the implementation of a prototype system	[56]
	Difficulties posed by incumbent technology	[74]

	Difficulties posed by existing technological conditions	[53]
	Good performance of RFID tags and GPS in harsh conditions	[78]
	Assuring separation of private and shared data and data security	[80]
Environment-related motivations	The need to manage the waste of electrical and electronic equipment (WEEE) and a product and components lifecycle including dangerous materials	[43]
	The need to monitor environmental sustainability in all stages of the supply chain and product life cycle	[80]
	The need to ensure that most empty bottles are led to recycling facilities for further exploitation and reuse	[81]
Critical criteria	A study presented a formalized, systematic analysis based on critical criteria when implementing traceability	[44]
Critical success factors	A study identified critical success factors and described lessons learned in detail	[46]
Challenges	**Description**	**Study Number**
Technology	Blockchain scalability	[33,39]
	Blockchain immaturity	[39]
	Design and management of barcodes in specific environments	[34]
	Barcode susceptibility to being counterfeit	[57]
	Time required by many implementation activities related to technology adoption	[44]
	Accuracy and effectiveness of RFID systems and their components in real-life environments and operations	[34,35,41,47,66,71,74,78,80]
	Extending RFID systems to the supply chain partners and assuring the sustainability of RFID systems	[46]
	Integration of enterprise and legacy systems	[44,46]
	Integrating IoT-based cyber-physical systems with diverse IoT devices and enterprise systems	[56]
	Privacy and security of personal data	[72]
	Developing and implementing new concepts of evolving data structures in IoT environments	[74]
Business and markets issues	Level of involvement and capabilities of those using the technology	[34,72]
	The need to change business processes prior to technology implementation	[34,53,74]
	Defining a leading company in the supply chain	[42]
	Lot identification	[42]
	Use of local identifiers	[44]
	Costs, cost-effective integration of the system and the need for investment	[34,35,39,44,47,71]
	Difficulty and cost of implementing item-level tracking and tracing	[57]
	Constraints posed by a company business model	[74,79]
	Tracing raw materials and unfinished parts in some sectors	[80]

	The need to redesign the product, in order for bottle manufacturers to be able to adopt the technological solutions	[81]
Limitations of models and methods	To measure and prove the impact	[42,46]
	To link traceability and environmental sustainability assessment of supply chains	[80]
Standards	Limitations of standards	[49]
	Lack of mature standards	[79]
	Lack of a standard for machine-to-machine communication (M2M) across supply chain participants	[56]
	Problems posed by existing standards to new developments and innovation	[70]

5.8. Outcomes of the Interventions

We searched for and analyzed both the quantitative and qualitative measures of a contribution to a CE and of a contribution to improving critical characteristics of data and information on traceable entities, such as accuracy, objectivity, relevance, accessibility, richness, timeliness, authorship, verifiability, and scalability, which would betoken the quality of a tracking/tracing solution.

None of the included studies planned for or declared the **outcomes of the intervention explicitly related to a circular economy**. Brief related mentions could be found in both groups (Table 19). In the same way, none of the studies included in the SR planned for or declared the **outcomes of the intervention that were directly related to the critical characteristics of data and information available on traceable entities**, even if the aim of most studies was obviously related to them. Discussions were generically focused on the capacity for improved information exchange and access to information, not on the specific characteristics of data and the information available on traceable entities or proving the effectiveness of a proposal through a positive impact on them. However, brief mentions could be found in both groups (Table 19).

Table 19. Mentions related to the sought outcomes in included studies.

Mentions of CE-related Outcomes on Studies Reporting on TMs or Modeling Traceability	**Study Number: Page Where Needed**
The capacity (of the method) "to realize the seamless flow and tracking of product information, and then to create value by transforming information into knowledge throughout all phases of a product's lifecycle."	[63] (p. 669)
The expected improvement in integration of the several systems participating in the process along the supply chain	[67,69]
A summary of product information requirements and their impact on end-of-life decisions	[73]
Mentions of the Characteristics of Data and Information on Traceable Entities on Studies Reporting on TMs or Modeling Traceability	**Study Number: Page Where Needed**
Overcoming the "inability of current traceability systems to link food chains records, inaccuracy and errors in records and delays in obtaining essential data"	[51] (p. 17)
A "significant reduction in the rate of errors"	[64] (p. 358)
Mentions of CE-related Outcomes on Studies Reporting on TSs or Components of TSs	**Study Number: Page Where Needed**
A study that worked on the link between traceability and environmental sustainability of supply chain, and planned for assessing the environmental impacts of production, while	[80]

effectively tracking products through their supply chain analyses of primary LCA data (e.g., electricity consumption, materials, chemicals) acquired and recorded by the system or fetched from a company data management system Two particularly relevant indicators were discussed, climate change and human toxicity, but no before-and-after assessment of any impact resulting from the deployment of the system was available	
Better use of materials and products	[34,72,74,79]
Improved coordination across a supply chain	[34,35,56,68]
Potential for improving energy management	[37]
Better management of electrical and electronic equipment and components from production to end-of-life, including dangerous materials and waste	[43]
Ability to support forward supply chains but also the reverse logistics and returnable-asset logistics	[49]
Previewed a contribution to a CE by preventing wastes at the source, promoting product design for the environment and supporting the achievement of public recycling, but without indications on what to measure and how	[81]
Mentions of the Characteristics of Data and Information on Traceable Entities on Studies Reporting on TSs or Components of TSs	**Study Number: Page Where Needed**
Increasing supply chain visibility and being faster	[34]
Real-time access to information, real-time collection of data, easier to collect, improved data exchange and supply chain visibility	[35]
"… ease of access and use of information", no measures provided	[37] (p. 120)
Being faster, data and information richness, scalability	[49]
A study proposed a group of measures for a before-and-after effectiveness analysis that included an item linked to information management, namely, "Data acquisition", classified as "Incomplete artificial collection" before the implementation and "Automatic and accurate mass capture" after the implementation	[61] (p. 352)
A study described qualitative outcomes as "the use and the interconnection of traceability stations, IoT devices, and company data management systems" that contributed "to reduce the time dedicated to data collection, data inconsistencies, and errors in data management, increasing data completeness and results accuracy"	[80] (p. 225)

6. Discussion

This review set out to examine a possible relationship between the development and implementation of TMs and TSs and a transition to a CE as documented in the literature. Overall, 49 studies were admitted to the SR. Three additional studies published during 2020 were also brought into the discussion.

6.1. To What Extent and in What Way Have the Use of Traceability Models and Traceability Systems Been Linked to a CE?

While the literature contained many interventions meeting the broad study criteria, it became immediately apparent that the link between traceability and the CE, involving the development of TMs and TSs, was rudimentary, both in terms of the number of studies and the soundness of the means used to document a connection or measuring an effect.

In fact, only one study referred explicitly to the CE, while introducing a technological solution aiming to provide tracking information [81]. However, the study only reported early conceptual work, with no mention of any CE principles or indicators under consideration.

The only study providing data on the environmental impacts of production in a network of companies aimed to establish a link between traceability and environmental sustainability [80], and used those indicators mentioned in the literature as adequate for the quantitative assessment of CE strategies [19]. No before-and-after assessment of an environmental impact was available, but qualitative and quantitative results, as assessed by the reviewers, suggest a capacity for improvement in all CE principles [18].

Qualitative evidence for TMs highlighted the capacity to create value by transforming information into knowledge throughout all phases of a product's lifecycle [63], the expected improvement in systems' integration along the supply chain [67] and the impact of clearly defining product information requirements on end-of-life decisions [73]. For TSs, empirical qualitative evidence included the better use of materials and products [34,72,74,79], improved coordination across a supply chain [34,35,56,68], the potential for improving energy management [37], the better management of equipment and components from production to end-of-life, including dangerous materials and waste [43], and the ability to support forward and reverse logistics in supply chains [49].

As for the impact on the quality of data and information available on traceable entities, the general focus was on the capacity for improved information exchange and access to information, even if it was not based on quantitative evidence, nor on the specific characteristics of data and information available, proving the effectiveness of a proposal through a positive impact on them. Only one study proposed a group of measures for a before-and-after effectiveness analysis that included an item linked to information management [61].

A move toward the proposal or use of evaluation methods was found in recent studies, within feasibility studies, case studies, experiments or tests of prototypes. They sought to prove the cost-effectiveness of a secure track and trace system [70], proposed criteria for an RFID-based traceability system evaluation [47], addressed the costs and benefits of a crankshaft traceability and tracking RFID-based system [74], developed an approach to predict traceability performance in agriculture food supply chains [40], developed evaluation methods and conducted experimental evaluations of an IoT-based cyber-physical system prototype [56], and validated the effectiveness of a Web-based platform for eco-sustainable supply chain management with tracing capabilities, while contributing to overcoming the lack of quantitative tools to support companies, along with monitoring and improving the environmental impact along the production chain [80].

6.2. What Are the Structural and Methodological Characteristics of the Studies on Traceability Models and Traceability Systems, Namely, When Linked to a CE?

Structural conditions, such as the resources available, regulations in place, pressure from stakeholders, and sectoral dynamics may influence the implementation of TSs [82] and research in this area [35,82]. In 2004, an exemplary study found that in beef supply chains, the European Union and Japan were leading the trend toward the adoption of mandatory traceability, as a response to the BSE (bovine spongiform encephalopathy) crisis, while the US had not adopted mandatory TSs, although several voluntary systems were in operation and new systems were being developed [83]. The results of this SR seem to confirm and extend part of those findings to other sectors. Between January 2003 and January 2020, thirty of the forty-nine included studies were conducted in Europe, eight in China and only two in the United States. Either through European Union entities and programs or national public bodies, public European money funded fifteen of the twenty-three studies that have declared a source of funding, while five studies were funded by Chinese national public bodies and no study declared having received funding from US-based bodies, public or private. Moreover, we observed more than a decade of investment and reports from projects addressing the several development stages, including pilots in different countries. However, considering the small number of cases and other peculiarities, we need to be careful when drawing conclusions in this regard. For example, temporal information was generically missing, as we only had access to publication dates, hindering our comparisons and conclusions regarding technological options, the challenges and limitations involved in implementation, and achievements in different countries.

As for the methodological aspects, the fact that only five of the forty-nine studies somehow stated research questions, that only eighteen described a methodology or research design/methods, and nineteen two fifths missed a definition or were unclear about a traceable entity signaled the paucity of studies quantifying results from evaluation activities or benchmarking to similar work. In fact, over half of the thirty-one studies reporting on TSs did not identify a study with which they could compare, were unclear or were not explicit about it.

Traceability, tracking, and traceability-related concepts were those topics more frequently discussed as the fundaments of a study, followed by RFID methods and tools. A group of studies [36,43,63,72,73,75,80,81] based their research on environment and lifecycle management areas, while only one referred explicitly to the CE [81].

Most studies addressed a design phase, while roughly half of them performed some sort of implementation and a little over two-fifths proposed or performed some sort of evaluation, in many cases described as feasibility studies. We found no evidence of a real-life large uptake of methods or tools as a result of the studies included in this SR, but a study proposing a web-based platform able to trace suppliers and related processes in order to improve decision-making regarding environmental sustainability in a real supply chain stood out [80].

The studies could be gathered in two groups, one composed of studies reporting on TMs or modeling traceability, and the other composed of studies reporting on TSs or the components of TSs. Within the first group, we found studies that had developed some sort of data/information model, modeled traceability infrastructures or frameworks, or frameworks with tracking capabilities, developed modeling methodologies or models for information analysis and management, modeled closed-loop product information tracking and feedback, developed ontologies, and discussed a methodology for managing aspects specific to traceability. Within the second group, we found studies that had developed traceability or/and tracking systems, discussed traceability services or the components of traceability systems, made proposals wherein traceability/tracking capabilities were a component/module of a larger system, proposed methodologies to analyze and sometimes improve a traceability system or part of it, addressed critical criteria when implementing electronic chain traceability, and discussed the experiences and lessons learned from developing RFID-based traceability systems.

We found a scant number of studies identifying the implementation costs and addressing the time required to implement and/or test a solution in the group of thirty-one studies reporting on TSs or components of TSs. These are aspects in need of consideration, given the many barriers to be overcome in order to promote awareness and companies' investments in these systems and to see them as more of an opportunity than as an expense, especially when SMEs are involved [35,84,85].

6.3. Which Level or Levels Do Traceability Models and Traceability Systems Cover and in What Way, Especially When Related to a CE?

Transitioning to a circular economy calls for intervention at the micro-level, with single companies not only embedding CE principles into their strategic management, operations and production, but also at the meso-level, fostering collaboration among companies, such as in supply chains and eco-industrial parks, and at the macro level, involving local communities, regions, and countries [86].

Through our SR we found that most studies on TMs focused on the supply chain, with a few detailing the material and information flows [58,65,69] and elaborating on the merging of products and product information through the entire lifecycle of the product [36]. Only two studies [55,63] embraced the multilevel and multidimensional modeling of the supply chain and of the entities being processed explicitly. As for TSs, while most studies also favored the supply chain level, a group of them discussed interventions at the company level, with an eventual future extension being given to the value chain, conditioned to the many limitations and challenges identified.

In both groups, over half of the studies focused on the food sector. In other industries, a more recent move was identified, confirming the need for tools able to foster and support better decision-making, control and accountability in complex industries dealing with great economic, environmental and social pressures, such as electrical and electronic equipment [43,55], energy [34,66], automotive parts [74], aircraft and air travel [46,72], construction [78], plastics [81], and the textile and apparel sector [45].

6.4. What Agents or Stakeholders Are Expected to Have a Role in the Development and Implementation of Traceability Models and Traceability Systems, Especially When Related to a CE?

Stakeholder engagement and participation, through cooperative design (co-design) and cooperative production (co-production) are increasingly used to achieve better systems, goods and services. For the provider, that implies identifying, profiling, and bringing them in to processes that, traditionally, were mostly closed to outside entities.

Regarding this SR, all studies on TMs and TSs named actors in the development process or stakeholders of the intended results but, most of the time, these were identified in a generic way. In many cases, stakeholders who had no direct intervention in the study were listed as beneficiaries in an abstract of the results. In other cases, stakeholders were named according to the generic role they played in the supply chain. A small group of studies on TMs and TSs named regulatory, monitoring, auditing and law enforcement entities and directives, which might be particularly important within a transition to a CE [87]. Government agencies may play a significant role while increasing by many times the complexity of the systems, elevating requirements such as data sharing, the confidentiality of information, governance and regulatory compliance [77].

A few studies required collaboration between external services, such as experts from different companies, researchers and consultants, especially regarding RFID technology, and members of the company’s staff, such as the management information system team and operations staff that were brought together to lead a project [46], the production managers and the product safety and quality managers participating in a case study [50] and company employees brought in to identify parts of the operating system [75].

Some studies reported having run interviews [34,35,42,44,47,75], questionnaires [62,65], visits to companies [46], a workshop with field workers [77] and a panel of experts [50] to obtain information or test methods. We were unable to draw conclusions regarding a connection with the establishment of any kinds of requirements, as the overlap between the set of studies employing those techniques to obtain information prior to or during development efforts and the set of studies stating requirements in the group of those reporting on TMs or TSs narrowed to one study [47].

6.5. To What Extent and In What Way Are Ontologies Being Used, Especially When Related to a CE?

Some of the reasons to develop an ontology are the need to make domain assumptions explicit and to share a common understanding of the structure of information among people or software agents [24]. These are tenets of traceability in any field while representing basic requirements for effective and efficient sharing of information and knowledge on traceable entities.

Therefore, it was noteworthy that, within the group of studies addressing TMs, only eight developed or used ontologies, or at least identified the need to embrace their use. In the group of studies reporting on TSs, only one study [56] mentioned the use of an IoT-aware ontology model, developed to support the research and published elsewhere [55].

The shortage of tools able to support the tracking of requirements for and the evaluation of ontologies across all stages of their development and use [24] could be one of the reasons for the scarce results. When small and medium enterprises (SMEs) are involved, the complexity of the effort and the resources needed may be a deterrent. Many times, they are not perceived as a priority [88]. Other aspects found through this that SR included the limitations of existing ontologies to extend them to traceability domains [51,64], the use of generic- versus domain-specific ontologies [60], and the guidance and leniency provided by regulations and global standards [60].

In the food industry, where traceability has been directly linked with important requirements of the sector, such as food quality and safety, parameters must be followed along the entire supply chain; we found that ontologies could play a fundamental role, assisting with the modeling of knowledge of interest and addressing many of the problems concerning data standards and data interchanges in the existing infrastructures [60]. Considering the expected increase in complexity entailed in planning, operating, managing and evaluating activities in a circular economy, with the involvement of different sectors and stakeholders, we expect a similarly important role to be played by ontologies. A primary, essential step to overcome this challenge is to identify the necessary data and information to be gathered, shared and managed at each stage of the product lifecycle, in order to assure circular pathways [63],[73]. In fact, ontologies and ontological frameworks have been identified as technologies that are needed to explore data and information in the context of circular manufacturing, namely, in the field of industrial symbiosis [89].

In the meantime, new studies on less widely reported industries have been published recently [90] and the area is poised to evolve rapidly in response to new needs, with ontologies becoming more descriptive and providing more contextual detail, supporting alternative views of the world and, thus, use by inhomogeneous user communities [91].

6.6. Do Traceability Models and Traceability Systems Reflect the Relevant Standards, Regulation and Indicators, and Consider Environmental, Social and Economic Perspectives, Especially When Related to a CE?

Standards represent the refined, consensual knowledge of individuals with expertise in specific subjects who are knowledgeable on the working conditions and the needs of the organizations they represent. Together with legislation, regulations and vetted indicators, they provide guidance to all kinds of organizations and to those monitoring, evaluating and endorsing, or not endorsing, their actions [92,93]. Therefore, they should be considered from the point of inception when engaging in initiatives as consequential as the deployment of internal and external TSs.

The results from our study show that only about half of the included studies declared that they had brought international and global initiatives and systems, regulations and standards to their research and that only a few of those did actually provide a detailed discussion on the topic, both in the group of those reporting on TMs and those reporting on TSs. Standards for markup languages and information modeling were those areas more frequently proposed for use within the first group, many times when in connection with feasibility studies or proposals for scenario validation, while scant references were made to GS1 standards and initiatives, ISO standards, EU directives and sector-related initiatives. Among the studies reporting on TSs, GS1 standards and initiatives were those areas more frequently named, followed by the standards for markup languages, web services, and information exchange between software systems and security, while scant references were made to ISO standards, EU directives and sector-related initiatives.

Global standards and initiatives facilitate the deployment of traceability systems and participants' collaboration by allowing developers and organizations to focus more on how to use the information than on how to obtain that information [94]. EPCglobal has provided interrelated standards for hardware, software and data interfaces, together with core services, in order to support an open supply chain. However, in practical terms, they fall short of supporting the needs of track and trace services as only elementary-level services were defined [49]. The situation is somehow reflected by included studies published between 2010 and 2013, regarding the effort and time required from companies and developers to implement real-life RFID-based TSs, even when embracing the standards, and concerns regarding the security aspects being underserved by global initiatives [70]. Additionally, we found studies proposing generic RFID traceability services with embedded algorithms that would allow the multiple aggregation of products into containers and would work efficiently by invoking EPCISs in parallel [49], discovery services to automatically obtain a supply network [54], a relay policy for EPCDS and a secure track and trace system based on the EPCglobal network, where the EPCDS is semi-trusted [70]. The latter amount to a challenge for developers while trying to provide new functionalities and services without modifying the architecture of the standard EPCglobal network [70].

No mention was found to the BS 8001 [18]. Only one study [80] referred to the use of an indicator related to the environmental impact of a supply chain, the climate change indicator, which was linked to the flow of goods between the actors involved in the supply chain, and the use of a social impact indicator, the human toxicity indicator, judged as being significant for the specific context of this study.

6.7. What Are the Technologies Being Proposed or Used to Implement Traceability Models and Traceability Systems and What Can We Expect from Their Use, Especially When Related to a CE?

Solutions based on information technologies are being implemented by companies of all sizes to reduce the complexity associated with tracking and tracing, to gain access to highly connected value chains and to rip the benefits of massive volumes of high-quality data on virtually any aspect of their businesses.

How to deploy technological solutions in a cost-effective way, in particular those involving RFID devices, how to access meaningful, business-oriented information from huge volumes of real-time data, and how to integrate this system into the company processes are some of the key questions to be solved [23]. The studies included in this SR somehow reflect a quest for answers.

Within the group of those papers reporting on TMs or modeling traceability, UML, XML ebXM and EPCglobal tools were the technologies most frequently proposed or used. Tools for the development and evaluation of ontologies and tools specific to process modeling, such as Petri nets and BPMN tools, were seldom found.

Within the group of those reporting on TSs, a significant number of studies proposed or used RFID technologies, an option in part driven by efforts to lower costs and improve performance. Still, the number of those still dealing with technological and contextual challenges related to their use was still quite large, with studies pointing out the immaturity of the technologies and difficulties in implementing them in real, oftentimes dynamic, conditions [35,71,74,78–80], with difficulties in attaching tags to certain materials and living animals [41], high implementation costs [47,57,66,71], the need for research in terms of accuracy improvement for active RFID [34], the sustainability of RFID systems [46] and the need for new software services and data structures, enabling the ripping of benefits from the data gathered by tags and sensors [74].

We have also identified a recent emphasis on distributed solutions, both in terms of TSs coordination and of the technological options made when implementing them, with many studies proposing flexible, modular solutions supported by web services and systems and resorting to the cloud for development tools, processing times and services, and distributed databases technology, such as blockchain. All three of the studies from 2020 that were subsequently reviewed outside the main set of included papers discussed blockchain-based solutions [95–97]. Nevertheless, all the reviewed studies proposing the use of blockchain were mostly conceptual, with no traceability capabilities that were either simulated or implemented in real settings. The general claim was in terms of transparency in the supply chain, proving the authenticity, reliability, integrity, and validity of the final products and of the elements that compose the whole supply chain, but without proving anything besides the integrity and authorship of data supported by blockchain. Research is needed to ascertain companies' willingness to embrace the technological options that they may perceive not only as less secure in terms of data handling but also as having embedded characteristics that expose too much of the unique characteristics of their manufacturing processes. A recent systematic review [98] identified, among other issues, the need for further examination of the benefits and challenges of blockchain technologies in terms of the circular economy and sustainable development.

The scant detail provided by most studies regarding the technological options for user-system interaction, user access to traceability information, and traceability data output may be a sign of the low technology readiness level (TRL) of many proposals. The information available on interface validation with end-users was meager, and if tests have been performed the user's appreciation remained mostly unclear. Together with the scant information found regarding efforts to collect and characterize working conditions and users' needs, preferences and limitations and considering the challenges experienced in field tests reported by many of the reviewed studies, all justify a strong call for research and investment in these areas, in line with recent initiatives [99].

Many studies on TSs or the components of TSs aimed at advancing specific aspects related to TSs and services, proposing methods and tools for integrating data from diverse sources and with diverse characteristics [35,68,79], integrating auto-ID technology in manufacturing and business processes [34], developing traceability services able to overcome the limitations of standards [49,54,70], tackling evaluation and proof of results by embedding measuring capabilities for efficiency gained from the traceability function [40], or deploying a testbed platform to conduct the experimental evaluation and cost-benefit analysis of a prototype system [56], advancing research on security in terms of track and trace for RFID-enabled supply chains [70], and proposing technology-based solutions to address eco-sustainability concerns [80,81].

Most studies included in this group identified business-related services and features built regarding traceability capabilities and technology, with a small group addressing eco-sustainability concerns and tackling lifecycle management and closed-loop arrangements [43,72,80,81].

6.8. What Are the Enabling Factors and the Challenges Related to the Development and Implementation of Traceability Models and Traceability Systems, Especially When Related to a CE?

Technological aspects related to methods, software and hardware, business- and market-related issues, regulations and guidelines aspects, standardization and classification in its multiple dimensions and needs, expectations, motivations, and limitations of diverse stakeholders typify important enablers and motivators identified by the studies addressing TMs and modeling traceability. The latter are particularly relevant in this fundamental phase of any development initiative, in the face of the huge challenges posed by high heterogeneity environments [36,38,45,52,55,67,69], the absence or non-consideration of standards in an industry [51,59], semantic inconsistencies and the lack of agreement on a concept's meaning and the relationship between terms exacerbated by current enterprise information systems [51,63], and the limitations of ontology-based approaches [75], even in sectors with many years of experience in traceability implementation [51]. The limitations of modeling methods, including the identification and evaluation of existing conditions [63,65], and the inability to model information flows [52] and IoT systems [55] further hamper the design phase. Business- and market-related issues, particularly when SMEs are involved [45,62,69,76], technology pitfalls and limitations [64,69,75], security and privacy concerns [36], issues related to governmental intervention, and regulatory bodies' mandates, especially regarding cross-border trade [77] are other factors demanding holistic approaches early in the modeling phase.

As for studies dealing with TSs, the broad enablers and motivators found by the SR were business- and market-related issues, environmental-related motivations, technological aspects, needs, expectations, the motivations and limitations of stakeholders, including regulators and governments, and the limitations and potential of existing standards. Factors deterring the implementation of traceability in a fish supply chain were analyzed and the critical criteria were described in detail for the planning and implementation phases, with motivation being identified as the most critical criterion in both phases [44]. In an aircraft engineering company, the implementation of an RFID project allowed the researchers to systematize four groups of critical success factors, namely, strong organizational motivation, implementation process efficiency, effective cost control and effective university–industry interaction [46]. Challenges identified by this SR also relate mostly to business- and market-related issues, as well as technology drawbacks and limitations. Problems posed by the standards [49,56,70,79] and limitations of models and methods to measure and prove an impact were identified; namely, when establishing the real value of traceability beyond the obligatory duty [42], developing analytical models [46] and establishing the link between traceability and the environmental sustainability assessment of supply chains [80].

6.9. Limitations of the Included Studies

The studies included in this SR presented some methodological weaknesses, the more prominent being the considerable number of studies that did not define or that were unclear about a traceable entity/unit, which is a fundamental element when modeling traceability or developing a traceability system, considering the downstream implications and challenges arising therefrom; the large number of studies missing a clear declaration of indicators able to measure and communicate an effect, a situation that is even more critical when the effect itself is not clearly identified because a definition of objectives is also missing; and the high number of studies that did not state their a priori objectives and/or research question and a research design/methodology. All these limitations not only had implications when trying to demonstrate results or benchmark against similar studies but also an impact on the ability of those trying to review the work in a systematic way. Ill-structured studies, where important information is missing, and ill-placed or misreported data slow down the review work considerably and may give rise to misunderstandings, interpretative subjectivity and an inability to perform comparative work.

The related limitations were the lack of rigor when defining the title and the keywords of a study, as observed in some cases where concepts used in the title and/or as keywords could not be found in the main text, and vice versa.

The absence of a chronological date that could be related to methodological and technological options and the work that was conducted was also a limitation of most studies, as only the publication date was available. Given the fast pace of technological development, this factor is relevant, especially where comparative work is involved and considering that a systematic review is supposed to provide updated guidance for future studies.

Lastly, a limited investment in positioning the research was observed, with some studies barely describing a theoretical background, including the main research field and a definition of the key concepts, as well as the context of application.

6.10. Limitations of the Review

This SR has some limitations. First, the search was undertaken in January 2020, being nearly 18 months old by the time we started drafting the report, due to the extensive work involved in data analysis and systematization and the work constraints experienced during parts of 2020 and 2021. To overcome this limitation, the databases were searched for studies from January 2020 to December 2020, using a query reflecting the core of this review: ALL ((“circular economy”) AND (“traceability system*” OR “traceability model*”)). The studies that met the inclusion criteria (n = 3) were reviewed and introduced in the discussion. However, we did not evaluate their methodological quality; therefore, these findings need to be treated with caution.

Second, the search was limited to articles published in the languages spoken by the research group members, and only papers published in English were finally included. The exclusion of papers in other languages could cause limited access to studies with significant findings related to our aim that were developed in different business, cultural and socio-economic contexts. Such is the case of papers eventually published in Chinese, given that, according to our findings, China is home to many initiatives in this field and public agencies have been funding related research.

Third, despite all the methodological tools and controls implemented and the rigorous approach followed, a degree of subjectivity was subjacent to the analysis and the categorization of information, particularly in some dimensions. Filling in the several extraction and categorization tables was quite complex, also due to the structuring and reporting options of many studies, particularly in terms of the implementation and evaluation phases.

Finally, due to the variations in outputs and outcomes assessed across the included studies, the scant number of studies focusing on the same or similar interventions and the different characteristics of traceability entities and contexts, it was not viable to crosscheck data from the included studies in detail or to perform a deep context–mechanisms–outcome (CMO) [100] analysis.

7. Conclusions

This review has demonstrated that the link between traceability and the circular economy, when assessed by published research and practice demonstrating the impact of the development of traceability models and traceability systems, is yet to be established. In fact, only one study reporting early conceptual work referred explicitly to the CE, with no mention of any CE principles or indicators under consideration. Qualitative evidence for TMs highlighted the capacity to create value by transforming information into knowledge throughout all phases of a product's lifecycle, the expected improvement in systems' integration along the supply chain, and the impact of clearly defining product information requirements regarding end-of-life decisions. For TSs, empirical qualitative evidence included the better use of materials and products, improved coordination across a supply chain, the potential for improving energy management, the better management of equipment and components from production to end-of-life and the ability to support forward and reverse logistics in supply chains. As for the impact on the quality of data and information available, our focus was on the capacity for improved information exchange and access to information, even if it was not based on quantitative evidence, and not on the specific characteristics of the data and information available on traceable entities and on proving a positive impact on them.

We conclude that sound research and practice documentation are required to establish evidence and foster the uptake of traceability systems and services by all the stakeholders. We found gaps in all the areas reviewed, signaling great research and innovation opportunities, especially connected to the CE. Circularity brings a new layer to a multi-disciplinary, multi-level and already very complex field, and calls for renewed efforts regarding conceptual approaches and research methods, data and process modeling, evaluation methodologies, economic and financial modeling, funding models and mechanisms, requirements engineering, the development and evaluation of ontologies, the development and appraisal of regulations, standards and indicators, and a broad spectrum of technological methods and tools. Based on our results, we defend the hypothesis that a deep understanding of the implementation context and of contextual dimensions, including the human factor, is of paramount importance and deserves considerably more research and investment.

Author Contributions: S.S.: conceptualization, methodology, investigation, data curation, writing—original draft preparation, reviewing and editing, visualization, validation, and approving the final version of the manuscript. A.R.: collaboration in conceptualization, investigation, data

curation, including data import and preparation on the Rayyan platform, visualization, writing—reviewing and editing, validation, and approving the final version of the manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: This research was partially funded by the FCT—Foundation for Science and Technology, Portugal, grant numbers UIDB/04058/2020 and UIDP/04058/2020.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The complete extraction tables are available from the corresponding author.

Acknowledgments: We acknowledge the contribution of our colleague Victor Moutinho, who co-screened a batch of titles and abstracts during the exploratory stage of the search for studies in electronic databases. We acknowledge the support of the GOVCOPP—Research Unit in Governance, Competitiveness and Public Policies.

Conflicts of Interest: The authors declare no conflict of interest.

Acronyms

QCRI	Qatar Computing Research Institute

Abbreviations

The following abbreviations are used in this manuscript, to keep the exact formulation used in the included studies from where the text has been extracted:

ATF	AMPLE Traceability Framework
BPMN	Business Process Modeling and Notation
CE	Circular Economy
CPS	Cyber-Physical System
ebXML	Electronic Business XML
EPC	Electronic Product Code
EPCIS	EPC Information Services
EPCDS	EPC Discovery Services
EU	European Union
GPS	Global Positioning System
GSC	Global Supply Chain
GS1	Global Standards 1
IoT	Internet of Things
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LNG	Liquefied Natural Gas
MESCO	Meat Supply Chain Ontology
PL	Production Logistics
QR	Quick Response
RCBTS	RFID-based Cattle/Beef Traceability System
RFID	Radio Frequency Identification
SC	Supply Chain
SCM	Supply Chain Management
SME	Small and Medium Enterprises
SOAP	Simple Object Access Protocol
SQL	Structured Query Language
SR	Systematic Review
SW	Software
TM	Traceability Model

TMs	Traceability Models
TS	Traceability System
TSs	Traceability Systems
UML	Unified Modelling Language
XML	Extensible Markup Language

Appendix A

First query: Search string on Scopus.

Scopus: ALL ((“circular economy”) AND (trace* OR track* OR tracing) AND (model* OR framework* OR “traceability system*” OR identifier* OR “traceable resource unit” OR descriptor*) AND (indicator* OR metric* OR measure* OR method* OR scale* OR standard*))

Second query: Search string on Scopus.

Scopus: TITLE-ABS-KEY (“circular economy” OR (reduc* AND reus* AND recycl*) OR circularit* OR upcycl*) AND ALL ((trace* OR track* OR tracing) AND (model* OR framework* OR “traceability system*” OR identifier* OR “traceable resource unit” OR descriptor*) AND (indicator* OR metric* OR measure* OR method* OR scale* OR standard*))

Third query: Search string on Scopus.

Scopus: TITLE-ABS-KEY ((“circular economy” OR “industrial symbiosis”) AND ontolog*)

References

1. Ellen MacArthur Foundation (EMF). Completing the picture: How the circular economy tackles climate change. *Ellen MacArthur Found. Mater. Econ.* **2019**, *3*, 1–62.
2. Geissdoerfer, M.; Savaget, P.; Bocken, N.M.P.; Hultink, E.J. The Circular Economy—A new sustainability paradigm? *J. Clean. Prod.* **2017**, *143*, 757–768.
3. EMF. Towards the circular economy: An economic and business rationale for an accelerated transition. *Ellen MacArthur Found. Rethink. Futur.***2013**, *1,* 1-98.
4. Lieder, M.; Rashid, A. Towards circular economy implementation: A comprehensive review in context of manufacturing industry. *J. Clean. Prod.* **2016**, *115*, 36–51.
5. EU Circular Cooperation Hub. Strategic Research and Innovation Agenda on Circular Economy. *Cicerone* **2020**. Available online: https://cicerone-h2020.eu/wp-content/uploads/2020/09/Circular-Economy-SRIA-2020.pdf (accessed on 14 May 2021).
6. INEC & ORÉE. Major Circular Economy Networks in Europe. Available online: https://institut-economie-circulaire.fr/wp-content/uploads/2020/03/majorcirculareconomynetworks.pdf (accessed on 14 May 2021).
7. Kalmykova, Y.; Sadagopan, M.; Rosado, L. Circular economy—From review of theories and practices to development of implementation tools. *Resour. Conserv. Recycl.* **2018**, *135*, 190–201.
8. Hahladakis, J.N.; Iacovidou, I. An overview of the challenges and trade-offs in closing the loop of post-consumer plastic waste (PCPW): Focus on recycling. *J. Hazard. Mater.* **2019**, *380*, 120887.
9. Johansson, N.; Henriksson, M. Circular economy running in circles? A discourse analysis of shifts in ideas of circularity in Swedish environmental policy. *Sustain. Prod. Consum.* **2020**, *23*, 148–156.
10. Junestrand, S. Towards a Circular Economy in the built environment: Blockchain as a solution for supply chain transparency. Available online: https://medium.com/@stefanjunestrand/towards-a-circular-economy-in-the-built-environment-blockchain-as-a-solution-for-supply-chain-79027a584123 (accessed on 28 April 2018).
11. Pishchulov, G.V; Richter, K.K.; Pakhomova, N.V.; Tsenzharik, M.K. A circular economy perspective on sustainable supply chain management: An updated survey. *J. Econ. Stud.* **2018**, *34*, 267–297.
12. International Organization for Standardization. ISO 9000:2015(en) Quality management systems—Fundamentals and vocabulary. *Geneva Int. Organ. Stand.* **2015**, *4*, 53.
13. Global Traceability Standard (GS1). GS1´s framework for the design of interoperable traceability systems for supply chains. *Release 2.0 Ratif.* **2017**, 1–58.
14. Bosona, T.; Gebresenbet, G. Food traceability as an integral part of logistics management in food and agricultural supply chain. *Food Control.* **2013**, *33*, 32–48.
15. GS1. GS1 Standards Document—Business Process and System Requirements for Full Supply Chain Traceability. *Glob. Traceability Stand.* **2012**. Available online: https://www.gs1.org/docs/traceability/Global_Traceability_Standard.pdf (accessed on 28 April 2018).

16. Kim, H.M.; Fox, M.S.; Gruninger, M. Ontology of quality for enterprise modelling. In Proceedings of the 4th IEEE Workshop on Enabling Technologies: Infrastructure for Collaborative Enterprises (WET ICE '95), Berkeley Springs, WV, USA, 20–22 April 1995; pp. 105–116.
17. Moe, T. Traceability in food manufacturing can range from in-house traceability in production plants to traceability in whole or part of the production chain from raw material to consumer. *Trends Food Sci .Technol.* **1998**, *9*, 211–214.
18. *BS 8001:2017*; Framework for Implementing the Principles of the Circular Economy in Organizations—Guide. British Standards Institution (BSI): London, UK, 2017.
19. Pauliuk, S. Critical appraisal of the circular economy standard BS 8001 : 2017 and a dashboard of quantitative system indicators for its implementation in organizations. *Resour. Conserv. Recycl.* **2018**, *129*, 81–92.
20. EMF. Circularity Indicators: An approach to measuring circularity—Project overview. *Ellen MacArthur Found. Granta Des*. **2015**. Available online: https://emf.thirdlight.com/link/yybss1obhtdv-ub419h/@/preview/1?o (accessed on 28 April 2018).
21. Behrens, A.; Taranic, I.; Rizos, V. Resource Efficiency Indicators for Policy-Making—CEPS Working Document. **2015**, *415*, 1–21. Available online: https://easac.eu/fileadmin/PDF_s/reports_statements/Circular_Economy/EASAC_Indicators_web_complete.pdf (accessed on 28 April 2018).
22. EASAC. Indicators for a circular economy. *EASAC Policy Rep.* **2016**, 30, 1–43
23. Sánchez, B.B.; Alcarria, R.; Martín, D.; Robles, T. TF4SM: A framework for developing traceability solutions in small manufacturing companies. *Sensors* **2015**, *15*, 29478–29510.
24. Neuhaus, F.; Vizedom, A.; Baclawski, K.; Bennett, M.; Dean, M.; Denny, M.; Grüninger, M.; Hashemi, A.; Longstreth, T.; Obrst, L.; et al. Towards ontology evaluation across the life cycle: The ontology summit 2013. *Appl. Ontol.* **2013**, *8*, 179–194.
25. Aung, M.M.; Chang, Y.S. Traceability in a food supply chain: Safety and quality perspectives. *Food Control.* **2014**, *39*, 172–184.
26. Ghisellini, P.; Cialani, C.; Ulgiati, S. A review on circular economy: The expected transition to a balanced interplay of environmental and economic systems. *J. Clean. Prod.* **2016**, *114*, 11–32.
27. Koberg, E.; Longoni, A. A systematic review of sustainable supply chain management in global supply chains. *J. Clean. Prod.* **2019**, *207*, 1084–1098.
28. Benoît, C.; Norris, G.A.; Valdivia, S.; Ciroth, A.; Moberg, .; Bos, U.; Prakash, S.; Ugaya, C.; Beck, T. The guidelines for social life cycle assessment of products: Just in time! *Int. J. Life Cycle Assess.* **2010**, *15*, 156–163.
29. Mhatre, P.; Panchal, R.; Singh, A.; Bibyan, S. A systematic literature review on the circular economy initiatives in the European Union. *Sustain. Prod. Consum.* **2021**, *26*, 187–202.
30. Shamseer, L.; Moher, D.; Clarke, M.; Ghersi, D.; Liberati, A.; Petticrew, M.; Shekelle, P.; Stewart, L.A.; PRISMA-P Group. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015: Elaboration and explanation. *BMJ* **2015**, *349*, 1–25.
31. Moher, D.; Liberati, A.; Tetzlaff, J.; Altman, D.G.; PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PLoS Med.* **2009**, *6*, e1000097.
32. Ouzzani, M.; Hammady, H.; Fedorowicz, Z.; Elmagarmid, A. Rayyan—A web and mobile app for systematic reviews. *Syst. Rev.* **2016**, *5*, 210.
33. Tian, F. A supply chain traceability system for food safety based on HACCP, blockchain & Internet of things. In Proceedings of the 2017 International Conference on Service Systems and Service Management, Dalian, China, 16–18 June 2017; pp. 1–6.
34. Wang, J.; Chi, H.L.; Shou, W.; Chong, H.Y.; Wang, X. A coordinated approach for supply-chain tracking in the liquefied natural gas industry. *Sustainability* **2018**, *10*, 4822.
35. Parreño-Marchante, A.; Alvarez-Melcon, A.; Trebar, M.; Filippin, P. Advanced traceability system in aquaculture supply chain. *J. Food Eng.* 2014, 122, 99–109.
36. Terzi, S.; Panetto, H.; Morel, G.; Garetti, M. A holonic metamodel for product traceability in Product Lifecycle Management. *Int. J. Prod. Lifecycle Manag.* **2007**, *2*, 253–289.
37. Ruiz-Garcia, L.; Steinberger, G.; Rothmund, M. A model and prototype implementation for tracking and tracing agricultural batch products along the food chain. *Food Control.* **2010**, *21*, 112–121.
38. Anquetil, N.; Kulesza, U.; Mitschke, R.; Moreira, A.; Royer, J.-C.; Rummler, A.; Sousa, A. A model-driven traceability framework for software product lines. *Softw. Syst. Model.* **2010**, *9*, 427–451.
39. Tian, F. An agri-food supply chain traceability system for China based on RFID & blockchain technology. In Proceedings of the 2016 13th International Conference on Service Systems and Service Management (ICSSSM), Kunming, China, 24–26 June 2016.
40. Chen, R. An intelligent value stream-based approach to collaboration of food traceability cyber physical system by fog computing. *Food Control.* **2017**, *71*, 124–136.
41. Hsu, Y.C.; Chen, A.P.; Wang, C.H. A RFID-enabled traceability system for the supply chain of live fish. In Proceedings of the 2008 IEEE International Conference on Automation and Logistics, Qingdao, China, 1–3 September 2008; pp. 81–86.
42. Bevilacqua, M.; Ciarapica, F.E.; Giacchetta, G. Business process reengineering of a supply chain and a traceability system: A case study. *J. Food Eng.* **2009**, *93*, 13–22.
43. Conti, M.; Orcioni, S. Cloud-based sustainable management of electrical and electronic equipment from production to end-of-life. *Int. J. Qual. Reliab. Manag.* **2019**, *36*, 98–119.
44. Karlsen, K.M.; Sørensen, C.F.; Forås, F.; Olsen, P. Critical criteria when implementing electronic chain traceability in a fish supply chain. *Food Control*. **2011**, *22*, 1339–1347.

45. Kumar, V.; Hallqvist, C.; Ekwall, D. Developing a Framework for Traceability Implementation in the Textile Supply Chain. *Systems* **2017**, *5*, 33.
46. Ngai, E.W.T.; Cheng, T.C.E.; Lai, K.H.; Chai, P.Y.F.; Choi, Y.S.; Sin, R.K.Y. Development of an RFID-based traceability system: Experiences and lessons learned from an aircraft engineering company. *Prod. Oper. Manag.* **2007**, *16*, 554–568.
47. Feng, J.; Fu, Z.; Wang, Z.; Xu, M.; Zhang, X. Development and evaluation on a RFID-based traceability system for cattle/beef quality safety in China. *Food Control*. **2013**, *31*, 314–325.
48. Bezerra, A.C.; Pandorfi, H.; Gama, R.M.; de Carvalho, F.F.R.; Guiselini, C. Development of a traceability model applied to goat and sheep meat production. *Eng. Agric.* **2017**, *37*, 1062–1072.
49. Kang, Y.S.; Lee, Y.H. Development of generic RFID traceability services. *Comput. Ind.* **2013**, *64*, 609–623.
50. Bertolini, M.; Bevilacqua, M.; Massini, R. FMECA approach to product traceability in the food industry. *Food Control*. **2006**, *17*, 137–145.
51. Pizzuti, T.; Mirabelli, G.; Sanz-Bobi, M.A.; Goméz-Gonzaléz, F. Food Track & Trace ontology for helping the food traceability control. *J. Food Eng.* **2014**, *120*, 17–30.
52. Thakur, M.; Hurburgh, C.R. Framework for implementing traceability system in the bulk grain supply chain. *J. Food Eng.* **2009**, *95*, 617–626.
53. Lavelli, V. High-warranty traceability system in the poultry meat supply chain: A medium-sized enterprise case study. *Food Control*. **2013**, *33*, 148–156.
54. Muñoz-Gea, J.P.; Malgosa-Sanahuja, J.; Manzanares-Lopez, P.; Sanchez-Aarnoutse, J.C. Implementation of traceability using a distributed RFID-based mechanism. *Comput. Ind.* **2010**, *61*, 480–496.
55. Tu, M.; Lim, M.K.; Yang, M.F. IoT-based production logistics and supply chain system—Part 1 modeling IoT-based manufacturing IoT supply chain. *Ind. Manag. Data Syst.* **2018**, *118*, 65–95.
56. Tu, M.; Lim, M.K.; Yang, M.F. IoT-based production logistics and supply chain system—Part 2 IoT-based cyber-physical system: A framework and evaluation. *Ind. Manag. Data Syst.* **2018**, *118*, 96–125.
57. Li, Z.; Liu, G.; Liu, L.; Lai, X.; Xu, G. IoT-based tracking and tracing platform for prepackaged food supply chain. *Ind. Manag. Data Syst.* **2017**, *117*, 1906–1916.
58. Thakur, M.; Sørensen, C.F.; Bjørnson, F.O.; Forås, E.; Hurburgh, C.R. Managing food traceability information using EPCIS framework. *J. Food Eng.* **2011**, *103*, 417–433.
59. Jansen-Vullers, M.H.; van Dorp, C.A.; Beulens, A.J.M. Managing traceability information in manufacture. *Int. J. Inf. Manag.* **2003**, *23*, 395–413.
60. Pizzuti, T.; Mirabelli, G.; Grasso, G.; Paldino, G. MESCO (MEat Supply Chain Ontology): An ontology for supporting traceability in the meat supply chain. *Food Control*. **2017**, *72*, 123–133.
61. Hu, J.; Zhang, X.; Moga, L.M.; Neculita, M. Modeling and implementation of the vegetable supply chain traceability system. *Food Control*. **2013**, *30*, 341–353.
62. Thakur, M.; Donnelly, K.A.M. Modeling traceability information in soybean value chains. *J. Food Eng.* **2010**, *99*, 98–105.
63. Xu, D.F.; Li, Q.; Jun, H.B.; Browne, J.; Chen, Y.L.; Kiritsis, D. Modelling for product information tracking and feedback via wireless technology in closed-loop supply chains. *Int. J. Comput. Integr. Manuf.* **2009**, *22*, 648–670.
64. Bechini, A.; Cimino, M.G.C.A.; Marcelloni, F.; Tomasi, A. Patterns and technologies for enabling supply chain traceability through collaborative e-business. *Inf. Softw. Technol.* **2008**, *50*, 342–359.
65. Olsen, P.; Aschan, M. Reference method for analyzing material flow, information flow and information loss in food supply chains. *Trends Food Sci .Technol.* **2010**, *21*, 313–320.
66. Sundberg, P.; Hermansson, S.; Tullin, C.; Öhman, M. Traceability of bulk biomass: Application of radio frequency identification technology on a bulk pellet flow. *Biomass Bioenergy* **2018**, *118*, 149–153.
67. da Silva, D.L.; Corrêa, P.L.P.; Najm, L.H. Requirements analysis for a traceability system for management wood supply chain on Amazon forest. In Proceedings of the 2010 Fifth International Conference on Digital Information Management (ICDIM), Thunder Bay, ON, Canada, 5–8 July 2010; pp. 87–94. Available online: https://icdim.org/icdim2010/default.php (accessed on 28 April 2018).
68. Zhang, Y.; Jiang, P.; Huang, G.; Qu, T.; Zhou, G.; Hong, J. RFID-enabled real-time manufacturing information tracking infrastructure for extended enterprises. *J. Intell. Manuf.* **2012**, *23*, 2357–2366.
69. Kelepouris, T.; Pramatari, K.; Doukidis, G. RFID-enabled traceability in the food supply chain. *Ind. Manag. Data Syst.* **2007**, *107*, 183–200.
70. Shi, J.; Li, Y.; He, W.; Sim, D. SecTTS: A secure track & trace system for RFID-enabled supply chains. *Comput. Ind.* **2012**, *63*, 574–585.
71. Olsen, P.; Borit, M. The components of a food traceability system. *Trends Food Sci. Technol.* **2018**, *77*, 143–149.
72. Wong, E.Y.C.; Wong, W.H. The development of reusable luggage tag with the internet of things for mobile tracking and environmental sustainability. *Sustainability* **2016**, *9*, 58.
73. Parlikad, A.K.; Mcfarlane, D.; Fleisch, E.; Gross, S.V. The Role of Product Identity in End-of-Life Decision Making. In *Auto-ID Center White Paper, Auto-Id Centre Institute for Manufacturing, University of Cambridge, Mill Lane, Cambridge, cb2 1rx, United Kingdom.*; MIT: Cambridge, MA, USA, 2003. Available online: https://www.alexandria.unisg.ch/21457/ (accessed on 28 April 2018).
74. Segura-Velandia, D.M.S.; Kaur, N.; Whittow, W.G.; Conway, P.P.; West, A.A. Towards industrial internet of things: Crankshaft monitoring, traceability and tracking using RFID. *Robot. Comput. Integr. Manuf.* **2016**, *41*, 66–77.

75. Ouertani, M.Z.; Baïna, S.; Gzara, L.; Morel, G. Traceability and management of dispersed product knowledge during design and manufacturing. *Comput. Aided Des.* **2011**, *43*, 546–562.
76. Folinas, D.; Manikas, I.; Manos, B. Traceability data management for food chains. *Br. Food J.* **2006**, *108*, 622–633.
77. United Nations Economic Commission For Europe. *Traceability for Sustainable Trade: A Framework to design Traceability Systems for Cross Border Trade (ECE/TRADE/429)*; United Nations Economic Commission For Europe: New York, NY, USA; Geneva, Switzerland, 2016.
78. Ergen, E.; Akinci, B.; Sacks, R. Tracking and locating components in a precast storage yard utilizing radio frequency identification technology and GPS. *Autom. Constr.* **2007**, *16*, 354–367.
79. Martínez-Sala, A.S.; Egea-López, E.; García-Sánchez, F.; García-Haro, J. Tracking of Returnable Packaging and Transport Units with active RFID in the grocery supply chain. *Comput. Ind.* **2009**, *60*, 161–171.
80. Papetti, A.; Marconi, M.; Rossi, M.; Germani, M. Web-based platform for eco-sustainable supply chain management. *Sustain. Prod. Consum.* **2019**, *17*, 215–228.
81. Plakas, G.; Ponis, S.T.; Agalianos, K.; Aretoulaki, E. Reverse Logistics of End-of-Life Plastics Using Industrial IoT and LPWAN Technologies—A Proposed Solution for the Bottled Water Industry. *Procedia Manuf.* **2020**, *51*, 1680–1687.
82. Li, L.; Paudel, K.P.; Guo, J. Understanding Chinese farmers ′ participation behavior regarding vegetable traceability systems. *Food Control* **2021**, *130*, 108325.
83. de Monteiro, D.M.; Caswell, J.A. *The Economics of Implementing Traceability in Beef Supply Chains: Trends in Major Producing and Trading Countries*; University of Massachusetts: Amherst, MA, USA, 2004.
84. Corallo, A.; Latino, M.E.; Menegoli, M.; Striani, F. The awareness assessment of the Italian agri-food industry regarding food traceability systems. *Trends Food Sci. Technol.* **2020**, *101*, 28–37.
85. Mattevi, M.; Jones, J.A. Food supply chain: Are UK SMEs aware of concept, drivers, benefits and barriers, and frameworks of traceability? *Br. Food J.* **2016**, *118*, 1107–1128.
86. Nikolaou, I.E.; Tsagarakis, K.P. An introduction to circular economy and sustainability: Some existing lessons and future directions. *Sustain. Prod. Consum.* **2021**, *28*, 600–609.
87. Alexandris, G.; Katos, V.; Alexaki, S.; Hatzivasilis, G. Blockchains as Enablers for Auditing Cooperative Circular Economy Networks. In Proceedings of the 2018 IEEE 23rd International Workshop on Computer Aided Modeling and Design of Communication Links and Networks (CAMAD), Barcelona, Spain, 17–19 September 2018.
88. Öhgren, A.; Sandkuhl, K. Do SME need ontologies? Results from a survey among small and medium-sized enterprises. In *Proceedings of the Tenth International Conference on Enterprise Information Systems—ISAS, Miami, FL, USA, 24–28 May 2015*; ISAS: 2008; Volume 1, pp. 104–111. Available online: https://www.scitepress.org/Papers/2008/17042/17042.pdf (accessed on 28 April 2018).
89. Acerbi, F.; Sassanelli, C.; Terzi, S.; Taisch, M. A Systematic Literature Review on Data and Information Required for Circular Manufacturing Strategies Adoption. *Sustainability* **2021**, *13*, 1–26.
90. Sauter, E.; Lemmens, R.; Pauwels, P. CEO & CAMO Ontologies : A Circulation Medium for Materials in the Construction Industry. In *Proceedings of the 6th International Symposium on Life-Cycle Civil Engineering, IALCCE 2018, Ghent, Belgium, 28–31 October 2018*; Caspeele, R., Taerwe, L., Frangopol, D.M., Eds.; CRC Press: London, UK, 2019; pp. 1645–1652.
91. Cullot, N.; Parent, C.; Spaccapietra, S.; Vangenot, C. Ontologies : A contribution to the DL/DB debate. In Proceedings of the 1st InternationalWorkshop on the Semantic Web and Databases, 29th International Conference on Very Large DataBases, Berlin, Germany, 7–8 September 2003; pp. 99–119.
92. Polverini, D. Regulating the circular economy within the ecodesign directive: Progress so far, methodological challenges and outlook. *Sustain. Prod. Consum.* **2021**, *27*, 1113–1123.
93. Bo, X.; Jia, M.; Xue, X.; Tang, L.; Mi, Z.; Wang, S.; Cui, W.; Chang, X.; Ruan, J.; Dong, G.; et al. Effect of strengthened standards on Chinese ironmaking and steelmaking emissions. *Nat. Sustain.* **2021**, *4*, 811–820.
94. Thiesse, F.; Floerkemeier, C.; Harrison, M.; Michahelles, F.; Roduner, C. Technology, Standards, and Real-World Deployments of the EPC Network. In *IEEE Internet Computing*; IEEE: 2009; Volume 13, pp. 36–43. Available online: https://www.proquest.com/docview/197338167 (accessed on 28 April 2018).
95. Pérez, J.J.B.; Queiruga-Dios, A.; Martínez, V.G.; del Rey, Á.M. Traceability of ready-to-wear clothing through blockchain technology. *Sustainability* **2020**, *12*, 7491.
96. Wang, B.; Luo, W.; Zhang, A.; Tian, Z.; Li, Z. Blockchain-enabled circular supply chain management: A system architecture for fast fashion. *Comput. Ind.* **2020**, *123*, 103324.
97. Zhu, P.; Hu, J.; Zhang, Y.; Li, X. A blockchain based solution for medication anti-counterfeiting and traceability. *IEEE Access* **2020**, *8*, 184256–184272.
98. Böckel, A.; Nuzum, A.; Weissbrod, I. Blockchain for the Circular Economy : Analysis of the Research-Practice Gap. *Sustain. Prod. Consum.* **2021**, *25*, 525–539.
99. Oliveira, J.; Lima, J.E.; da Silva, D.; Kuprych, V.; Faria, P.M.; Teixeira, C.; Cruz, E.F.; da Cruz, A.M.R. Traceability system for quality monitoring in the fishery and aquaculture value chain. *J. Agric. Food Res.* **2021**, *5*, 100169.
100. Pawson, R.; Greenhalgh, T.; Harvey, G.; Walshe, K. Realist review—A new method of systematic review designed for complex policy interventions. *J. Health Serv. Res. Policy* **2005**, *10* (Suppl. 1), 21–34.