A Survey on IoT as Enabler for Sustainable Supply Chains

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***Abstract*—text**

***Index Terms*—IoT, Internet of Things, supply chain, sustainability, emissions reduction, green supply chain management**

I. Introduction

Information technology has been used in companies since the 1970s [1]. The term Industry 4.0 refers to the fourth industrial revolution. It is the next stage in the organization and control of the industrial value chain. People, machines, and products are directly networked with each other. Along the supply chain, processes are digitally transformed and prepared for the digital age. An important component of data acquisition and control in supply chains is Internet of Things. Processes, machines, devices, and objects can digitally exchange data and process it in real-time via the Internet [2]. IoT serves as an enabler to digitally automate supply chains and become a key technology to make them sustainable. Companies are increasingly setting their own goals to make their supply chains more sustainable and to respond to the consequences of climate change.

According to the Paris Agreement art. 2, the global average temperature increase is to be limited to 1.5 degrees compared to the pre-industrial era [3]. The IPCC states that the remaining global carbon budget that may be emitted is about 400 billion tons to limit the temperature rise to 1.5 degrees [4]. This is intended to prevent serious and irreversible consequences of climate change [9]. Today, climatic changes in the global South, but also in the global North, are already having a strong impact on the ecosystem and on people. Many animal and plant species are threatened with extinction, heatwaves and droughts lead to crop failures and trigger large-scale fires, and people lose their homes due to heavy rainfall and floods. In particular, industrialized countries have a responsibility to reduce the pollution and exploitation of the environment. These countries have a particularly high per capita emission, as can be seen in [5]. Oceania had the highest carbon emission in 2020 with about 13 tCO_2/person, followed by North America with about 11 tCO_2/person. In Europe, emissions have been 6.6 tCO_2/person. Countries in the global South have particularly low emissions with South America (2.3 tCO_2/person), Central America (1.8 tCO_2/person), and Africa (1.0 tCO_2/person). A large share of carbon is generated in supply chains. Supply chains generate around 60% of global CO_2 emissions [6]. Thus, they take a major role in the fight against the climate crisis. However, according to [7], companies are struggling to decarbonize their supply chains and achieve net-zero emissions. Partly, action is needed at the industry level, which is difficult to implement because of many different interests. The supplier landscape is often fragmented and difficult to monitor, leaving sources of emissions unattended. In addition, collecting data to set concrete targets and implement standards is difficult.

The purpose of this paper is to address the issues described above. The aim of the paper is to identify and evaluate current solutions in research that use IoT to make supply chains more sustainable and environmentally friendly. From this, conclusions can be drawn for future research. In this way, areas that have not yet been sufficiently researched can be investigated in a targeted manner so that research gaps can be closed. This suggests the following research question: *What existing solutions are in research using the Internet of Things Technologie in supply chains to make them more sustainable and environmentally friendly?*

This paper is structured as follows. In Section II, the current state of research is presented. It provides a scientific classification of IoT and Green Supply Chain Management. The used methodology to conduct the survey is described in Section III. A systematic literature search was used. Section IV reviews scientific papers that use IoT to reduce emissions in supply chains and make them more sustainable. The papers are compared and examined in terms of various research aspects. Section V takes a different perspective on IoT and examines how sustainable IoT's own footprint is. In Section

VI, a specific solution is examined and studied in more detail. This solution deals with improving resource efficiency in food supply chains by the use of IoT. Interpretations of the paper results, open issues, recommendations for future research, and limitations of this study are discussed in Section VII. Finally, Section VIII concludes the survey.

II. Preliminaries

A. Internet of Things (IoT)

The term Internet of Things has been used since 1999 to describe the networking of objects and machines via the Internet. Devices are given a unique identity in the network. This enables them to communicate via the Internet and perform tasks in a fully automated manner. Production processes become more efficient and less expensive as a result. With these capabilities, IoT is an elementary component of Industry 4.0, as self-organization of industrial processes is enabled and production steps can be linked across the entire value chain [12]. In addition to Machine-2-Machine communication, they also provide an interface for users to operate and control devices from any location. Technology plays a particularly large influence in the development of intelligent smart systems in industry [10]. Especially in the field of Big Data, IoT plays a very important role, as a large amount of data can be generated by sensors [35]. Based on the multitude of possibilities for the use of IoT and the amount of data, new business models can emerge [11].

Microprocessor technology and the Internet form the technical basis of IoT. These processors are built into devices, giving them electronic intelligence. Another important component of IoT is RFID technology. This technology consists of two components. A small transponder is attached to an item with which the obejct can be scanned. An electromagnetic field is created by means of a reader, which allows data to be exchanged from the transponder to the reader. This makes it easier to identify and track items and goods. The data exchange is contactless.

In [13], a reference architecture for IoT based on the current state of research is described, as shown in Fig. 1. At the lowest level of the model are sensors and actuators. Sensors have the ability to measure various physical or chemical properties. The conversion of a physical parameter into an electronic signal takes place. Actuators work the other way around. They translate an electronic signal into a physical signal and thus can influence their environment. These two components are part of a hardware device. Drivers enable the control of all components on the device by means of software. Gateways are responsible for exchanging data between devices using protocols. They can translate data into other formats and send it over the Internet. IoT integration middleware takes care of receiving and processing data. Various functionalities can be implemented to analyze the data. Application is the top layer and, as software, provides the direct interface to users so that they can gain insights. The application accesses the middleware.

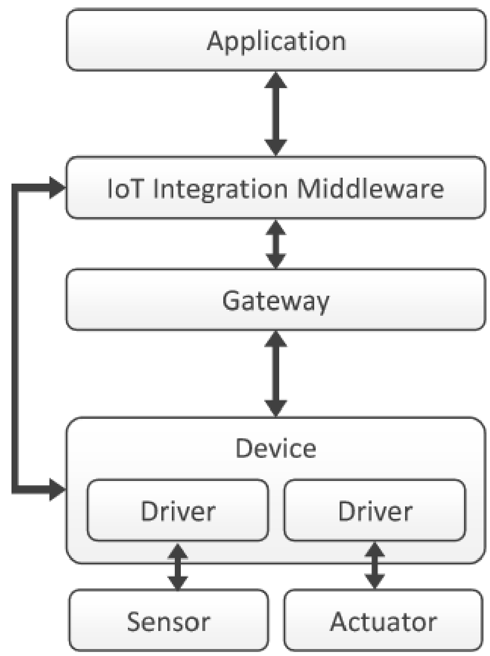

Fig. 1. IoT reference architecture based on [13]

B. Green Internet of Things (G-IoT)

According to [15], two different aspects are considered in Green Internet of Things. On the one hand, it is about using IoT technology to make existing software and hardware more sustainable. By using IoT, these can be made more efficient and effective. The entire supply chain can be integrated and monitored with complete coverage. This can reduce emissions and optimize logistics chains.

On the other hand, it is about IoT making itself more sustainable. Even if the energy consumption of IoT devices is low individually, however, a large amount of energy is consumed when entire IoT networks are considered. Therefore, these networks must be designed with respect to the lowest possible energy consumption. In general, throughout the lifecycle of

IoT devices, care should be taken to ensure that they have a low impact on the environment. For this, the aspects of design, production, utilization, disposal, and recycling are important [14].

C. Green Supply Chain Management (GSCM)

Supply chain, in general, refers to the establishment and management of logistics chains. The complete process, including the flow of materials, money, and information, is considered from the extraction of raw materials to the end consumer. Supply chain management then involves organizing the various players and steps along the value chain in such a way that products and services can be brought to market and to the customer economically.

Environmental practices and supply chain management are integrated, known as Green Supply Chain Management (GSCM), to support companies in improving their environmental performance throughout the supply chain. Several studies suggest that green supply chain management has a positive impact on the economic performance of companies [20]–[24]. In [17] it is defined that within the supply chain it is about using environmentally friendly inputs that are transformed into outputs and can be recovered and reused after their lifecycle. For a sustainable supply chain, the economic, social, and environmental aspects must be taken into account to the same extent [18]. Efforts are made to minimize emissions and waste, reduce the use of resources, and link supply chain steps more effectively so that all environmental standards are met [16]. Green supply chains can reduce pollution and production costs, drive economic growth, create competitive advantages in the form of increased customer experience, positive corporate reputation, and provide more opportunities for the export of their products to environmentally friendly countries [19].

Emissions are divided into three categories using the Greenhouse Gas Protocol. Scope 1 includes all direct emissions from own or controlled sources, such as company vehicles. Indirect emissions from the generation of electricity, steam, heating, and cooling used by a company are assigned to Scope 2. Scope 3 emissions, which include all upstream and downstream emissions in the supply chain, are particularly difficult for companies to measure.

III. Methodology

Based on [25], a systematic literature search was conducted to identify and extract relevant papers from previous research.

The focus of the literature review is on the presented results of the papers considering the influence of the used IoT technology. In addition, the scientific methodology and the application area to which the paper refers will be considered. The aim of the literature review is to describe, explain and finally synthesize existing literature in the context of the domain. A neutral perspective is adopted so that the current state of research is presented in a value-free manner. The coverage of the literature review is representative-selective, so that a selection of papers is reproduced that reflects the most essential research aspects of the domain. Since this is a paper in the context of the Internet of Things & Security seminar, the target group can be defined as professionals with sufficient background knowledge.

Before searching the databases, a concept map was created to identify and infer relevant search terms, as shown in Fig. 2.

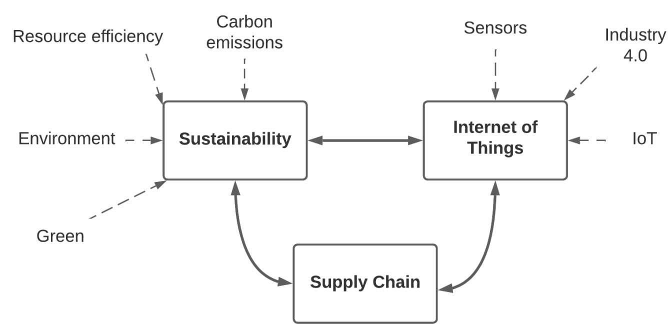

Fig. 2. Concept map for the systematic literature search.

Searches were conducted in the two databases Google Scholar and Primo FU Berlin. Title, abstract, subject, and keywords were queried. For the first run, the following search terms were used:

- supply chain AND sustainability AND internet of things
- supply chain AND carbon emissions AND internet of things
- supply chain AND green AND internet of ihings

Based on the concept map, further different search queries were carried out, in which relevant papers were selected for the survey. After the initial results of the search query, these were refined. Green and Sustainable Supply Chain Management were found particularly frequently in the papers, which is why the search term was thus expanded. Furthermore, a forward and backward search was performed on the most important papers in order to better classify the papers in the existing research and to identify additional relevant papers.

IV. Main

Reference	Application field	Research method	IoT technology	IoT impact	Outcomes
[27]	Food logistics	Simulation study	Wireless sensor network	Reduction of food losses and carbon emissions	Distribution network, Intelligent Containersby order exchange algorithm
[28]	Perishable goods	Case study with a major Swiss retailer	Temperature tracking sensors (TTI, data logger, RFID)	Profit increase and emission reduction	Supply Chain Simulation Model
[29]	Supply chain innovation	Literature review	EPC IoT architecture	Material flow, information flow, capital flow, and carbon footprint control	IoT based business model and research state
[30]	Order Management in food industry	Exploratory research based on simulation study	RFID, IoT infrastructure and blockchain	Reduction of order management times	Simulation scenarios highlighting the impact of new technologies on sustainability aspects
[31]	Manufacturing Systems	Empirical Analysis	IoT as part of Industry 4.0 technologies	Diminish the volume of resources misdirected and the emissions	Implications of technological change
[32]	Low carbon logistic	Conceptual analysis	RFID, GPS, and sensors	Improve circulating logistics, low carbon and reduction in logistics activity	Low carbon logistics model based on IoT
[33]	Manufacturing	Literature review, multiple criteria decision-making approach, expert interviews	Industrial Internet of Things	IoT adoption for sustainability in Supply Chain Management	Relative importance of enabling factors and interdependencies among them
[34]	Management of scrap metal	Case study from a scrap metal producer	IR fill level sensors	More efficiently and effectively management of resources	Framework for assessing SSCM for industry 4.0 and results of the proposed solution
[35]	Smart green businesses	Qualitative content analysis	Sensors, data warehouses, data processing platforms, and cloud	Big Data based on advanced IoT	Multilevel framework for implementing a green IoT-based supply chain
[36]	Retail sector	Exploratory semi-structured interviews and thematic analysis	Variety of IoT forms (RFID, sensors, telematic etc.)	Supply chain integration and performance	Findings on IoT forms providing additional capabilities in data auto-capture, visibility, intelligence, and information sharing for greater integration of retail supply chains
[37]	Agri-food supply chain	Interpretative structural modelling and Fuzzy-Decision-Making Trial and Evaluation Laboratory	RFID tags and readers, sensors, Blockchain, AI, BDA, robotics, cloud computing, and Zigbee	Multi-tier configuration type and IoT-based governance mechanisms	Sustainable based multi-tier system for agrif-food supply chain
[38]	Food logistics	Reference modeling	Sensors	Reduction of inefficiencies, costs, emissions, and social impact	Simulation tool to study the extant dynamics underling the Food supply chain
[39]	Retail sector	Empirical analysis	RFID, sensors	Information monitoring, flow, consolidation, and management	Significance of indicators for their perception of eco-quality

TABLE I
COMPARISON OF SURVEYED PAPER.

V. IoTs own footprint

VI. Detailed consideration of two solutions

Food sector ist einer der wichtigssten Sektoren, großer Impact und Lebensgrundlage [8]

bcg sektor mit meisten emissionen in supply chains

2021 sehr aktuell

wurde in Computers in Industry vol. 127 veröffentlich, spricht für Qualität des papers

The aim of Computers in Industry is to publish original, high-quality, application-oriented research papers that:

• Show new trends in and options for the use of Information and Communication Technology in industry; • Link or integrate different technology fields in the broad area of computer applications for industry; • Link or integrate different application areas of ICT in industry.

The food sector has shown low response to embrace IoT.

We present a framework to improve the resource efficiency of food manufacturing.

The framework is based on design and implementation of a number of IoT-based tools.

The framework helps monitoring food waste generation and use of energy and water.

The paper was written by the three authors Sandeep Jagtap, Guillermo Garcia-Garcia, and Shahin Rahimifard. All three have several years of experience in various projects on sustainable food supply chains and have completed their PhD in this field. Sandeep Jagtap focuses on Sustainable Manufacturing, Circular Economy and Industry 4.0 applications. While Shahin Rahimifard's research has a focus on Operational Planning of Manufacturing Systems, Guillermo Garcia-Garcia has a chemical background and specializes in Waste Management, Sustainable Engineering and Environmental Impact Analysis. The paper integrates with their current research projects and builds on their previous scientific contributions.

VII. Discussion

VIII. Conclusion

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