ROLE OF GLOBAL FORUMS IN LEVERAGING DIGITAL AND SOFTWARE INNOVATION TO ADDRESS CLIMATE CHANGE

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ABSTRACT

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Global forums such as the Conference of Parties (COP) and the World Economic Forum (WEF) have mentioned the need to leverage the full potential of digital and software technologies to adapt and mitigate the effects of climate change. However, the correlation between digitalization and its negative impact on climate change has not been on the global forums' agenda yet. This research aims to explore the state of efforts by global forums in leveraging digital and software innovation for climate change. And it also aims to investigate the importance of bringing to the attention of the global forums the climate change impacts of software innovation and development. The study consists of 2 parts. One is the systematic literature review of the existing reports, publications, and articles from global forums and Intergovernmental Organizations (IGOs). The second part is the interviews of 2 groups of participants. One group is policymakers including IGOs and government representatives. Another group is researchers on sustainable digitalization and green/sustainable software engineering. The findings show that global forums mainly promote the positive impacts of digital and software innovation. The acknowledgement of the negative impacts of these technologies is very low. Moreover, global forums have no focus or awareness of the software's impact on climate change. Most participants agreed that global forums should include the topic of software's impact on climate change for sustainable digital transition.

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Sincerely,

Soha Ali

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ABBREVIATIONS

IGOs	Intergovernmental Organizations
UNFCCC	United Nations Framework Convention on Climate Change
COP	Conference of Parties
WEF	World Economic Forum
ITU	International Telecommunication Union
UNEP	United Nations Environment Programme
UNDP	United Nations Development Programme
UN	United Nations

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1 Introduction

United Nations referred to climate change as a major crisis of current times (United Nations, 2020). International climate change experts and organisations have increasingly issued dire warnings about cutting greenhouse gas (GHG) emissions to limit the temperature to 1.5 degrees Celsius (Masson-Delmotte, 2018). It is imperative to adopt an urgent system-wide collaboration and transformation to tackle the climate crisis; otherwise, there's a good chance of the earth's temperature rising by 2.7 degrees Celsius by 2100 (Climate Action Tracker, 2019). Digital technologies have been recognised as a potential solution to adapt and mitigate the effects of climate change (UNFCCC [b], 2016). Intergovernmental and nongovernmental organisations worldwide continuously advocate for data analytics and technological innovation to leverage opportunities unleashed by digital transformations and information technologies (WWF, 2017; UNEP, 2022). According to United Nations Environment Programme (UNEP), digital technologies have the potential to mitigate the effects of climate change (UNEP, 2022). There are active discussions on global forums to understand the capability of digital technologies to address escalating climate change concerns. The United Nations (UN) Secretary General's *'Roadmap for Digital Cooperation'* highlights the need to accelerate digital cooperation, inclusion, innovation, and global connectivity for a sustainable future (UN, 2020). The use of digital technologies in value creation and sustainable development has put an imperative on industries to explore the latest technologies. Moreover, it has also compelled the industry to learn how to leverage information by harnessing digital, social, and mobile business tools to drive innovation and spur growth (WEF, 2021).

On the other hand, it is also of utmost importance to recognise technology's contribution to environmental problems, such as its negative impact on GHG emissions and global warming (Karyono, 2015; Okafor 2020). Digital technologies have created high user demand and, more significantly led to the emergence of new industries such as e-commerce, online streaming, artificial intelligence, and cloud computing etc. (Qureshi, 2022). Due to the proliferation of digital technologies, there is growing concern about the associated environmental impact and contribution to GHG emissions by these technologies. Globally Information and Communication Technologies (ICT) and digital industry accounts for approximately 3.4% of GHG emissions (Freitag et al., 2021). The emission percentage is

expected to grow by 14% by 2040 if remains neglected (Belkhir et al., 2018). Research shows that major advancements in the digital sector are not aimed at mitigating or adapting to climate change (Freitag et al., 2021).

1.1 Problem Statement

The above-mentioned narratives, deduced from global forums, IGOs and academia, lead to 2 opposing arguments. First, digital technologies are necessary to adapt and mitigate climate change; hence, the need to promote access, innovation, development, deployment, and investments in the sector. Second, digital technologies are detrimental to the environment, and their emissions calculations are not certain. The digital sector has a high chance of emissions gains due to the increasing availability and demand of digital and software services.

In this discussion, the focus of the global forums has mainly been on leveraging and harnessing the full potential of digital technologies to address climate change. However, digitalisation and software technologies' negative impact on climate was not on the sustainability policy agenda and negotiations until recently (Liu et al., 2019).

Some studies suggest that to drastically reduce the digital carbon footprint of the digital sector, the current policies and regulations in ICT are not enough. These policies need to go beyond the tangible to incorporate the intangible, i.e., go beyond the hardware and also consider the software running behind cutting-edge digital technologies (Calero et al., 2013; Specht, 2022). Software systems are at the core of digital technologies and a major player in digital transformation. Sustainable software, also known as green software, to catch the phenomena, has received researchers' attention and is recognised to be an essential subject for a sustainable digital future (Lago et al., 2013; Pang et al., 2016). Researchers identify the consequential environmental impact of software and emphasise the need for green software development, whether it is AI algorithms, blockchain applications or data processing (Calero et al., 2015). Studies believe software sustainability has often been neglected and overlooked (GSF, 2021).

As digital technologies are expanding and offering an upsurge to the fourth industrial revolution, businesses are constantly and eagerly adopting them (WWF, 2017; EC, 2021).

Amid this digital revolution, it is important to consider the software's negative impact on the environment, which is a key driver of the digital economy. The narrative offered by global forums to harness the full potential of digitalisation to mitigate and adapt to climate change will also require attention to the negative effects of digitalisation.

Therefore, this thesis explores the state of efforts by the global forums in leveraging digital and software technologies to address climate change.

1.2 Research Questions

Following are the research questions of this study.

RQ1: What is the state of efforts by global forums in leveraging digital and software innovation to address climate change?

Rationale: Global forums play a huge role in setting global agendas and narratives. Climate change poses significant threats to the planet's ecosystems, human societies, and economies, necessitating swift and effective action at a global scale. Global forums, as platforms for international cooperation and policymaking, have the potential to drive collective efforts to combat climate change. Global forums mention the role of digitalisation to address climate change. By leveraging digital and software innovations, these forums can tap into transformative technologies that offer novel solutions for climate mitigation and adaptation. However, the significance of their role and landscape of efforts in leveraging digital and software technologies is unexplored. The research question explores the state of efforts by global forums in harnessing the potential of digital and software technologies for climate change while focusing on mitigating its negative impacts.

RQ1.1. How do global forums address the positive and negative effects of digital and software technologies on climate change?

Rationale: Digital and software technologies have both positive and negative impacts on climate change. Where digitalisation shows the potential to mitigate and adapt to climate change, it also comes with negative impacts. Hence, to what extent the global forums consider the positive and negative impacts of digital and software technologies are not explored. This sub-research question focuses on the positive and negative impacts of digital and software technologies addressed by global forums. Since global forums set the global

narrative, this question is important to explore the efforts in each dimension to describe a clear picture of the landscape of efforts by these forums.

RQ1.2. To what extent the global forums are leveraging digital and software innovations to address climate change?

Rationale: This sub-research question aims to explore the scale and scope of efforts by global forums in leveraging digital and software innovation to identify the boundaries, state of work, and gaps in the current efforts by these forums. Understanding the extent to which digital and software technologies are currently addressed within global forums will shed light on the level of commitment and progress in harnessing these transformative tools for climate action.

RQ2: What is the significance of addressing the climate change impact of software innovation and development at global forums to make the digital transition sustainable?

Rationale: Software is at the core of digital technologies. Green and sustainable software is considered a new discipline and software's impact on climate change is neglected in climate change discussions related to digital technologies. However, considering the impacts of software during its development can mitigate the negative impacts, ultimately reducing the negative impacts of digital technologies. This research question explores the significance of addressing the climate change impact of software innovation and development at global forums. Understanding the importance of integrating climate considerations into software innovation and development discussions at these forums will illuminate the pathway towards a sustainable digital transition. This research seeks to underscore the urgency of addressing climate change implications in the software domain, as it not only aligns with global climate commitments but also paves the way for a greener, resilient, and ethically responsible digital future.

1.3 Aim and Objective

The thesis investigates how global forums, like COP and DAVOS, leverage digital and software technologies to address climate change. It also explores the importance of

discussing the impacts of software development on climate change to make the digital transition sustainable.

This research uses a mixed-methods approach, including primary and secondary data collection.

Primary data is gathered through semi-structured interviews with two distinct groups of participants:

Group 1: Policymakers including government and IGOs representatives.

Group 2: Researchers on Sustainable digitalization/green software etc.

Interviews aim to obtain insights into the current efforts by global forums, challenges, and opportunities in leveraging digital and software technologies for climate change mitigation, as well as the importance of addressing the impacts of software development on climate change in global forums.

Secondary data is collected through a literature review, including initiatives, reports and whitepapers from global forums and IGOs. The literature review aims to understand the current landscape of global forums regarding digital and software technologies to address climate change. The synthesis of primary and secondary data enables a robust understanding of the present state of digital and software technologies in climate change mitigation and the significance of incorporating its impact into the discussions of global forums to foster a sustainable digital transition.

1.4 Thesis Structure

The research is divided into five sections. Chapter 1 sets the foundation of the thesis by defining the introduction including the aim and objectives, research questions and thesis structure. Chapter 2 includes the background of the research and a review of existing publications by global forums and IGOs. Chapter 3 defines the research methodology including the format of data collection for literature review and interviews, the data analysis, the ethical considerations, and the reliability and threats to the validity of the study. Chapter 4 analyses the findings and results from the literature review. Chapter 5 analyses the findings and results from the interviews. Chapter 6 includes a discussion of the literature and

interview findings, answers to research questions, and describes the research limitations, and research implications as a way forward. Chapter 7 provides the conclusion.

2 Background

As the world started to plan economic recovery, especially in the post-COVID-19 era, it has been argued largely that the world needs to operate more digitally (QTS, 2020). According to European Green Deal, 'A roadmap for recovery', the current worldly crisis paved the way for the digital economy. Hence, investing in digital technologies and infrastructure is critical to achieving a sustainable future and mitigating climate change (The European Council, 2020).

The digital economy is growing at a faster pace than the real economy (Qureshi, 2022). The digital economy accounts for 53.3 trillion US dollars in 2023, which is 50% of the global economy in 2023 (Statista, 2023). According to World Economic Forum, digital resilience and the digital market have become a mandate for countries to not only thrive but also to survive the 21st century (WEF, 2020).

COP21, in 2015, also highlighted the role of digital technology in mitigation and adaptation measures to combat climate change (United Nations, 2015). In 2017, during COP23, UNFCCC organized a panel of high official experts to bring to the table ICT as a climate change solution and showcased the potential of digital solutions in attaining Sustainable Development Goals (SDGs) (UNFCCC, 2017).

Despite the overall optimism with respect to the role of digital technology in the mitigation and adaptation of climate change in various sectors, history shows that industrial emissions have grown continuously despite digital technologies' efficiencies made to other sectors (Freitag et al., 2021). In fact, the rapid evolvement of digital technologies, such as Artificial Intelligence (AI), Blockchain, Internet of Things (IoT) and Cloud Computing, as well as the increasing demand for streaming, scrolling, and other online activities are driving up the energy consumption of the digital industry (Specht, 2022). Yet, the negative impact of digital technologies on climate change was not on the sustainability policy agenda and negotiations until recently (Liu et al., 2019).

Moreover, software is the most neglected element when it comes to environmental impacts, CO2 emissions, global warming and/or climate change impacts of digital technologies (Kern, 2014). Software is immaterial and therefore is not mainly considered a carbon

contributor; however, its use brings massive energy consumption and resource depletion (Hilty et al. 2015). Climate policies in some countries have started to pay attention to tackling digital emissions by enforcing rules and regulations for promoting the use of renewable energy, reducing electronic waste (e-waste), and enabling a circular economy, but these efforts need to go beyond physical and incorporate the development, use and deployment of these technologies (Specht, 2022).

Green and sustainable software: Green software is a multi-disciplinary concept including climate science, software practices and architecture, electricity markets, hardware, and data centre design (Principles, n.d.). Green software is defined in a study as one whose development, deployment, and use have less impact on the environment (Dick et al, 2013). This impact can be direct, indirect, or rebound (Hilty et al, 2006). Another definition of green and sustainable software is software that considers its direct and indirect impacts during development and continuously evaluates and optimizes its effects throughout its appropriation and utilization (Johann et al, 2011). Moreover, green software is also categorized into four categories i.e., less energy consumption, smart operations, managing carbon emissions, and software for climate change (Calero et al, 2015).

A study states that green and sustainable software solutions can reduce 25% to 30% energy consumption of data centres which can possibly reduce resource usage and less hardware equipment (Hilty et al. 2015). Even after more than a decade of research, optimizing software in terms of energy consumption and environmental impacts is still considered a relatively new concept involving various misconceptions (Calero et al, 2017). A study reports the scientific evidence on the topic of green and sustainable software engineering and found only 4% of evidence exists in industrial practices whereas 8% are the expert opinions and 88% are simulated scenarios (academic or theoretical studies), which unveil a huge gap between the real world and theoretical research (Mourão et al., 2018).

3 Methodology

This section describes the methodology used to conduct this master's thesis research, which explores the state of efforts by global climate change forums in leveraging digital and software innovation to address climate change. It also investigates the importance of bringing to attention the climate change impact of software innovation and development.

The methodology uses multiple methods for data collection, including reports from global forums and IGOs, along with semi-structured interviews of policymakers and green software researchers. The following subsections provide a detailed description of the methodology applied.

3.1 Research Process and Design

The research process and design have a critical role in defining the structure, validity, and reliability of research. This section provides a detailed overview of the adopted research process and design, including different research phases and methods employed. To effectively answer the research questions, a qualitative research design is considered the most suitable. Figure 1 provides a visual representation of the research process and design.

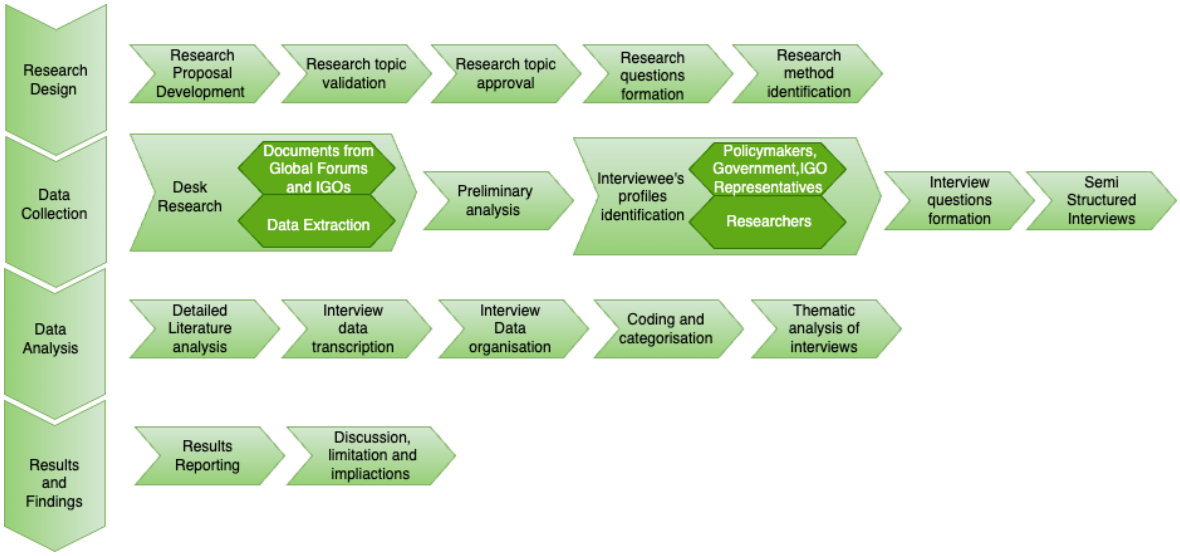

Figure 1: Research Process and Design

The first phase of the research process, Research Design, was to develop a research topic proposal. After careful consideration and deliberations with the thesis supervisor(s), the topic was further validated through external resources i.e., expert(s) in global policy and agenda makings. This step was important to ensure that the research problem is viable and holds significant importance to address through a master's thesis. The topic validation process led to further solidification of research questions and methods.

The second phase of the research process, Data Collection, involves a review of existing literature (including publications, reports and documents from global forums and IGOs to inform on the current landscape of effort by global forums and identify gaps. In this phase, I also identified the profile of the interviewees and formed a list of potential participants. I defined 2 different groups of participants based on the goal and nature of the study. I chose semi-structured interviews to acquire detailed responses. The questions for the interview were designed after preliminary literature analysis. Interview questions were open-ended to provide participants with enough liberty to express their opinions, perspectives, and experiences.

In the third phase, Data Analysis, the data collected from primary (interviews) and secondary (literature/documents) sources went through a thorough and diligent analysis. This phase involves the transcription of interview data. Organization of data for thematic analysis. Categorization and coding of data were performed for meaningful interpretations in thematic analysis.

Finally, the fourth phase, Results and Findings, was carried out in parallel with other phases. Writing of the results and findings was in progress from the early phases of the literature search. The analysis of interviews was analysed later in June and July 2023. Informal daily notes, diaries, and diagrams also helped in shaping the final thesis report. This final stage of the research includes the final thesis report and sharing of the research findings with the relevant stakeholders. The approved version of the master's thesis report will be published in 'LUTPub' i.e., LUT University's publication repository.

3.2 Data Collection

Qualitative research is a valuable approach to exploring complex subjects and gaining an in-depth understanding of a topic. This section provides a detailed overview of the data collection process of literature review and interviews.

3.2.1 Data collection for literature review

To collect data for the literature review, I manually searched:

- The official website of UNFCCC to find documents or reports aiming at digital and software technologies for climate change; and
- COP and WEF's DAVOS meeting agendas discuss ICT/digital technologies and climate change.

Particularly, I also focused on finding whether the role of software has been mentioned in those reports and documents.

For both research questions, I chose the year 2007 as the starting point, as this year, a report was published by Gartner that estimated ICT GHG emissions to be around 2% globally. It was the point that made a shift and received the attention of policymakers towards addressing the environmental impact of ICTs (Karlsson et al., n.d.).

The following section provides a detailed description of the search strategy, inclusion/exclusion criteria and data extraction technique adopted to collect articles.

Search strategy and article selection: In this section, the adopted strategy to search articles and inclusion/exclusion criteria are described. Since the target of this study was to analyse articles published in the global forums, the first step was to decide which forums to review. The chosen ones were:

- COP: the biggest and only global forum of its scale and scope that has climate change as its prime objective.

- WEF: although its primary focus is economic concerns at the global level, it has also adopted climate change as part of its agenda and reflects on the use of digital technologies to address climate impact.

Table 1 shows the web pages used to review these forums. For COP, since it is under the UNFCCC, I explored UNFCCC and recent COP meetings to identify relevant topics, bodies, documents, and the agenda of recent climate change negotiations at COP's forum.

Table 1: Global forums and search strategies

Forum	Web Page	Search strategy	Observations
COP	UNFCCC's general website at https://unfccc.int/	Using the search engine available on the website, I shortlisted all articles that have the keyword "technology" and manually checked for articles that discuss ICT, digital and/or software technologies	Of the 14 technology topics under UNFCCC, only two considered the role of digital technologies in climate change: the Technology Executive Committee (TEC) and Climate Technology Centre and Network (CTCN)
	COP13-COP27 websites	Manually, searched the agenda, sessions, and documents available on the websites for topics related to technology and specifically ICT, digital and software technologies in the context of climate change.	In all 15 recent COPs, digital and software technologies were not found on the agenda of the forum. Although all agendas had the role of technology for climate change. Only 3 articles were included from UNFCCC COP.
WEF	DAVOS 2023 https://www.weforum.org/events/world-economic-forum-annual-meeting-2023	WEF DAVOS 2023 agenda at the official website and searched for topics related to ICT, digital and software technologies in the context of climate change.	In the DAVOS agenda, the use of ICT, digital and software technologies was found. But in the context of climate change, only 4 articles were found.

As I went through the websites, I applied the inclusion and exclusion criteria. This selection resulted in 3 articles from COP and 4 from WEF. After forward and backward snowballing, 17 articles/works were included from UNFCCC, COP including articles from UN-based IGOs and four from WEF, resulting in 21 articles in total.

The inclusion and exclusion criteria are listed in Table 2 below:

Table 2: Inclusion and Exclusion Criteria

Inclusion Criteria	The article focuses is ICT, digital and/or software technologies and climate change/environmental sustainability. Article includes the correlation of ICT/digital/software technologies and their impact on climate/environment. Article is published on global forums or UN-based IGOs website. Article is published after 2007.
Exclusion Criteria	The article is not in the English language. Article is not published on global forums or UN-based IGOs websites. Article includes ICT, digital and/or software technologies but not in relation to climate change or the environment.

The table 2 provides insights into the inclusion and exclusion criteria adopted during the article selection to conduct the literature review.

Data extraction for literature review: The data from articles were collected in an Excel sheet by employing the data extraction method. The data were extracted according to predefined categories and involved answering specific questions against each category. Table 3 shows a table with all categories, their description and RQs associated with each category.

Table 3: Data extraction categories

Data ID	Categories title	Description	RQ
ID1	Name	Name of the title of the article or work	General
ID2	Type	Are the articles a report/publication/initiative by global forums or IGOs?	General
ID3	Year	In which year the article was published	General
ID4	Positive impacts promoted/highlighted	Does the article mention the positive impacts of digital technologies on climate change?	RQ1.1
ID5	Type of technologies promoted/highlighted	Which types of technologies have been mentioned or promoted?	RQ1.1
ID6	Kind of positive impacts mentioned/highlighted	What are the positive impacts mentioned or highlighted by using digital technologies for climate change?	RQ1.1
ID7	Quantification of positive impacts	Does the article quantify the positive impacts? If yes, what are those numbers?	RQ1.1

ID8	Strategy for leveraging positive impacts	Does the article provide any strategy on how to leverage/promote the positive impacts of digital technologies on the climate? If yes, which are those strategies?	RQ1.2
ID9	Negative impacts highlighted	Does the article mention the negative impacts of digital technologies on climate change?	RQ1.1
ID10	Type of technologies with negative impacts	Which type of technologies have been mentioned that cause negative impacts?	RQ1.2
ID11	Kind of negative impacts	What are the negative impacts mentioned or highlighted by using digital technologies?	RQ1.1
ID12	Quantification of negative impacts	Does the article quantify the negative impacts? If yes, what are those numbers?	RQ1.2
ID13	Strategy for mitigating negative impacts	Does the article provide any strategy on how to leverage/promote the negative impacts of digital technologies? If yes, which are those strategies?	RQ1.2
ID14	Software's impact on climate/environment	Does the article mention explicitly the impact of software innovation/development on climate change/environment? If yes, what are those impacts?	RQ1 RQ2
ID15	Strategy to mitigate negative effects of software and enhance positive impacts	Does the article provide any strategy or mechanism to mitigate the negative effects of software innovation/development and enhance the positive impacts? If yes, which are those strategies?	RQ1 RQ2
ID16	Importance of green software development	Does the article mention the importance of green/sustainable software?	RQ2
ID17	Quantification of positive and/or negative effects	Does the article provide any figures/numbers on the software's positive or negative impacts on the environment/climate change? If yes, what are those impacts?	RQ1 RQ2

The table 3 provides detailed insights into the data collected and its relationship with the research questions. The IDs associated with each category will be used later to present the findings from the literature review in chapter 4.

3.2.2 Data collection for interviews

The primary data collection method in this research is semi-structured interviews. This method allows a comprehensive understanding and finding of themes, patterns, commonalities, and distinctions in the participants' perspectives on the research topic. For the latter, interviews were conducted with two different groups of participants. To ensure the desired output is gained through the research questions, I conducted the pilot interview. One

pilot interview was conducted for each profile. The pilot interview helped in understanding the validity of interview questions i.e., whether the desired result will be achieved through the interview questions. After the pilot interview, the data was analysed to check if the desired outcome can be achieved via these questions. There were minor changes made to the interview questionnaire. For instance, replacing the word ‘sustainability’ with ‘climate change’ to reduce the ambiguity for the interviewees in the interpretation of interview questions. This is done because sustainability can be social, economic, or environmental. However, the focus of this study is on climate change which is closely related to the environmental dimension.

After the pilot interview, the actual interview sessions started with both policy makers and green software researchers. groups. One group is policymakers/government representatives, or representatives from intergovernmental organizations (IGOs). The second group is researchers in the field of sustainable digitalization/sustainable ICT, broadly, with knowledge or focus on green and sustainable software engineering and development. This diverse range of participants ensures an in-depth exploration and comprehensive understanding of the research topic from different lenses. See appendix 1 and 2 for interview questions.

Purposive sampling was employed to select participants who have relevant expertise and experience in the field to address the research problem respective of the participant groups. Purposive sampling was used to employ the possibility of selecting participants intentionally who can provide rich and diverse insights to answer research questions. The sample size was defined as a minimum of 10 participants in each group. Most of the interviews were recorded to collect data, organise, and transcribe later. In cases where the interview was not recorded, upon the request of participants, detailed notes were taken and validated later by the participants to ensure the finding’s validity and reliability. For the virtual interviews, data was transcribed during the meeting recording using the team's internal meeting transcription feature. For in-person meetings, the recording was made on the mobile phone recorder and later transcribed using the Gladia transcription app. The transcribed data was organised and stored for data analysis.

3.3 Data Analysis

In this section, details on the data analysis process are provided to effectively answer the research questions. For data analysis, thematic analysis is employed to perform an in-depth analysis of the collected data and identify key themes, patterns, and relationships between data sources. Primary and secondary data were analysed separately in separate phases. For secondary data analysis, data collected in an Excel sheet was analysed. Categories were grouped according to research questions and analysed respectively. The results from secondary data analysis are reported in section 2.

For primary data analysis, data from interviews were analysed. Interview data was prepared in different files and folders according to participant groups for thematic analysis. Data cleaning was performed before uploading transcripts to the qualitative data analysis tool to ensure the data repetition, irrelevancy and noise is eliminated. I used the NVivo app for thematic analysis of primary data. Data coding was performed to organise and structure interview findings. The purpose of assigning codes to data segments was to grasp concepts and ideas in a meaningful way. Codes were grouped into similar and interrelated categories to identify overarching themes, patterns, and relationships between data groups to answer the research questions. Detailed analysis was performed after finalising the data categories and formulating commonalities and discrepancies in data groups to report results and findings. Section 4 provides the results of the interview analysis.

3.4 Validity and Reliability

In this section, the strategies to enhance the validity and reliability of this research are presented to ensure the credibility and trustworthiness of the research. To enhance the validity of the research, careful measures were taken throughout the research design and process. Firstly, the qualitative approach was chosen to gain a comprehensive understanding of the research topic. Multiple data sources are used to conduct this master's thesis research to provide in-depth insights into the research problem, and gaps, and to depict a holistic view of the research topic. Comprehensive data analysis was conducted from documents and reports from global forums and IGOs, and interviews from two distinct and relevant groups of participants. This strategy of collecting primary and secondary data provided a rich and

holistic exploration of the role of global forums in leveraging digital and software innovation to address climate change. The inclusion of multiple data sources and data types helped to mitigate bias and aided in achieving an accurate representation of the research topic.

Furthermore, careful considerations were employed in selecting interview participants for primary data collection. The use of purposive sampling technique was adopted to ensure that the most relevant participants are approached with desired expertise in accordance with the research topic. The purpose of selecting two different groups of participants is to involve diverse ranging perspectives from the most relevant stakeholders i.e., policymakers such as IGO, government representatives, people from global forums, and experts in sustainable digitalisation/ICT and green software. The questions for interviews were designed with careful consideration to eliminate any bias.

The reliability of the research is established by adopting the systematic reporting procedure during data collection, analysis, and reporting. Detailed documentation of each research phase, including data collection, interview questions, data analysis, and research findings are maintained to ensure transparency. During all phases of the research process, adherence to mentioned strategies and research protocols was strictly followed to provide robust and reliable insights into the research topic.

3.5 Ethical Considerations

This section provides details on ethical considerations adopted throughout the research process. Adhering to ethical considerations is an important part of this research, as it involves interviewing different participants to collect primary data to effectively answer the research questions. All participants were provided with a participant information sheet and an informed consent form that outlines the goal, objectives, procedures, and potential risks and benefits of participating in the study. Participants were provided with additional details about the research topic. The confidentiality and anonymity of participants is strictly maintained. Names of all participants were anonymised. Collected data was securely stored and used solely for research purposes.

In the next chapter, the findings of the literature review are discussed.

4 Literature Review

To conduct a literature review for this study, I adapted the guidelines of a Systematic Literature Review (SLR) to plan the study and report its findings. The goal was not to carry out a full SLR including academic and non-academic work. Instead, it sought to review the existing publications of global forums and IGOs.

This literature review seeks to answer the following research questions:

RQ1: What is the state of efforts by global forums in leveraging digital and software innovation to address climate change?

RQ1.1. How do global forums address the positive and negative effects of digital and software technologies on climate change?

RQ1.2. To what extent the global forums are leveraging digital and software innovations to address climate change?

RQ2: What is the significance of addressing the climate change impact of software innovation and development at global forums to make the digital transition sustainable?

This section discusses the results of the literature review, including the classification and analysis of articles. Table 4 shows how the result sections are associated with research questions and corresponding data IDs from the data extraction table (Table 3 in chapter 3).

Table 4: Result sections and corresponding RQs and data IDs

Sections	**RQs**	**Data IDs**
Positive and negative effects	RQ1.1	ID4, ID6, ID7, ID9, ID11, ID12
Scale and scope of efforts by global forums	RQ1.2	ID5, ID8, ID10, ID13,
Climate Change impact of software innovation and development at global forums	RQ2	ID14, ID15, ID16, ID17

The following sections are organised according to the table 4. Each row in table answers the research questions. The IDs come from the table 3. The detailed analysis is done below:

4.1 Positive and negative effects

This section presents the findings related to RQ1.1, which investigates the effects of digital and software technologies on climate change highlighted/addressed by global forums.

4.1.1 Positive and Negative effects highlighted (ID4, ID9)

From 21 articles analysed from global forums and IGOs, 8 articles promote digital technologies for climate change and highlight only the positive impacts of digital technologies to mitigate and adapt to climate change. Out of these 8 articles, 5 are from global forums and 3 from IGOs. On the other hand, only 1 article from global forums, i.e., from WEF (WEF, 2020) discussed solely the negative side of digital technologies.

Finally, 12 articles mention both the positive and negative impact of digital technologies on climate change. Out of the 12 articles, only one article is from global forums and 11 from IGOs, which shows the inclination of global forums towards leveraging the use of digital technologies. Although, it is mentioned that sustainability is not an inevitable outcome of digital technologies (UNEP, 2021). It is also worth observing that there is a tendency to focus on the positive impact of digital technologies. For example, the recent initiative 'CODES' by intergovernmental and international collaborations highlights the negative impact of digital and software technologies, however, the main narrative remains on harnessing the positive potential of digital technologies (CODES, 2022). Another example is the UN Secretary General's *'Roadmap for Digital Cooperation'* where negative environmental/climate impacts of enabling digitalization are acknowledged, despite that the main motive of the roadmap remains on leveraging the use of digital technologies. The roadmap does not provide any concrete and pragmatic approach to how to tackle the negative externalities caused by digital and software innovation (UN, 2020).

4.1.2 Kind of positive and negative impacts highlighted (ID6, ID11)

Of the 21 articles, 18 articles provide insights into the kind of positive and negative climate impacts that can be caused by employing digital and software technologies. From those, 9 provide elaboration on the kind of positive impacts, out of which 5 articles are from global

forums and 4 articles from IGOs. There is one article, from the global forum, that elaborates on the kind of negative impacts. The remaining 8 articles, all from IGOs, provide details on the kind of both positive and negative impacts.

Among the positive effects of promoting digital technologies to address climate change, articles mention that digital technologies bring a reduction in greenhouse gas emissions (ITU [a], 2019). Moreover, digital technologies mitigate climate change by reducing the sector's emissions and helping other sectors in achieving their carbon reduction goals (UNFCCC [b], 2016). Moreover, innovation and development in the digital sector are labelled as crucial to monitor and protect the environment to combat climate change and accelerate global sustainability goals (UN, 2020). Examples of negative impacts include higher emissions (Johnson, 2022), intensive energy consumption (Johnson, 2022), and excessive e-waste generation (ITU [a], 2019).

4.1.3 Quantification of impacts (ID7, ID12)

Only 5 articles quantify the positive impacts, out of which 2 articles are from global forums and 3 articles are from IGOs. For negative impacts, 3 articles provide the negative quantification of the digitalization on environment and climate change, out of which one article is from global forums and 2 are from IGOs. The other 13 articles do not provide any number, figures, or stats on the positive or negative impacts of digital and software technologies.

It is worth noting that the numbers used to quantify impacts contain some discrepancies and are mainly predictions. For instance, for positive impacts, UNEP mentions in its *'Digital Transformation Programme'* that digital technologies can reduce at least 20% of CO2 emissions (UNEO, 2021). Similarly, International Telecommunication Union (ITU) mentions a 17% reduction possibility by employing digital technologies for climate change (ITU, 2019). Finally, WEF reports 15% of potential reductions can be made by using digital technologies for climate change (WEF, 2019). The same goes for the negative impacts, there is a lack of consensus on the numbers provided. For example, UNFCCC mentions 3-6% GHG generated by ICT, UNEP highlights a 2.3% share of digital technologies in global emissions, and WEF mentions 2% global emissions contributions by overall ICT. This

emphasizes the need for accurate measures of digital solutions with transparency, and evidence (UNEP DTU, 2020).

Table 5 provides a complete overview of these findings.

Table 5: Article classification according to RQ1.1

Data IDs and Categories title	**Articles**	**Global forums**	**IGOs and others**
ID4: Positive impacts promoted/highlighted	**Positive only:** (ITU [a], 2019), (UNFCCC [b], 2016), (UNFCCC, 2017), (UNEP [b], 2022), (UN Secretary-General, 2021), (UNFCCC, 2022), (WEF, 2021), (WEF, 2022) **Both positive and negative:** (ITU [b], 2019), (ITU [a], n.d.), (ITU [b], n.d.), (UN, 2020), (ITU, 2020), (UNEP DTU, 2020), (UNEP [a], 2022), (CODES, 2022), (Johnson, 2022), (UNEP, 2021), (ITU, 2022), (WEF, 2013)	**Positive only:** 5 **Both positive and negative:** 1	**Positive only:** 3 **Both positive and negative:**11
ID6: Kind of positive impacts mentioned/highlighted	**Positive only:** (ITU [a], 2019), (ITU [a], n.d.), (ITU [a], n.d.), (UNFCCC [b], 2016), (UNFCCC, 2017), (UNEP [b], 2022), (UN Secretary-General, 2021), (UNFCCC, 2022), (WEF, 2021), (WEF, 2022), **Both positive and negative:** (ITU [b], 2019), (ITU [a], 2019), (ITU [b], n.d.), (UNEP DTU, 2020), (UNEP [a], 2022), (Johnson, 2022), (UNEP, 2021), (ITU, 2022)	**List of impacts mentioned:** Improvement in climate change adaptation and mitigation. Monitoring and tracking of climate change. Data and transparency. Improvement in materials and resource efficiency. Reduction in transportation costs. Improvement in disaster risk management. Improvement in environmental conservation.	**List of impacts mentioned:** Reduced greenhouse gas emissions. Improved energy efficiency. Increased use of renewable energy sources. Help achieve SDGs. Optimize the use of resources. Enable circular economy.

ID7: Quantification of positive impacts	(ITU [b], n.d.), (UNFCCC [b], 2016), (UNEP [a], 2022), (UNEP, 2021), (WEF, 2013)	**Quantification of impacts:** The digital sector could help avoid the production of around 12 gigatonnes of CO2 by the year 2030. 15% of potential reductions can be made by using digital technologies for climate change.	**Quantification of impacts:** Digital transformation can reduce at least 20% of CO2 emissions. Digital transformation can accelerate the use of natural resources in products by 90%. Digital technologies can help reduce 17% of global CO2 emissions.
ID9: Negative impacts highlighted	**Negative only:** (WEF, 2020) **Both positive and negative:** (ITU [b], 2019), (ITU [a], n.d.), (ITU [b], n.d.), (UN, 2020), (ITU, 2020), (UNEP DTU, 2020), (UNEP [a], 2022), (CODES, 2022), (Johnson, 2022), (UNEP, 2021), (ITU, 2022), (WEF, 2013)	**Negative only:** 1 **Both positive and negative:** 1	**Negative only:** 0 **Both positive and negative:** 11
ID11: Kind of negative impacts	**Negative only:** (WEF, 2020) **Both positive and negative:** (ITU [b], 2019), (ITU [a], 2019), (ITU [b], n.d.), (UNEP DTU, 2020), (UNEP [a], 2022), (Johnson, 2022), (UNEP, 2021), (ITU, 2022)	**List of impacts mentioned:** Digital technologies involve extensive electricity usage and energy consumption. Digital technologies contribute to e-waste. Digital technologies emit carbon emissions.	**List of impacts mentioned:** Digital technologies contribute to GHG emissions. Digital technologies generate e-waste and its improper disposal has a negative effect on the environment. Digital technologies are energy-intensive due to growing data traffic and the demand for data centres. The digital sector increases the user demand and need for new equipment.
ID12: Quantification of negative impacts	(UNEP DTU, 2020), (UNEP [a], 2022), (WEF, 2013),	**Quantification of impacts:** The ICT industry accounts for 2% of global CO2 emissions	**Quantification of impacts:** The ICT sector accounts for 3-6% of global GHG. Globally 50 million tons of e-waste are produced a year and only 20%

			of this e-waste is recycled. Digital technologies have a 2.3% share of global emissions.

The table 5 mentions the findings and summarises the whole section in a detailed and comprehensive manner by addressing all relevant categories described in table 4.

4.1.4 Summary to RQ1.1

To conclude, global forums are contributing towards promoting the use of digital technologies, but the negative impacts are not addressed sufficiently on their agenda so far. Most work on negative externality is being carried out by IGOs, which shows the importance of tackling the negative externalities caused by digital and software innovation. Finally, there is a lack of a clear quantification of how current climate technology negotiations, efforts and policies in ICTs are reducing GHG emissions (WEF, 2020).

4.2 Scale and scope of efforts by global forums

This section presents the findings related to RQ1.2, which investigates the scale and scope of the global forum's efforts in leveraging digital and software innovations to address climate change.

4.2.1 Type of technologies mentioned (ID5, ID10)

From 21 articles analysed from global forums and IGOs, 11 articles mention the type of digital technologies that are beneficial to address climate change. Out of 11 articles, 3 are from global forums and 8 are from IGOs. These technologies include cloud computing, IoT, blockchain, and AI. For example, the UNFCCC mentioned that enabling cloud-based technologies allow the possibility of remote work and reduce the need for physical infrastructure (UNFCCC [b], 2016). Moreover, the use of AI enables climate change

predictive modelling, strengthens data collection, and helps countries and businesses in keeping their emission reduction trajectories (Johnson, 2022).

The type of digital technologies that cause negative effects are mentioned in 3 articles, 1 from global forums and 2 from IGOs. These digital technologies include datacentres, AI, blockchain, end-user devices, and IoT. For instance, UNEP has mentioned the emissions and energy-intensive activities in data centres by cryptocurrency mining (UNEP, 2021) and end-user devices that generate e-waste (UNEP DTU, 2020).

4.2.2 Strategy for leveraging positive impacts (ID8)

Of the 21 articles, 16 of them suggest strategies on how to leverage the positive impacts of digital and software technologies. From these, 6 articles focus on only leveraging positive impact. Out of which 3 belong to global forums and 3 to IGOs. The remaining 10 articles from IGOs suggest both; strategies to leverage positive impacts and mitigate negative impacts. The strategies mentioned are the development of policies, regulations, capacity building, and recommendations for governments in areas of digitalization and climate change (ITU [a], 2019). Moreover, UN Secretary-General highlights the importance for all UN member states, the UN system, and all other stakeholders to promote digital public goods including open-source software, open data, and open artificial intelligence models (UN, 2020).

4.2.3 Strategy for mitigating negative impacts (ID13)

The strategies to mitigate the negative impacts of digital and software technologies on climate change are mentioned in 12 articles. From those, 2 articles only focus on the strategies to mitigate negative impacts and belong to global forums (WEF, 2013; WEF, 2020). The remaining 10 articles from IGOs suggest both; strategies to leverage positive impacts and mitigate negative impacts. The strategies to mitigate the negative impacts of digital technologies include the use of renewable energy (WEF, 2013), and circular economy principles in the digital sector to mitigate its negative effects (WEF, 2020). Moreover, the need for collaboration among all stakeholders such as governments, industry, and civil society (ITU [a], 2019).

Table 6 provides a complete overview of these findings.

Table 6: Article classification according to RQ1.2

Data IDs and categories title	**Articles**	**Global forums**	**IGOs and others**
ID5: Type of technologies promoted	(UNFCCC [b], 2016), (UNFCCC, 2017), (UN, 2020), (ITU, 2020), (UNEP DTU, 2020), (UNEP [b], 2022), (Johnson, 2022), (UNEP, 2021), (ITU, 2022), (UN Secretary-General, 2021), (WEF, 2022)	**Type of technologies:** Cloud computing. Internet of Things. Artificial intelligence. Drones for enabling the monitoring of natural disasters and environmental conservation. Machine Learning for Enabling the optimization of energy usage. Digital public goods. Digital twin.	**Type of technologies:** Virtualization. Energy-efficient hardware. Cloud computing. Internet of Things. using more efficient servers, Artificial intelligence. 5G and 6G networks. Quantum computing. Blockchain. Carbon removal technologies.
ID8: Strategy for leveraging positive impacts	**Strategies to leverage positive effects only:** (UNFCCC [b], 2016), (UN, 2020), (UNEP [b], 2022), (UN Secretary-General, 2021), (WEF, 2021), (WEF, 2022) **Strategies to leverage positive and mitigate negative effects:** (ITU, 2022), (UNEP, 2021), (Johnson, 2022), (CODES, 2022), (UNEP [a], 2022), (UNEP DTU, 2020), (ITU, 2020), (ITU [b], n.d.), (ITU [a], n.d.), (ITU [a], 2019),	**Strategies to leverage positive impacts:** By accelerating partnerships and collaboration between the ICT sector, governments, and other stakeholders in achieving climate goals. Forming a digital public goods alliance.	**Strategies to leverage positive impacts:** By promoting collaborations and partnerships ICT/Digital sector in developing countries, and the need to promote universal access to ICTs. By making policies, regulations, capacity building and recommendations to governments in areas of ICT, climate change, and the environment. By applying an environmental lens across the digital work to promote sustainable digital transformation. By creating international standards. By endorsing clean digital technologies and related programmes/initiatives.

			By creating action plans for sustainable digitalization.
ID10: Type of technologies with negative impacts	(UNEP DTU, 2020), (UNEP, 2021), (WEF, 2020)	**Type of technologies:** ICT and digital technologies in general.	**Type of technologies:** Data Centres. Networks. Internet of Things. End-user devices. Cryptocurrency mining.
ID13: Strategy for mitigating negative impacts	**Strategies to mitigate negative effects only:** (WEF, 2013), (WEF, 2020) **Strategies to leverage positive and mitigate both positive and negative effects:** (ITU, 2022), (UNEP, 2021), (Johnson, 2022), (CODES, 2022), (UNEP [a], 2022), (UNEP DTU, 2020), (ITU, 2020), (ITU [b], n.d.), (ITU [a], 2019), (ITU [a], n.d.)	**Strategies to mitigate negative effects:** By using renewable energy sources and improving the energy efficiency of digital technologies to mitigate their negative effects. By promoting a circular economy for sustainable digital transition. By investing in sustainable technologies to mitigate the negative effects of digitalization.	**Strategies to mitigate negative effects:** By highlighting the importance of proper management of digital tools to prevent negative effects. By enabling collaborations among various stakeholders, including governments, industry, and civil society, to leverage the full potential of ICTs in addressing climate change. By putting forward emission-reduction trajectories networks and datacentres. By gaining accurate estimates of the GHG impacts of ICT devices and ICT solutions, with open and transparent data. By the digital industry tackling its own carbon footprint. By developing consistent metrics to measure the impact of technology on the environment and climate change.

The table 6 mentions the findings and summarises the whole section in a detailed and comprehensive manner by addressing all relevant categories described in table 4.

4.2.4 Summary to RQ1.2

To conclude, the promotion of digital and software technologies with positive impacts is highlighted more in both global forums and IGOs. The scale and scope of the global forum's efforts in leveraging digital and software innovation to address climate change include the use of advanced digital and software systems to attain climate change goals and use digital tools to mitigate the existing climate change effects. On the other hand, the strategies to mitigate the negative impact of digital and software technologies are discussed to a lesser extent. Global forums have provided some strategies for enhancing positive impacts and mitigating negative effects, but IGO efforts are relatively more prevalent. These are mentioned by WEF only.

4.3 Climate Change impact of software innovation and development at global forums

This section presents the findings related to RQ2, which investigated the importance of addressing the climate change impact of software innovation and development at global forums.

4.3.1 Software's impact on climate/environment highlighted (ID14)

From 21 articles analysed from global forums and IGOs, only 3 articles from IGOs have explicitly highlighted that software innovation and development have a negative impact on climate/environment. From those, only 1 article (CODES, 2022) mentions the importance of environmentally sustainable and green software. The other 2 articles highlight the use of software for sustainability and climate benefits. For instance, the UN Secretary General's *'Roadmap for Digital Cooperation'* promotes software applications and open-source software but does not highlight the environmental impacts or importance of developing green software.

4.3.2 Strategy to mitigate negative effects of software and enhance positive impacts (ID15)

There is only one article from 21 analysed that highlights the importance of mitigating the negative effects of software and enhancing positive impacts (CODES, 2022). This article is a report from a recent coalition formed between intergovernmental and international organizations, including IGOs such as UNEP and United Nations Development Programme (UNDP). The coalition only includes the action plan for the roadmap for the digital coalition by UN Secretary-General. The action plan's motive is to leverage digital and software technologies for sustainability and climate change. This action plan is not in force yet.

4.3.3 Importance of green software development (ID16)

There is only one article out of 21 analysed that highlights the importance of green software innovation and development to achieve sustainable digitalization (CODES, 2022). It has mentioned the importance of green software engineering for sustainable digitalization.

4.3.4 Quantification of positive and/or negative effects (ID17)

There is no article from global forums neither IGOs that provide the quantification of software's impact on climate change.

Table 7 provides a complete overview of these findings.

Table 7: Article classification according to RQ2

Data IDs and categories title	**Articles**	**Global forums**	**IGOs and others**
ID14: Software's impact on climate/environment	(UN, 2020), (UNEP DTU, 2020), (CODES, 2022),	-	Acknowledges.
ID15: Strategy to mitigate negative effects of software and enhance positive impact	(CODES, 2022)	-	**Strategies**: By making policies, standards and norms for green software development.

			By training in sustainable software engineering.
ID16: Importance of green software development	(CODES, 2022)	-	**Green software development:** Software and applications that are socially responsible, ethical and environmentally sustainable throughout their lifecycle.
ID17: Quantification of positive and/or negative effects	-	-	-

The table 7 mentions the findings and summarises the whole section in a detailed and comprehensive manner by addressing all relevant categories described in table 4.

4.3.5 Summary to RQ2

To conclude, global forums do not consider the software's impact on climate/environment. IGOs also do not have a specific topic of promoting green software and/or tackling the environmental or climate change impacts of software systems on their agendas. However, IGOs have started putting some attention towards this topic in collaboration with the public and private sectors.

4.4 Summary of overall literature review

Global forums play a critical role in promoting and advocating for digital technologies to address sustainability, however, the negative impact of digitalization on climate change has just started to take momentum in global agenda settings. However, the representation of negative impacts is not found on the UNFCCC COP's agenda. There are efforts by UN-based IGOs have their focus on leveraging positive and mitigating negative impacts of digital and software technologies. There are discrepancies in the quantification of positive or negative impacts of digitalization, found in the publications of different forums and IGOs. The positive effects are generally climate monitoring and tracking, and reduction in GHG

emissions. The negative impacts mentioned include e-waste, energy consumption, and contribution to GHG emissions. Global forums and IGOs have also mentioned several technologies that cause positive or negative impacts on climate change along with the strategies to leverage positive impacts and mitigate negative impacts. Most of the articles from IGOs provided both sides of the picture i.e., positive, and negative impacts. However, the negative impact of the software part of digital systems is not acknowledged by global forums.

5 Interview Findings

This section reveals the results from the interviews conducted with two distinct groups of participants. The first group was composed of nine policymakers and IGO representatives (one less than aimed for). The second group of participants consisted of 10 researchers from green/sustainable ICT, digitalization and/or software.

The pilot interview was conducted on 24 April 2023. The first actual interview was conducted on 26 April 2023 and the last interview was conducted on 27 June 2023. The average time spent on each interview, irrespective of the participant group, was 30 minutes. As the nature of the study involves participants from different parts of the world, most interviews were conducted virtually, and 5 interviews were conducted face-to-face.

Table 8: Summary of the primary data attributes

Attributes	**Values**
Number of interviews in each group	Group 1: 9 Group 2: 10
Interview schedule	26 April 2023–27 June 2023
Interview length	30 minutes on average
Interview method	Face-to-face: 5 Virtual: 12 (MS teams) & 2 (Zoom)

Table 8 provides a summary of the primary data attributes to evaluate the qualitative research performance.

5.1 Group 1: Policymakers, IGO and government representatives

To answer research questions, it is very important to include the perspective and insights from the experts in policy-making and global agenda settings. Incorporating views from this set of participants holds significant importance to visualize the current landscape of global forum's efforts in leveraging digital and software innovation, and most significantly, the importance of bringing to attention the climate change impact of software innovation and

development at global forums. Table 9 provides the professional roles of the participants in Group 1.

Table 9: IDs and Roles of Group 1 Participants

Interviewee ID	Participant role
P-1	Under-Secretary-General of the United Nations and Executive Director of the UN Environment Programme (UNEP)
P-2	SDG Advocate for United Nations (UN) Secretary-General on the Sustainable Development Goals (SDGs) & President of the UN Sustainable Development Solutions Network
P-3	Chief Scientist of the United Nations Environment Programme (UNEP)
P-4	Former Vice President of World Bank & Former Dutch Minister of Education and Science
P-5	President of Conflict and Education Learning Laboratory & Former Executive Secretary at the United Nations Environment Program (UNEP)
P-6	Resident Representative of the United Nations Development Programme (UNDP)
P-7	Finnish Minister of Transport and Communications
P-8	Policy Chair of Green Software Foundation (GSF)
P-9	Policy expert on climate, sustainability, and Digital Transformation

The results from the interviews of group 1 are divided into four main themes and further sub-themes based on thematic analysis of interview data. The analysis of interview results is presented below:

5.1.1 Digitalization and climate change

The relationship between digitalization and climate change is intertwined, as it is responded by all 9 participants that digital and software technologies are essential to mitigate and adapt to climate change. Participants in this group believe that digital and software technologies are one of the keys to tackling climate change. The following sub-sections include the topic of digital and software technologies with respect to climate change to provide detailed insights into the observations made by participants' responses. The responses in section i) ii) iii) and iv) below are elaborative opinions of the interviewees. These outcomes/topics are brought up by the participants themselves.

i) Digital and software technologies as an economic driver

Digital and software technologies are at the centre of social and economic development, as stated by 6 participants. According to these participants, the digital and software industry drives economies because it gives rise to efficient ways of consumption and production. This point is illustrated below by P-2:

> *"Digital and software innovations are at the heart of economic and social development. Software running these technologies, by design and development, do and will play a crucial role in mitigating climate change. Don't forget that the impact of these technologies is bound to be profound on what we are faced with as a result of climate change."*

Three of the participants also reported that the race of growth among different industries and countries has overshadowed the sustainability within the digital sector. I.e., they believe that there is so much potential for economic growth from digital advancements, that the environmental sustainability of digital technologies is not prioritized.

ii) Digital and software technologies delivering climate benefits

Eight out of 9 participants stated that digital and software technologies are beneficial in achieving climate goals. For instance, 5 of them stated that digitalization has revolutionized various sectors and has brought efficiency in industrial processes. Moreover, 2 participants reported that emerging digital and software technologies have greatly aided in data collection to make informed decisions on climate action by climate monitoring and future predictions.

iii) Digital and software technologies as environmentally detrimental

Six of the participants responded that where the digital and software sector has the potential to deliver positive impacts, it also has environmental consequences and contributes to climate change. Two of these participants also reported that the digital and software sector requires a lot of dedicated efforts, which is currently lacking before it actually starts to impact the global sustainability agenda positively. Among these, 3 of the participants believe that there is excessive advocacy by politicians and global leaders on digital and software technology's benefits for climate change. These participants further elaborated that this advocacy by global leaders and politicians has undermined the negative externalities caused by advanced digital and software technologies. For instance, P-9 stated:

> *"When you look at the overall impact of digital and software technologies, the way it is now happening, even though the world becomes more and more*

> *digital, we have by far not reached the point where we wanted to. Some politicians always talk about new innovations and technologies purely in positive terms that we'll just get climate change solved by itself by employing digital technologies. Unfortunately, it will not solve most of our climate change problems."*

iv) Digital sector takes its own responsibility

According to the views of 5 participants, the digital sector is the only sector that provides the potential to achieve climate action goals of other sectors, while also tackling its own impact on climate change. Three of them further pressed on the topic by stating that the digital and software sectors need to take their own responsibility for delivering sustainability within the sector itself. These participants also believed that leaders of the digital and software industry are keenly aware of the negative impacts of these technologies and must work to strive for delivering environmental sustainability in the sector. Moreover, one of the participants stated that it is the responsibility of developers and designers of digital and software technologies to consider sustainable and green practices while developing these systems.

According to P-1:

> "*Digital and software sector is critical to combating challenges imposed upon by climate change. Of course, all current and discussions of late, are unanimous in how one of the most innovative industries of our time – the digital and software – cannot only help us by supporting our efforts to combat climate change but also to make its own progress and development and innovation environmentally sustainable."*

Summary: Participants in this group believed that digital and software technologies are important in delivering climate benefits and economic development. However, there is awareness of the negative impact of digital and software technologies on climate change. Several participants identified the positive impacts of digitalization on climate and the economy. On the other side, the practical consideration of negative impacts on the environment/climate is comparatively low. Moreover, it is suggested that the digital sector needs to take its own responsibility for emissions reduction and mitigation of negative environmental/climate change impacts.

5.1.2 Disparity among developed and developing countries

This topic was brought up by some of the participants themselves. Five out of 9 participants mentioned that there is a huge disparity between advanced industrialized countries and developing countries. Among these, 3 of the participants also highlighted the need for digital equity and digital access worldwide to harness the benefits offered by digital advancements. For instance, 5 of the participants elaborated that developed economies have practices and standards employed for industries to adhere to sustainable and climate-friendly practices, including the digital and software sector. On the other hand, 4 participants reported, from their work experiences with developing countries, that sustainable and climate-friendly use and development of the digital and software sector is not considered in the developing world. These participants also highlighted that there is a lack of focus and resources in the developing world when it comes to sustainable digital transformation. Interviewee P-3 further pressed on the issue by stating that this gap between developed and developing countries needs to be bridged because climate change is a global crisis, and every country will suffer from it despite their economic standings. According to interviewee P-5:

> *"There are still ways to go before digital and software innovation and its uses and applications actually impact the sustainability agenda, particularly in the huge gap that exists between the advanced industrialized countries and the developing countries. For instance, it is true that the digital and software entities in the US, Canada, Japan, and the EU follow a rather strict environmental protocols but what is, regrettably, also true that there are hardly any protocols in place in countries like China and India, two of the fastest and largest economies in the world. From personal experience, at the highest level, I can tell you that in so many countries there are hardly any efforts in place to make digital and software development sustainable. As long this gap exists – if not widens – digital and software industries will continue to play "catch-up" in dealing with climate change."*

Two of the participants further elaborated on this issue by stating the need for amendments in the trade agreements among countries. For instance, the import/export agreements of digital and software technologies among developed and developing countries should also adhere to sustainable and climate-friendly development standards.

Summary: To conclude, it is identified as important to bridge the disparity between the developed and developing countries regarding digital and software technologies' environmental/climate change impacts considerations. Participants stated that digital access needs to be increased for all countries to attain climate change benefits offered by modern

digitalization. Developing countries should include sustainability and climate considerations while developing digital systems, and the trade agreements between developing and developed countries regarding digital and software technologies should include sustainability as a standard.

5.1.3 Policies and regulations

All 9 participants stated that policy and regulations are critical for green and sustainable software development and for mitigating negative impacts associated with rapid advancements in software innovation and development. This point is further illustrated by interviewee P-6 below:

> *"Policymakers and regulators must work on creating legislations and policies to encourage environmentally sustainable practices in the digital and software sector. It is the resource mobilization and capacity constraints that hinder the implementation of such measures. It is the allocation of resources combined with political will at the policy level that is the key."*

The following sub-sections provide detailed insights into the observations made by participants' responses on the role of policies and regulations. The responses in sections i) ii) and iii) below are the elaborative opinions of the interviewees. These outcomes/topics are brought up by the participants themselves.

i) Gap between policymakers and researchers

Five out of 9 participants stated the gap that exists between policymakers/ regulators and the research community/academia. Three of the participants highlighted that policymakers are not well aware of the software's impact on the environment/climate. However, 2 of the participants stated that there is not sufficient dialogue or a platform between the policymakers and researchers to disseminate knowledge on green and sustainable software innovation and development. Two of the participants further elaborated on the issue by stating that it is the job of academia to bring the topic of green and/or sustainable software development to the attention of knowledge of policymakers and regulators. For instance, P-7 stated:

> *"There's not enough knowledge between the experts to really show like what is the impact if you change from one kind of software to another. So, we should have a more concrete examples before we start talking with politicians. It is*

> *the research community that needs to make the politicians understand otherwise it is definitely not a thing that the politicians would recognise by themselves."*

ii) Public demand required

Four of the participants reported that to push political will towards employment of regulations and policies to promote sustainability software sector, public-centred awareness is required. All these 4 participants believed that it is the public that needs awareness to change the societal discourses and drive the political will to act in the sector of green and sustainable software. This point is illustrated by interviewee P-2 below:

> *"There are some areas of success in both software industry's growth and environmental sustainability, but in neither case are we close to achieving a globally scaled approach to real solutions. That's because the defining aspect of both of these challenges is that they won't be solved by markets. They require political decisions, and political decisions require political will. Not the political will of leaders, because our leaders are mostly followers. It requires societies to decide to act in their interest, in the interest of others on the planet, and in the interest of future generations. That is hard, because it requires public consensus that needs to be built on an understanding of these problems in their mechanistic sense, as well as the development of shared values that these problems are important to address."*

On another side, 2 of the participants also stated that there are various positive elements attached to the use of software technologies which makes its negative impacts more challenging to address. For instance, interviewee P-7 said that considering all the benefits offered by digital and software technologies, regulations and policies can raise the chances of restrictions on the use of advanced technologies. The interviewee further stated that it is one of the reasons that the public might not want these policies and regulations to hinder the way they consume these technologies. Interviewee P-4 stated:

> *"Politician are overwhelmed by short run concerns; only if the public at large will ask for change, politician can follow. So, focus in public research on wide scale dissemination among opinion leaders. This topic has not reached even the level of the weekly additions of major newspapers in the world."*

iii) Requirement for scientific evidence

Six of the participants reported that there is not sufficient scientific evidence on the climate change impact of software innovation and development. These participants further highlighted that to put regulations and policies in any sector and/or bring any topic on political negations/agenda, scientific evidence is required for detailed understanding and to

make informed decisions. According to these participants, clear and transparent data is required to act on the political level regarding the climate change impact of software technologies. Moreover, 3 of the participants highlighted that educational institutes need to bring the topics of sustainable digitalization, and green and sustainable software in the curriculum. Moreover, universities need to fund research to develop more insights into the impact of digital and software technologies on climate change. For instance, interviewee P-5 stated:

> *"There is a need for the education sector, particularly the universities, to be more active in initiating a curriculum as well as sponsored research to raise the awareness of how critical the issue of sustainability is within the digital and software industrial arena and what can be done to make these industries more sustainable. That research, in turn, will enhance the policy debate and decision-making at all levels – public and private sectors."*

Summary: To summarize, policies and regulations have been highlighted by all participants as an important aspect to tackle the environment/climate change impacts of software innovation and development. The gap between the policymakers and researchers hinders in the way of knowledge access and understanding of the software's impact. A common platform for these stakeholders will encourage understanding and awareness about the topic. Moreover, public demands are considered important in policymaking. The enablement of public understanding and demand along with scientific evidence would help bring this topic to the policy agenda and will result in effective policies and regulations.

5.1.4 Role of Global Forums

Eight out of 9 participants agree that global forums like COP and DAVOS are effective forums for discussing green and sustainable software innovation and development to drive sustainable digital transition. According to the opinion of these 8 participants, bringing the discussion of climate change impact of software innovation and development on global forums will stimulate awareness, deliver climate benefits of using software technologies, aid in achieving sustainable development in the sector itself and all other sectors that rely on these technologies. This point is illustrated by interviewee P-3 below:

> *"All credible global forums including COP and DAVOS have been spaces that have resulted in exponential understanding of environmental issues and challenges. I have no doubt, with scientific evidence, debate on software*

> *innovation and development and the resultant environmental impact will bring about the desired results."*

Furthermore, interviewee P-5 stated:

> *"These forums can and must bring to the attention of the global community to understand the importance of supporting institutions that would bring evidence to the table the necessity to enhance funding for institutions that influence policy and decision-making. It is absolutely crucial to develop a green software innovation and development agenda…an agenda that is based on scientific evidence."*

Summary: To summarize, the significance of bringing the topic of software innovation and development's impact on the environment and climate change to the global forum's agenda is supported by the majority of the participants. Hence, it suggests that addressing this topic on global forums will be crucial to attain sustainable benefits of software technologies, and ultimately support sustainable digital transformation.

Table 10: Overall summary of the responses on themes and sub-themes by Group 1

Numbers of themes and sub-themes	**Themes and sub-themes**	**Out of 9 interviewees**		
		Supported by	**Not supported by**	**Not mentioned by**
5.1.1	Digitalization and climate change	9	0	-
i)	Digital and software technologies as an economic driver	6	-	3
ii)	Digital and software technologies delivering climate benefits	8	-	1
iii)	Digital and software technologies as environmentally detrimental	6	-	3
iv)	Digital sector takes its own responsibility	5	-	4
5.1.2	Disparity among developed and developing countries	5	-	4
5.1.3	Policies and regulations	9	0	-
i)	Gap between policymakers and researchers	5	-	4

ii)	Public demand required	4	-	5
iii)	Requirement for scientific evidence	6	-	3
5.1.4	Role of global forums	8	1	-

Table 10 provides the summary of all themes and sub-themes described above from the interview findings of group 1. The table shows the number of participants that supported the topic, not supported the topic, and does not mention anything about the topic.

5.2 Group 2: Researchers

Group 2 entails a set of interview participants including researchers from green/sustainable ICT, digitalization and/or software. Insights from this group of participants are critical to get a snapshot of empirical evidence from existing research on the impact of digital software technologies on climate change, and the importance of discussing, in the global forums, the implication of software on climate change. Table 11 provides the professional roles of interview participants from Group 2.

Table 11: IDs, Roles and Practical Information of Group 2 Participants

Interviewee ID	**Participant role**	**Practical Information**
R-1	Green and sustainable IT	**Years of experience:** 25 years **Roles included:** Consultancy, research, teaching. **Expertise:** Green IT and software engineering
R-2	Sustainable software engineering	**Years of experience:** 5 years **Roles included:** Researcher. **Expertise:** Sustainability in and of software engineering
R-3	Sustainability and ICT	**Years of experience:** 19 years **Roles included:** Programmer, Researcher, Teacher **Expertise:** Sustainability, Human-Computer Interaction, ICT.
R-4	Environmental sustainability of ICT	**Years of experience:** 20 years **Roles included:** Programmer, Researcher, Teacher **Expertise:** Sustainability, Computer science, Environmental impact of ICTs

R-5	ICT for sustainability	**Years of experience:** 18 years **Roles included:** Researcher, Teacher **Expertise:** Sustainability, software engineering, ICT, and software for organizational sustainability.
R-6	Software engineering and sustainability	**Years of experience:** 13 years **Roles included:** Researcher, Teacher **Expertise:** Sustainability, software engineering, energy systems.
R-7	Sustainability and digital transformation	**Years of experience:** 20 years **Roles included:** Researcher, Teacher **Expertise:** Sustainable digitalization, environmental impact of ICTs.
R-8	Green and sustainable digitalization	**Years of experience:** 30 years **Roles included:** Researcher, Teacher **Expertise:** Sustainable information systems, sustainable software engineering
R-9	Environmental sustainability of ICT	**Years of experience:** 16 years **Roles included:** software developer, Researcher. **Expertise:** Sustainability, software development, software processes, software sustainability design and architecture
R-10	Software sustainability	**Years of experience:** 15 years **Roles included:** Designer, developer, Researcher, Teacher **Expertise:** Sustainability, green software engineering

The results from the interviews of group 2 are divided into five main themes and further sub-themes based on thematic analysis of the interview data. The analysis of interview results is presented below:

5.2.1 Digitalization and climate change

Digitalization and climate change relation is mentioned by all 10 participants in this group. The following sub-sections divide the topic of the correlation between digitalization and climate change to provide detailed insights into the observations made by participants' responses. The responses in sections i) ii) and iii) below are elaborative opinions of the interviewees. These outcomes/topics are brought up by the participants themselves.

i) Digital and software technologies as an economic driver

The use of digital technologies is considered a key driver for economies as many industries rely on digital tools to operate. Four of the participants believe that the dominance of economic concerns overshadows the negative environmental impacts caused by the

excessive use of digital technologies. For example, interviewee R-8 said that big companies use digital platforms for marketing which results in more consumption and production in society. Moreover, 3 of the participants reported that digital technologies are developed to push economies and for society to overconsume, which is considered a positive progress in many economies. For example, R-8 said:

> *"Modern digitalization such as AI and whole power of machine learning, this is horrible in a sense that we use the most advanced technology humanity ever developed to motivate society to over consume."*

It is predicted by 4 of the participants that due to the fast pace of digital growth; the environmental footprint of the sector is expected to grow. Whereas one of the participants reported that, despite the digital carbon footprint being more likely to grow, there's a potential for digitalization to reduce carbon emissions from other sectors. However, 2 of the participants reported that the research community needs to build a consensus among themselves and agree on a shared methodology of calculations of the positive and negative effects of ICT. These participants also highlighted that there are different figures and numbers surrounding the positive and negative effects of ICT which makes its impact hard to interpret.

ii) Degrow digitalization

Four of the participants stated that due to the economic benefits offered by deploying digital technologies, its use is largely supported by the capitalist agenda. These 4 participants also believed that economic interests need to be balanced out with environmental concerns, which is possible by degrowth in ICT. According to these participants, the main motive of the development in the digital sector is performance and efficiency gains, which results in excessive consumption and more reliance on digital applications. Three of these participants suggested that the degrowth of the sector can be a possible way to mitigate the negative externalities of digital technologies, as stated by R-5:

> *"There is a lot of techno-optimistic that with digitalization we can solve climate change. But maybe what we have to do is reduce the digitization in some sectors because we are only having some marginal efficiency, which is completely negated by the increase of consumption of digital services and make people rely on more digital services when they don't need. But digital service providers always say that it is much more efficient than before. Yes, but now it demands 1000 more of these services which makes the net effect negative in the end because there's much more energy consumption, etcetera.*

So, we might need to Degrow the ICT sector to gain actual sustainability in the sector."

iii) Digital and software technologies as environmentally detrimental

Digitalization has environmental consequences and negative impacts on climate change. Digitalization's negative impact on environment/climate change is mentioned by 9 out of 10 participants. However, 5 participants stated the negative impacts depending on the type and context of digital technologies. For instance, these participants have mentioned AI, Blockchain, and cloud computing as environmentally detrimental. It is also highlighted that sustainable and green digitalization is an important area of research to combat digitalization's negative impacts and enhance positive effects.

Summary: To summarize, the topic in this sub-theme overlaps with the group 1 topic. However, in this group there is a suggestion to deal with the increasing negative impacts of digital and software technologies is recommended. The degrowth in the digital sector is highlighted by a few participants as an important factor to mitigate climate change impacts of the digital and software sectors. Moreover, digital technologies are identified as environmentally detrimental by the participants. It has been mentioned that digital and software technologies drive economies which is a huge incentive for the negligence of its negative impacts.

5.2.2 Software and climate change

Software innovation and development have a certain environmental impact and contribute to climate change. All 10 participants in this group agree that software has an impact on climate in many ways and needs attention in terms of research and development of green software. Software's climate impact is reported by these participants in 3 ways: energy consumption, use of extensive hardware resources and contribution to carbon emissions. These participants also provided the insights on development of green and sustainable software, such as sustainability considerations during software architecture development, efficient coding, and sustainable design practices. For instance, R-2 stated:

> *"The software aspect of this digital transformation, or digital technologies or digital systems require attention in terms of climate change implications, we need to look at it and to put more effort in research on software's impact on climate change."*

On the other side, 4 of the participants consider software as a part of climate change solutions. For instance, using software to achieve sustainable development goals and using AI applications for climate predictive analysis.

It is also mentioned 5 of the participants that the research community has made a lot of effort in exploring sustainable and green software, and there is data and research available. However, it is also mentioned by 3 of the participants that green and sustainable software engineering and development is considered a new discipline of study. These 3 participants suggested that more research is needed in this domain to acquire open and transparent data about software's impact on the environment and climate. The following sub-sections divide the topic of the correlation between software and climate change to provide detailed insights into the observations made by participants' responses.

The following sub-sections divide the topic of the correlation between software and climate change to provide detailed insights into the observations made by participants' responses. The responses in sections i) and ii) below are the elaborative opinions of the interviewees. These outcomes/topics are brought up by the participants themselves.

i) Context-specific software impacts

The context of the software application means the purpose for which a specific application is developed and in which environment it is deployed, which plays a huge role in software's impact on climate change. This context was specified by the participants themselves. Four of the respondents believe that developing green, sustainable, and energy-efficient software will not work unless its usage scenario is also considered. For instance, R-1 and R-6 further elaborated that the software developers may develop green and energy-efficient software, which consumes less energy and require less computationally intensive hardware to run on. However, if that software application is used to extract more fossil fuels or any other environmentally hazardous scenarios, it will not be a sustainable usage and result in more software-driven negative climate impacts. For further illustration, according to R-1:

> *"For most systems the most important impact is what application does. For example, IT systems for the oil and gas industry. You've got the same sort of software development effort, the same sort of carbon footprint from running it*

> *on servers. But if it enables the development of fossil fuels, the selling of fossil fuels, then that has a very high negative impact on climate."*

ii) Software innovation and development lacks focus on environmental sustainability

It is reported by 5 participants that software innovation and development processes do not consider environmental sustainability as a key requirement. These participants stated that the main concern in software innovation and development is about adding more services to the software application which increases the processing power, due to over functionality. According to these participants, performance and efficiency gains in software applications result in additional complexities and require extensive resources to operate on. To tackle this, 3 of the participants suggested that it may be beneficial to reduce the functionalities and not over-do a software application when it's not necessary. This point is illustrated by R-2:

> *"During software development, more accuracy, and more performance is looked for the most meaning bringing more and more complexity. The question is do we need that much complexity? Maybe that context doesn't require that much complexity, accuracy, and energy consumption and so on. Maybe we can reduce complexity a little and try to have a more efficient use in a way that it matches the purpose of goal of the usage of the software."*

Summary: To summarize, the software's impact on the environment and climate is mentioned by all participants. However, a few of them also stated that software technologies also deliver positive impacts. The environmental and climate change impacts depend on the context in which the software application is used. Moreover, half of the participants believed that the research community have made a lot of progress in identifying the software's impacts on climate and defining the concept of green and sustainable software. A relatively low number of participants think that green and sustainable software is a new discipline, and more research is required. Another perspective presented is that software innovation and development generally have a lack of focus on environmental sustainability.

5.2.3 Role of Global Forums

The importance of bringing to attention the climate change impact of software innovation and development at global forums is reported by 8 out of 10 participants. From those, 5 participants clearly reported that global forums play a role in addressing the software's impact on climate change, whereas 3 gave hesitant responses. All 8 participants believed

that global forums should include the negative climate impact of digital technologies and especially software that drive those technologies. These participants also stated that global forums play a crucial role as it raises concern on the global level and provides a platform for negotiation between various stakeholders on a broader level. Raising this discussion in one of the sessions at global forums can stimulate awareness around the topic and may result in pragmatic measures towards developing green software. This point is illustrated by R-4 opinion:

> *"Global forums are very useful in improving the public attention of an issues. I don't know how they are able to suggest right effective solution. But they are important to make the attention high. And absolutely yes, it is really important to bring digital and software technologies climate change impact on their agenda."*

On the other side, 2 participants believe that global forums are not the most effective place to raise the discussion on the issue of software's climate change impacts. According to these participants, software impact on climate is a minor issue to be discussed on the global forums and it should be discussed by a small group of people, such as within IT forums and/or green and sustainable software engineering community. R-7, for example, believe that:

"In global forums, the political actors gather to resolve wicked issues. The problem of efficiency of software to mitigate its climate impact isn't so much a wicked issue. I don't see the role of policy and regulators in this place. Hence, COP wouldn't be the forum where I would locate this debate. I do believe it's a global issue. I do believe that the knowledge and the practice need to be communicated around the planet. The issue should be discussed between the software engineering community which is also global already."

Summary: To summarize, the significance of bringing the topic of software innovation and development impact on the environment and climate change to the global forums agenda is supported by most of the participants. Moreover, a lower number of views also stated that global forums are not effective platforms to raise the discussion of green and sustainable software because it is a minor issue.

5.2.4 Awareness among all stakeholders

This topic was brought up by some of the participants themselves. Stakeholder awareness is reported by 8 participants as an important aspect related to the climate change impacts of digital, and especially software innovation and development. These 8 participants believed that awareness among all relevant stakeholders is the first and foremost step towards green

digital transition and development of green/sustainable software. The identified stakeholders by these participants include policymakers, researchers, industry, and the public/users. Six participants suggested that one of the ways to raise awareness is to create a platform for open and transparent discussions between all stakeholders. Three of the participants also pressed that green software discourse needs to go beyond academia and a pragmatic approach is required to make a change at a broader level. Nevertheless, 2 of the participants also believe that it is quite challenging for policymakers, researchers, and developers/industry to meet on one platform to exchange the dialogue and accelerate the discussion on green and sustainable software.

Six of the participants believed that raising awareness will urge stakeholders to demand sustainable digital products and services. Moreover, R-1 further elaborated on this point by stating that the industries that buy software systems and services for their business operations, should also set procurement standards for acquiring green and sustainable software.

Summary: To summarize, several participants suggested that awareness among all stakeholders including policymakers, industry, researchers, and users is crucial to implement green and sustainable software knowledge for climate benefits. The awareness among these stakeholders has the potential to stimulate awareness on a global level and urge stakeholders to take action. However, the lack of common platforms for these stakeholders to discuss and negotiate on the topic is a hurdle to addressing the issue.

5.2.5 Policies and regulations

Nine out of 10 participants believed that regulations and policies can play an important role in addressing the negative climate change impact of digital and software innovation. According to 5 of these participants, there is empirical and scientific evidence in research that shows software's negative impacts, such as software degrading the hardware resulting in e-waste, software driving hardware's energy consumption, and software's new versions pushing hardware obsolescence etc. These participants further stated that the aforementioned aspects can be addressed through regulations and policies by putting certain standards for software systems.

However, 3 of the 10 participants believed that green and sustainable software is a new discipline and regulating it would be challenging at this moment. Moreover, these participants further highlighted that due to the fast pace and exponential growth of the digital and software sector, it would be cumbersome for the regulators to understand the dynamics and act in the meantime.

The remaining one of the participants stated that something needs to be concrete to put regulations in place whereas software is intangible and difficult to regulate. This point is illustrated below from R-6's opinion:

> *"It's not clearly understood at the moment, even within software community about the software's impacts, and definitely not within regulations. The technology regulation generally is hard because you need to not only understand the legal side, but also the software or the technology side itself. And some of the technologies are designed to avoid regulation. For instance, blockchain's and its Bitcoin application is a good reference. So, you cannot have a regulation of Bitcoin within a single country by itself. The only way you can regulate it if you do worldwide kind of regulatory framework. So, there should be a lot more regulation than there is."*

The following sub-sections divide the topic of the correlation between software and climate change to provide detailed insights into the observations made by participants' responses. The responses in sections i) and ii) below are elaborative opinions of the interviewees. These outcomes/topics are brought up by the participants themselves.

i) Gap between policymakers and researchers/academia

Knowledge and awareness gap between policymakers and researcher/academia is reported by 6 participants. The participants mentioned the importance of bridging this gap to attain sustainable benefits from digital and software technologies. All these 6 participants stated that it is important to make the policymakers understand and find a common ground to initiate the discussion. Four of the participants believe that it is the responsibility of the research community to raise concerns towards policymakers and help them understand the issue. Three of them further reported that research and data on 'green software and software's impact on climate change' are available, but the research community couldn't disseminate the knowledge to the policymakers. The reason mentioned by all three participants is that the understanding of software's impact on climate is complex and hard to interpret by other stakeholders. This makes it more challenging to find a common ground

for policymakers and researchers to understand cross-sectoral concerns. This point is illustrated by R-8:

> *"I think that the level of reflection in the political world on this digitalization development and its consequences is very low. This is how we, in research, were thinking about maybe 25 years ago. The communication between research and responsible politicians is really lacking. Because it is researchers' responsibility.*
>
> *I don't say that politicians are not responding and considering the issue. That doesn't explain the thing. It's that we as researcher failed to inform policy in a way that they can understand it."*

ii) Public demand required.

Six out of 10 participants stated that the public should demand sustainable and green software services. This narrative is supported by all 6 participants, who stated that the public has the power to force the industry to change their traditional ways of operations and policymakers to act towards regulating digital and software technologies. Two of the participants believed that cultural, attitudinal and value change in society would aid in gaining the desired outcome and bringing the stakeholder on the same ground.

Another perspective presented by interview R-9 is that the way to raise awareness among the public is for companies to develop software in a way that creates awareness. For example, eco-feedback for consumers/users. Two other participants also reported that first software companies need to make a paradigmatic shift and then involve user-centric awareness. These 2 participants believe that change in user behaviour is crucial to attaining long-term positive effects. Interviewee R-5 further elaborated that change in societal and cultural values would be beneficial because it's the society that needs to change and make sustainable decisions.

Summary: To summarize, the majority number of participants agreed that policies and regulations are a way ahead to tackle the environmental and climate impacts of software innovation and development. However, a smaller number of participants also believed that it will be difficult to create policies and regulate the software sector to deliver green and sustainable development because it's a new discipline and needs further understanding. Moreover, the gap between policymakers and researchers is a hindrance in tackling the sector's negative impact. One of the reasons mentioned is the inability of the research community to disseminate the knowledge to policymakers and regulators. Participants also

suggested that public demand and awareness would be beneficial in making policymakers realize the importance of the topic.

Table 12: Summary of the responses on themes and sub-themes by Group 2

Numbers of themes and sub-themes	**Themes and sub-themes**	**Out of 10 interviewees**		
		Supported by	**Not supported by**	**Not mentioned by**
5.2.1	Digitalization and climate change	10	0	0
i)	Digital and software technologies as an economic driver	4	-	6
ii)	Degrow digitalization	4	-	6
iii)	Digital and software technologies as environmentally detrimental	9	-	1
5.2.2	Software and climate change	10	0	0
i)	Context-specific software impacts	4	-	6
ii)	Software innovation and development lacks focus on environmental sustainability.	5	-	5
5.2.3	Role of global forums	8	2	-
5.2.4	Awareness among all stakeholders	8	-	2
5.2.5	Policies and regulations	9	1	-
i)	Gap between policymakers and researchers	6	-	4
ii)	Public demand required	6	-	5

Table 12 provides the summary of all themes and sub-themes described above from the interview findings of group 2. The table shows the number of participants that supported the topic, not supported the topic, and does not mention anything about the topic.

5.3 Summary of overall interview findings:

The results present 6 main themes including both groups. Figure 2 presents the visual representation of all themes and sub-themes identified from both groups. The legend on the right-end corner describes the colour and shape information. The colours represent the themes associated with the group of participants. For instance, the green colour represents group 1 of interview participants i.e., policymakers/government/IGO representatives. We will refer to this in the following text as "policymakers". The blue colour represents group 2 of interview participants i.e., researchers. We will refer to this in the following text as "researchers". The rectangles represent the main themes and rounded-corner rectangles represent the sub-themes. The diamond and circle represent the research questions the themes and sub-themes answer. Following is the summary of the results describing the commonalities and discrepancies between the two groups interviewed.

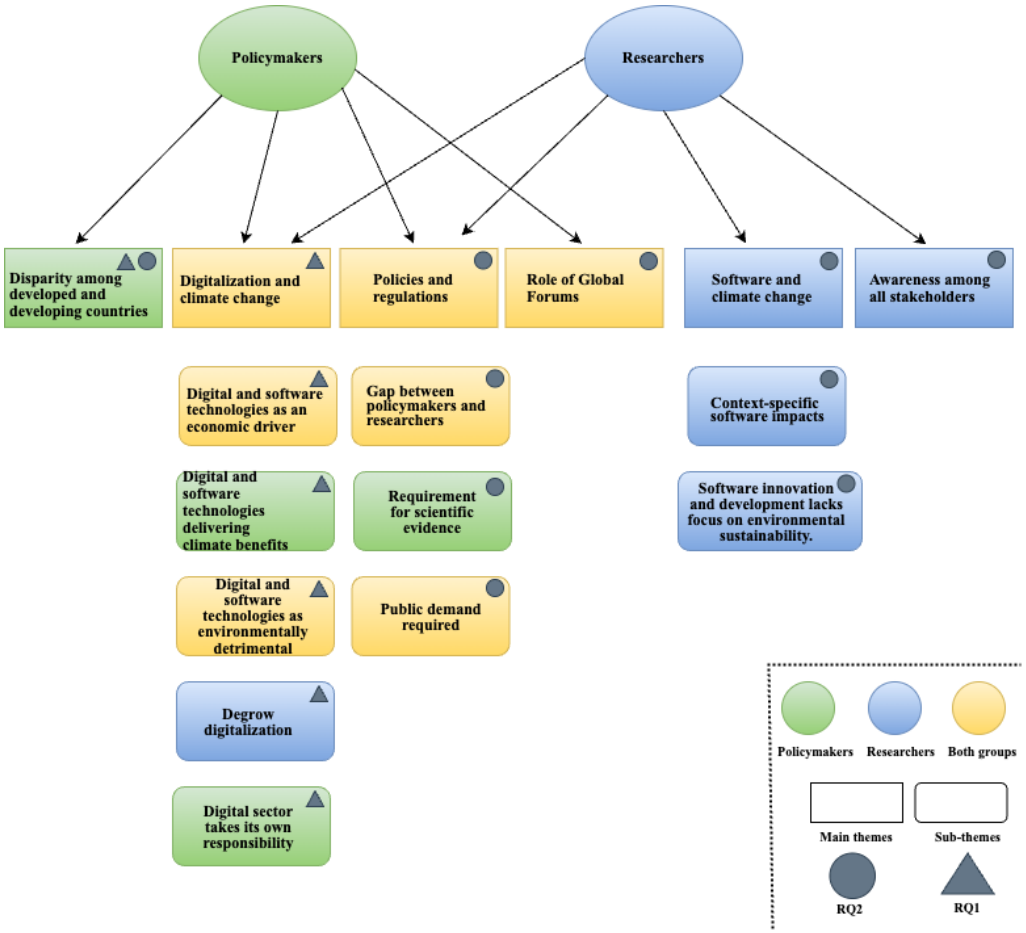

Figure 2: Commonalities and Discrepancies in interview findings from policymakers and researchers

Three of the themes are similar, although they contain some commonalities and discrepancies in the sub-themes. The relationship between digitalization and climate change is identified by both groups of participants. However, policymakers shed light on the benefits of digital and software technologies as well as few of them recognized the negative impacts. On the other side, researchers mainly presented negative impacts. However, 2 researchers mentioned the degrow of the digital sector as a solution to mitigate its negative impacts. Moreover, the importance of policies and regulations is also identified by both groups of participants. Both groups of participants believed that policies and regulations are important to ensure the sustainability of the software sector. Both groups of participants believed that there is a gap between policymakers and researchers which hinders in the way of knowledge dissemination, awareness, and informed decisions. Furthermore, both groups of participants also stated that public demand is required to bring the topic of green and sustainable software to the policy agenda.

Policymakers stated that there is a lack of scientific evidence from research on the environmental and climate change impact of software and emphasized the need for scientific evidence on green and sustainable software. Whereas researchers stated that there is knowledge and scientific evidence available to address the topic on the policy agenda. Another theme is the role of global forums which is mentioned by both participants. Majority number of participants in both groups that software innovation and development-related environmental/climate change impacts should be addressed on global forums.

Moreover, another theme identified in the results of policymakers' interviews is the disparity between developed and developing countries. The participants suggested that the sustainability and green software development efforts are very low in developing countries as compared to developed countries. This gap should be bridged to ensure sustainable benefits for all countries around the world. On the other side, this disparity was not mentioned by the researcher's groups of participants.

There are 2 more themes addressed by the researcher's group. One is software and climate change. All participants in this group stated that there are impacts of software innovation and development on climate change. These impacts are context-specific, meaning depends on the environment and context in which the software application is used. Moreover, the researcher also mentioned that software innovation and development have a lack of focus on environmental sustainability. The impacts of software innovation and development were not

mentioned by policymakers. The other theme is awareness among all stakeholders. The researchers believed that awareness among all stakeholders is the key to achieving the climate and sustainability benefits of software technologies. This aspect has not been addressed or mentioned by policymakers.

6 Discussion

This section discusses the findings of this research and provides a reflection on the results in correspondence with the research questions. The motivation of this thesis research was to develop a better understanding of the role of global forums in leveraging digital and software innovation to address climate change. The study was divided into 2 parts. The first part was to explore the current landscape of efforts by global forums in leveraging digital and software innovation. The second part was to identify the importance of bringing to the global forum's attention the climate change implication of software innovation and development. The research problem was developed into 2 research questions as stated below:

RQ1: What is the state of efforts by global forums in leveraging digital and software innovation to address climate change?

RQ1.1. How do global forums address the positive and negative effects of digital and software technologies on climate change?

RQ1.2. To what extent the global forums are leveraging digital and software innovations to address climate change?

RQ2: What is the significance of addressing the climate change impact of software innovation and development at global forums to make the digital transition sustainable?

The discussion on the research questions is organised in the sub-heading according to the research questions to provide a clear perspective.

6.1 RQ1: What is the state of efforts by global forums in leveraging digital and software innovation to address climate change?

The current efforts by global forums have their focus on the use of digital and software technologies to address climate change, as it is indicated by the findings of the literature review and primary data analysis. The positive impacts and potential of digital and software technologies to address climate change are highlighted by global forums and IGOs, whereas

there is a lack of focus by these forums on the negative impacts of such technologies on the environment\climate. Yet, research has shown clearly that digital technologies are a significant driver of GHG emissions and are unsustainable and environmentally damaging (Junior et al., 2018; WEF, 2020). However, on the other side, global forums and international organisations recognised digital technologies as a potential solution to adapt and mitigate the effects of climate change by reducing the sector's own emissions and helping other sectors achieve their carbon reduction goals (UNFCCC [b], 2016).

The global forum's agenda for climate change does not have the topic of sustainable digital and software technologies or environmental/climate change negative impacts of digital and software technologies. These points of view by two different yet important stakeholders i.e., policymakers and researchers contradict each other, hence failing to produce a clear understanding of the digital sector's contributions towards climate change.

6.1.1 Advocacy on positive impacts of digital and software technologies

Despite the evidence from scientific research on the growing negative impacts of digital technologies, the positive effects are highlighted and promoted by global forums mainly. A report on digital sustainability by (Karlsson et al., n.d.) also states industries need to focus on leveraging positive effects than paying attention to the negative effects as a way forward. However, the history of digitalisation-driven efficiencies shows that industrial emissions have grown continuously despite digital technologies making efficiencies in various sectors. This implies that digitalisation itself cannot make efficiencies unless it is coupled with other efforts and solutions. For instance, to deliver digitalization benefits for climate change and sustainability, digital technologies need to be completely substituted by traditional means of operations instead of being used as an add-on. This aspect is also mentioned by Freitag et al. (2021) in their critical work on ICT-related estimations, trends, and regulations.

One reason observed from the findings of this thesis behind the efforts and advocacy on promoting digital technologies by the global community is economic benefits. This point is mentioned by both groups of participants during interviews that digitalization drive economies and economic concerns overshadow the environmental benefits. This is true that digitalization is delivering economic benefits for countries. For instance, the digital economy accounts for 53.3 trillion US dollars in 2023 which is 50% of the global economy in 2023

(Statista, 2023). But to be sustainable it is important to strike the balance between all three dimensions of sustainability i.e., social, economic, and environmental. However, scientific studies have predicted that digitalization-enabled emissions are expected to grow exponentially if remain neglected. For example, Belkhir et al., (2018) predicted these emissions to grow 14% by 2040. Another study claims that the emissions from information and communications technologies could increase up to 23% of global GHG emissions and could consume 51% of global electricity in 2030 (Andrae et al., 2015). These varying figures make the ICT carbon footprint questionable and the consumption uncertainties high (Enerdata, 2019). It is important to ensure that the use of digital and software technologies is enhanced positively and does not add to climate change.

Another point deduced from the literature review and interview results of policymakers is that global forums present the narrative that the full potential of digital technologies needs to be harnessed to achieve sustainability and climate goals. However, without paying attention to the negative impacts and contributions of GHG by digitalization, the full potential cannot be harnessed. This point is also mentioned in an opinion editorial on COP26 where authors have identified the importance of paying attention to the negative impacts of digital technologies to promote the environmental and climate benefit of these technologies (Dwivedi et al., 2022). The notion presented by global forums that digitalization will save the world from climate change effects is not true. It is also indicated by the recent report *'Digital Reset'* that digital technologies will not solve most of our environmental and climate crises (Lange, 2023). Hence, it is to understand that digital and software technologies will not save the planet from climate crisis without paying concentrating efforts on making digital systems green and tackling the sector's growing negative impacts.

6.1.2 Responsibility of global forums

The forums highlighting the benefits of employing digital technologies for climate change also need to understand that there are negative externalities attached to the use of digital technologies. The results of this study also indicated the point that excessive advocacy of the positive impacts of digital and software technologies by politicians and global forums has overshadowed the negative aspects. The constant promotion by global forums and IGOs on the use of digitalisation may exacerbate the negative impacts. It is the responsibility of

global forums and all IGOs that present digital technologies as climate change solutions, to also shed light on the negative impacts to promote a clear picture for their followers. To further elaborate on this aspect, digitalisation for climate change and sustainability is fostered in most global recommendations and roadmaps for climate change. For instance, whether it is UN Secretary General's *'Roadmap for Digital Cooperation' (*UN, 2020) or UN Secretary General's 'Our Common Agenda' (UN Secretary-General, 2021), the crucial role of digitalisation to achieve climate and sustainable development goals is mentioned. This imperatively encourages UN member states (i.e., governments and firms that are party to the global forums) to invest in the development and deployment of digital technologies (DESA, n.d.) which is highlighted as climate-saviour by global forums. It is important to consider all aspects of the digital phenomenon to ensure that benefits are harnessed without giving rise to negative impacts.

6.1.3 Digital sector's lack of sustainable progress

The window of action is closing and it's time to take a pragmatic approach to deal with the adverse effects of climate change (UNEP [c], 2020). According to the IPCC and UNFCCC, the climate pledges are not ambitious enough to drastically reduce global warming (Maizland, 2022). One of the points from the interview results of policymakers is that the digital sector is taking its own responsibility to tackle its emissions and negative impacts while also delivering positive impacts elsewhere. However, the targets of the digital industry are not ambitious enough to tackle the impacts of climate change (Hoosain et al., 2020). Most innovations in the digital and software sector are not aimed at delivering environmental sustainability either in the sector itself or in other sectors. Digital and software technologies may offer some positive impacts towards dealing with the adverse effects of climate change. But digitalization is not the only major solution. It can only help in accelerating the efforts but cannot fulfil the climate goals by itself (Lange, 2023).

Moreover, it is important to ensure that the development in the digital and software sectors is also green and sustainable. This means the design and development of these technologies along with their lifecycle needs to be green and sustainable. To leverage the positive potential, it is important to think about mitigating the negative otherwise the excessive use of these technologies and their enablement in other sectors may end up in more emissions.

For instance, Freitag et al. (2021) and Dwivedi et al. (2022) have also mentioned that there is no evidence so far of digital technologies delivering the promised positive impacts for climate change and sustainability. Hence, given the dramatic changes digitalization have brought in recent years, it would be an absolute lapse to overlook the negative impact wrecked by these technological advancements (Hoosain et al., 2020).

6.1.4 Climate goals and digital technologies

To achieve the aimed climate targets, a major concentrated effort involving all stakeholders on multilateral levels will be crucial. As indicated in the UN Secretary General's 'Our Common Agenda' that member states need to develop an agreement towards the need for a multilateral approach under the United Nations to combat the present-day challenges (UN Secretary-General, 2021). Given the fact that the world's average temperature will still rise to 2.1 degrees Celsius at the current pace of industrial efforts (Climate Action Tracker, 2019). Even if more than 100 countries that have signed pledges achieve their goals, the temperature will still be 1.8 degrees Celsius (Maizland, 2022). This raises some critical question that *do we as a world can afford another sector (i.e., emerging digital and software sector) to also contribute to climate change by adding more to the CO2 and GHG emissions?* Most policymakers and researchers agreed that the topic of software's impact on climate change should be discussed in global forums. Yet, some of the participants in this research stated that the digital sector's contribution to GHG emissions is very low compared to other sectors which makes the digital sector less important to be looked at in terms of climate change by global forums. However, this raises a concern that *the world should wait for the digital sector's emissions to grow and become a major contributor to climate change to get the attention of the global forums. Or the global forums should start tackling the digitalisation and software technologies' negative climate impacts now before it gets too late?*

Furthermore, digital technologies are at the core of delivering climate solutions as indicated by global forums, IGOs, policymakers and governments around the world. Why UN Sustainable Development Goals agenda is not fully applicable to digital and software technologies? Shouldn't digital and software technologies be a part of SDGs or shouldn't at least any one of the development goals target the digital and software sector for climate

change? Hoosain et al. (2020) mentioned the lack of alignment of digital initiatives with SDGs. Dwivedi et al. (2022) also indicated that the UN SDGs agenda favours merely its own motives. This is a point of concern if digital is to provide so much good *why is there a lack of alignment with the global sustainability agenda? Moreover, why isn't the topic of digital and climate change making its way to the main agenda of these forums and leading organizations? Why research initiatives conducted or funded by these forums and leading organizations are not aimed at gathering data for SDGs to enhance digital and software technologies application?* The lack of data availability to tackle 68% of UN SDG indicators related to the environment is mentioned in the report of the Geneva Environment Network along with the UN Environmental Program (Geneva Environment Network, 2021). The world is more than halfway to the 2030 agenda and still facing a lack of progress and ambition to deal with the climate crisis. Maybe the world needs to shift its focus from relying solely on any new technological interventions and consider both positive and negative aspects in parallel to avoid the major setback later.

6.2 RQ2: What is the significance of addressing the climate change impact of software innovation and development at global forums to make the digital transition sustainable?

According to the findings of this research, the significance of bringing to attention the software innovation and development impacts on climate change to the global forums is resulted as positive. Policymakers from IGOs and governments agree that global forums should address the topic of software-driven environmental and climate change impacts. Moreover, most experts on sustainable and green digitalisation and software, also agree that green and sustainable software is an integral part to achieve sustainable and climate-friendly digitalisation. Hence, tackling software innovation and development-related environmental/climate change implications at global forums is a necessary part to support the sustainable digital transition.

Software is at the core of every digital system and has an impact on the greenness and sustainability of digital systems (Hilty et al. 2015). However, green and sustainable software is not on the global forum's agenda yet neither there is any acknowledgement of the

importance of green and sustainable software development in promoting digitalisation for climate change. However, global forums play a key role in enhancing climate change discussions. Since, software technologies are embedded in many industries, and sectors and have become the key driver of many economies (EC, 2020; Germany, 2023), bringing this topic to the global forum's agenda will result in promoting sustainability in the overall digital environment. The findings of this study also imply that continuous collaboration and partnerships among stakeholders, more research and development along with policy interventions are necessary to ensure that the growth of the software industry is well-aligned with the global climate goals.

6.2.1 Scientific Evidence

The interview results from policymakers presented the narrative that there is not enough research and scientific evidence on the climate change impact of software, which is why it is not brought to the agenda yet. However, it has been almost 2 decades of research on green and sustainable software. Although there is still room for more knowledge development, along with concrete figures and numbers regarding software's climate impacts, there is enough evidence presented by academia on the impact of software on the environment and climate change. One of the arguments in the research findings stated that software is intangible and to consider something's impact on the environment or climate, it must be concrete. However, the research has defined the impacts of software in many ways that are concrete. For instance, software-driven energy consumption, software-driven hardware obsolescence and software-driven e-waste etc (Leboucq, 2017; Kern et al., 2018). The research community has made it clear that software impacts significantly the performance, efficiency, and energy consumption of the digital system. Moreover, the impact does not only lie in the development but also in the lifecycle of the use of software applications (Dick et al, 2013). However, research has also shown that developing software with green and sustainable practices can reduce the environmental and climate change impact of digital technologies (Morisio et al., 2015; Calero et al, 2015). *Even though the software is intangible, it leaves tangible impacts and hence requires tangible measures to reduce its impacts. This evidence alongside many others, holds significant value and presents enough scientific evidence to consider the software's impact on climate and promote green and sustainable software innovation and development.*

6.2.2 Need to bridge the gap between stakeholders

The gap between both stakeholders (i.e., policymakers and researchers) and the lack of awareness for policymakers and global forums on the environmental/climate change impact of software innovation and development is one of the prevalent findings of this research. The reason identified from the results is that software is complex and its impacts on environment/climate change are difficult to comprehend by other stakeholders than software engineering researchers and practitioners. This gap needs to be bridged to avoid misinformation and disinformation on the impact of software innovation and development on environment/climate change.

The findings of this study also imply that continuous collaboration and partnerships among stakeholders, more research and development along with policy interventions are necessary to ensure that the growth of the software industry is well-aligned with the global climate goals. The Global Agenda Council for Sustainability report identified the need for stronger collaborations among policymakers and other stakeholders to build holistic strategies that ensure the long-term benefits of ICTs (WEF, 2013). Bridging the gap will equip policymakers and regulators to understand and find a level-playing field of negotiations to address the issue of software innovation and development's impact on climate change. On the other side, the loose collaborations will be among these stakeholders, and informed decisions on leveraging software systems for climate change will be hard to make. However, to bridge the gap, we need to ensure that there is sufficient knowledge and data to inform policymakers and global forums on the impacts of software technologies.

Academia is one of the major sources of research and knowledge. However, despite the research progress and knowledge development on green and sustainable software, the results show that academia was unsuccessful to raise the topic to the policymakers and global forums. The findings revealed that the climate implications of software innovation and development have not reached policymakers to capture their attention. Further, it is reported that politicians are not well informed on the topics of software innovation and development and its climate change implications. The result of the study also indicates that it is the responsibility of the research community to disseminate the knowledge to policymakers and global leaders. *Climate change is a global issue and digitalisation is global as well*. To achieve the climate action goals and maximize the benefits of digital and software solutions,

it is crucial and of utmost importance to bring together stakeholders from relevant sectors such as policy, industry, government, academia, and civil society to develop a common agenda (Hoosain et al., 2020). *The collaboration among policymakers and researchers/practitioners is also important because one stakeholder has knowledge/expertise and the other has the authority, both need to work together to acquire the maximum benefits of the knowledge implementation. It makes global forums an effective platform to address the issue because it involves all stakeholders and gets together with the global community.*

6.2.3 Inconsistency and lack of consensus in research

The inconsistency in the research and inability of researchers to disseminate the knowledge of green and sustainable software to the global forums and policymakers is also one of the significant findings and presents an important point. The reason deduced from the results is that there are no common platforms for these stakeholders to come together and initiate a dialogue on green and sustainable software innovation and development for a sustainable digital transition. The policymakers, in this study, argue that there is not enough knowledge and scientific evidence on the software's impact on climate change/environment. On the other side, researchers reported that there is knowledge and scientific evidence to initiate the discussion on the software's impact on climate change. Moreover, as previously mentioned, research and knowledge exist for almost 2 decades of research on green and sustainable software. What is missing here is that the knowledge has not been disseminated in the right way to the policymakers. It is the responsibility of the research community to bring this knowledge to the policymakers for informed decision-making. However, the lack of consensus among the research community on the climate impact of digital technologies in terms of emissions makes the scientific evidence and knowledge vague. For instance, Freitag et al., (2021) in their study provide an in-depth understanding of the varying numbers of GHG and/or CO2 emissions of ICTs and several omissions made in ICT emissions calculations. This is also consistent with the findings from interviews of group 2 where the participants emphasized on the research community to build consensus on the digital sectors' emission calculation methodology.

However, more research and transparent data are indeed required to start looking into the possibility of regulating software technologies. Current information, knowledge, and data on the topic of software's impact on environmental sustainability and climate change is fragmented and scattered hinders in the way of informed decision-making (Amsterdam Economic Board, 2022). With more research, the chances of having evidence-based discussions among policymakers and researchers will increase. Moreover, *what is important here is that alongside research there should be consensus and rightful dissemination of knowledge beyond the research community and reach to the right stakeholders.*

6.2.4 Disparity among developed and developing states

One of the important factors which are highlighted by participants during this research is that there is a huge disparity between developing and developed countries regarding green and sustainable software innovation and development. Consideration of green and sustainable software in developing countries is very low even though developing countries develop more software services and systems for developed countries (Kumar, 2017; Clayton, 2023). This point is also stated by group 1 participants. Those participants have worked on global levels with both developed and developing states and reported from their professional experiences, the lack of focus of developing countries on green and sustainable software innovation and development. One of the reasons identified from the results and literature is the lack of awareness and education in developing countries regarding sustainable software engineering and development. (Mishra et al., 2020) mentions in their study that even after dire warnings of global warming and climate change, there are very few education tracks introduced in recent years on green and sustainable topics. The education and awareness initiatives on green or sustainable software either in research or academics mainly exist in Europe followed by a few in the United States and Canada (Calero et al., 2020). *This is important to understand as mentioned earlier that global warming and climate change are a global crisis and every country despite its economic standing will suffer from its effects. This also makes it important for global forums like COP and DAVOS to address the topic of sustainable and green software innovation and development to spread awareness in developing countries as well. As these developing countries are member states of the UN, bringing this aspect in the form of binding agreements and enforcing mechanisms can help*

promote sustainability in one of the fastest-growing sectors around the world (i.e., the digital and software sector).

6.3 Limitations

The limitations of this study are the following:

- Most interview participants in this study belonged to the global north i.e., developed countries. The representation of the global south i.e., developing countries is very low which may have caused the biased in the opinions regarding the issue or may have not provided a holistic view at the global level. The involvement of participants from developing countries would have been beneficial to understand why the disparity exists when it comes to sustainability in digital and software innovation. Since developing countries develop more digital and software solutions, it would have been aided greatly to understand their opinion on the importance of bringing the climate change impact of software innovation and development to global forums. Moreover, developing countries are suffering more from the climate crisis, hence their opinions in this study would have been very instrumental to present a clear picture. The reason behind this underrepresentation of participants from the global south is the lack of access to researchers and policymakers.
- Another limitation of this research is the non-availability of literature on the research topic. Due to the unavailability of related work and existing literature on the research topic, the results and outcomes are discussed in the light of primary data mainly. The topic is novel and should be the focus and prime concern of multilateral organisations, governments, NGOs, academia, and civil society.

6.4 Research Implications

Incorporating the topic of software innovation and development's impact on climate change in the global forum's agenda may have the following implications:

- The discussion in the global forums will stimulate and accelerate awareness. It will bring to the attention of all countries (developed and developing) despite their

economic standings and will create a level playing field for all countries to contribute to the discussion.

- It will create chances for negotiations on amendments in the trade agreements regarding environment/climate change impacts software technologies. The developing countries will adhere to the practices of developing green and sustainable software to improve their trade and economic conditions.

- It will create binding agreements and enforcing mechanisms such as Paris Agreement and Glasgow Pact. The incorporation of an article regarding green and sustainable digital and software technologies in these agreements will enhance sustainable practices in the digital and software sector. Countries and industries to be relevant will need to agree to these agreements and adopt some standards and policies to ensure the green and sustainable digital revolution. It may help in enhancing the digital potential and sustainable value offerings on a global level.

- The agenda presented or promoted by global forums reflects countries' agenda. For instance, UN Sustainable Development Goals are adopted by many countries, and industries as a roadmap. Moreover, countries and industries started to report and accelerate the work on those 17 SDGs. Similarly, UN Secretary *General's 'Roadmap for Digital Cooperation'* and *'Our Common Agenda'* are also adopted by countries and industries as a way forward. So, by bringing green and sustainable software, it would also start to reflect in reporting, contributions, and agendas on all levels.

- These forums have a wide range of topics, themes and sectors related to climate change and sustainability. Since digital and software technologies are revolutionizing various sectors and are interrelated with many of these topics and themes. Addressing this topic in global forums will serve as an effective platform to create synergy with other fields and topics.

- Bringing this topic to the global agenda will stimulate awareness, accelerate the education and training initiatives in the software engineering field, provide more data and transparency when all relevant stakeholders will collaborate, bridge the gap among policymakers and researchers/practitioners, create consensus among global and local players by providing a globally negotiated roadmap/guideline/standard.

- It will also result in specific initiatives to mitigate environmental\climate change implications of software and promote green and sustainable software. This will help in developing a comprehensive understanding of software impacts and provide more data and knowledge for policymakers, governments, and global organizations to take informed decisions.

7 Conclusion

Global Forums have their focus on promoting the use of digital and software technologies for climate change. Global forums have recognised the negative impacts of digital technologies, but the relationship between digital technologies and climate change is not on their agenda. IGOs have mainly mentioned the negative impacts of digital and software technologies. However, there are some discrepancies in the published quantifications of the impacts of digital and software technologies by different IGOs. Moreover, interview results stated that there is also a lack of consensus among researchers in the calculations of the impacts of digital and software technologies. Global forums play a role in leveraging digital and software innovation since they set a global narrative. For instance, the interview findings reported that there is a disparity between developed and developing countries when it comes to addressing the climate change impacts of digital and software technologies. The topics of sustainable digitalization and green/sustainable software engineering mainly exist in developed countries and their representation is very low in developing countries. Since global forums include both countries, they have the potential to raise awareness around the topic across developing countries.

The findings from the literature review and interviews concluded that global forums are essential and play a role in addressing the climate change impact of software innovation and development. However, policymakers also emphasized that scientific evidence is required to bring and address the climate change impacts of software innovation and development at global forums. Policymakers believed that there is not enough knowledge on green and sustainable software yet. However, researchers claimed that there is enough knowledge to address software's impact on climate change in global forums. This also leads to another finding which is the gap between stakeholders i.e., policymakers and researchers. Policymakers, in this study, stated that there is not enough knowledge, and they are unaware of the software's impact on climate change scientific evidence. The bridging of this gap, with researchers taking the lead for rightful and timely knowledge dissemination to policymakers, will be crucial as concluded by the interview results.

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Appendix 1

Interview Questions Group 1: Policymakers, Government and/or IGO Representatives

Section 1: Background Information

- What is your current role in shaping policy related to climate change and the environment?
- How familiar are you with the impact of digitalisation and software innovation on climate change?

Section 2: Climate Change Impact of Digital and Software Innovation

- How does digital and software innovation play a role in mitigating climate change?
- Are you aware of any effect of digitalisation and software innovation on climate change? Which ones?
- Global Climate Change forums, IGOs and environmental NGOs often promote and advocate for the use of digitalisation and software innovation for climate change. Are they also discussing the efforts to make digitalisation and software innovation themselves more sustainable? How common are these efforts, compared to promoting digitalization and software innovation for climate change?
- In your opinion, what role can global forums like COP or DAVOS play in addressing the effects of digitalisation and software innovation on climate change?
- Are there policies, regulations, or guidelines to promote sustainability within digitalisation and software innovation? If so, which ones? If not, what role can policy take with respect to the effects of digitalisation and software innovation on climate change?

Appendix 2

Interview Questions Group 2: Researcher on Sustainable digitalization and/or Green/Sustainable Software Engineering

Section 1: Background Information

- For how many years have you been working with software development?
- Which roles have you played with respect to software development? What is your current role?

Section 2: Software and Climate Change

- What is your perception about the impact of software innovation and development on the climate change?
- Does software aspect of digital technology/systems development require attention in terms of its climate change implications?

Section 3: Climate Change Impact of Digital and Software Innovation

- How does digital and software innovation play a role in mitigating climate change?
- Are you aware of any effect of digitalisation and software innovation on climate change? Which ones?
- Global Climate Change forums, IGOs and environmental NGOs often promote and advocate for the use of digitalisation and software innovation for climate change. Are they also discussing the efforts to make digitalisation and software innovation themselves more sustainable? How common are these efforts, compared to promoting digitalization and software innovation for climate change?
- In your opinion, what role can global forums like COP or DAVOS play in addressing environmental/climate change impact of software and its whole development lifecycle? do you feel this is a good venue to discuss the issue? Why?
- Are there policies, regulations, initiatives and/or guidelines to promote environmentally sustainable software innovation and development? If so, which

ones? If not, what role can policy take with respect to the effects of digitalisation and software innovation on climate change?