# Navigating the Triple Transition: a Holistic Taxonomy toward a Sustainable and Regenerative Digital Transformation.

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***Abstract*—Digitalization and Sustainability emerge as pivotal forces shaping contemporary society. While their convergence presents remarkable prospects, critical challenges and disconnections persist, necessitating a comprehensive exploration. This study addresses a significant gap in the literature by examining the intricate understanding and assessment of sustainable and regenerative digital transformation, currently navigated independently. Society remains unaware to the potential pitfalls associated with digitalization, often presented as a panacea for unrealistic expectations and green hypocrisy narratives. Despite the transformative potential, systematic interdisciplinary efforts in digital transformation with and for sustainability are deficient. This research advocates for a holistic conception of the enabling and systemic impacts of digital paradigms on society and the environment. Taxonomies have proven instrumental in unravelling intricate sustainability aspects, providing structured frameworks for clearer comprehension and categorization. In addressing extant caveats, our study proposes a taxonomy of key dimensions and topics defining digital transformation with sustainability and regeneration lens, to enabling the triple transition (digital, ecological, and socially just). The methodology encompasses: 1) an in-depth literature review and desk research on the convergence of digitalization and sustainability; 2) qualitative analysis supported by text mining and visualization; 3) forthcoming expert elicitation to refine and validate findings. To our best knowledge, this is the first 360-degree taxonomy covering the hallmarks of sustainable and regenerative digital transformation. The results provide a more holistic understanding of this promising nexus between digital transformation and regenerative sustainability for navigating the triple transition and opening hopeful future research and policy avenues.**

***Keywords— Digital Transformation, Regenerative Sustainability, Taxonomy, Sustainable Development Goals (SDGs), Impact Assessment, Triple Transition.***

## I. INTRODUCTION

Digitalization and sustainability arise as companions on the journey towards a greener, flourishing, and socially just future, serving as transformative forces for challenging conventional economic and societal models. Indeed, digital technologies have permeated and revolutionized all aspects of life, blending digital and physical worlds to create novel realities. Understanding the dynamics and impacts of digital transformation (DT) on social and environmental realms becomes imperative, necessitating science-based tools for optimal articulation of the nexus between digitalization and sustainability. Despite growing interest, the convergence between these realms remains opaque, characterized by utopian narratives and a lack of scientific substantiation. The breach between sustainability and digital disciplines, coupled with a limited awareness of the impacts of novel paradigms, further complicates the landscape. Defying transformations against the status quo requires concerted efforts involving all stakeholders and a clear roadmap. Besides, economic growth continues to strain the environment, prompting the need for a holistic approach outlined in the UN 2030 Agenda for sustainable development (SD). However, understanding sustainable digitalization and translating this vision into reality faces challenges due to unclearly defined drivers and means. Sustainability itself is undergoing an identity crisis, requiring a systemic approach for credibility. While digitalization is recognized as pivotal for achieving the Sustainable Development Goals (SDGs), a comprehensive framework and practical tools for responsible implementation are lacking [1].

The current 2030 Agenda presents DT in an incomplete and fragmented manner, ignoring ecological and social impacts. The call for a triple transition – digital, ecological, and socially fair – has not been fully integrated into the SDGs or digital strategies. Hence, breaking down silos between disciplines and fostering convergence is emphasized as crucial for achieving SD.

In the dynamic debate on the digital-sustainability nexus, optimistic, cautionary, and pessimistic perspectives arise, including considerations of both utopian and dystopian visions [2]. Bremer [3] stress the need for stakeholder

involvement, multidisciplinary approaches, improved measurement methodologies, robust data provision, and enhanced use of standards to address uncertain digital impacts. Within the nexus, we identify significant challenges, such as fragmentation and inadequacy of existing frameworks, disconnection between digital and sustainability agendas, breaches between disciplines and stakeholders, limited understanding of phenomena, and insufficient awareness about the digital impacts on sustainability. Extant frameworks lack comprehensive coverage, necessitating a collective understanding of sustainable digitalization, along with robust metrics. Addressing these caveats is imperative for advancing a more informed discourse on the relationship between digitalization and sustainability. The call for a paradigm shift is central, emphasizing the need to bridge divides and adopt a convergence-based approach that melds digital and environmental perspectives for sustainability [4]. Our research echoes this call, advocating for comprehensive reforms to seamlessly integrate sustainability into digital strategies and promote regenerative approaches.

Venturing beyond conventional paradigms, we explore novel sustainability concepts like the triple transition, degrowth, and regeneration. We also encourage to evolving sustainability and Environmental, Social and Governance (ESG) frameworks to adapt to changing realities. Anticipating emerging frameworks, we grapple with the challenge of enhancing measurement and monitoring tools. Our exploration extends to alternative pathways for integrating digitalization within the 2030 Agenda and future post-agenda, contributing to the ongoing debates. Finally, we advocate for pursuing a **Sustainable and Regenerative Digital Transformation (SRDT)**, which aims not only to mitigate negative impacts but also to leverage positive contributions for people and the planet. To tackle these challenges, a preliminary understanding of the key dimensions and topics defining SRDT is emphasized, which requires a multidisciplinary and "pluriversial" approach. In our concluding reflections, we synthesize insights, define future directions, and offer recommendations. Hence, the primary objective of this research is to unravel caveats and controversies in current narratives of DT, providing insights and practical tools to deal with them.

The pivotal research questions guiding this study are delineated as follows:

*RQ1 - What key dimensions and features define a robust framework for sustainable and regenerative digital transformation?*
*RQ2 - How can sustainability and digitalization converge to create a comprehensive framework that promotes and measures sustainable digitalization effectively?*

Recognizing the identified gaps, we undertake the following activities:

• Comprehensive literature review and desk research on DT and sustainability frameworks to identify the main dimensions and features that characterize their intersection.
• Development of a Taxonomy outlining the key dimensions and features encapsulating the nexus SRDT, supported by text mining and visualization techniques, along with forthcoming expert elicitation.

The article adopts a structured organization, starting with an introduction, the background on the topic is provided to contextualize the study. Subsequently, the research methods section unfolds. The subsequent sections present the research findings. This narrative approach guides the audience through the study, presenting arguments that substantiate the proposed insights and practical tools. The ensuing critical analysis examines the main revelations and their implications. The article culminates with a conclusion, underscoring its contribution to the current research landscape and outlining promising avenues for future research endeavours.

## II. METHODS

This research employs a robust methodology combining diverse techniques and unfolding in distinct phases to examine the relationship between digital transformation (DT) and sustainability (see Table 1 and Table 2).

The initial stage involves an extensive scientific literature review using Scopus, Web of Science, and Google Scholar, combined with desktop research, mapping existing frameworks associated with the assessment of DT, sustainability, and their convergence. Given that scientific frameworks often do not fully reflect the progress of digital transformation [5], grey literature and the most relevant reports from international organizations, practitioners and regulators were considered. From 346 documents examined, 155 were selected for an in-depth analysis. A qualitative analysis, supported by text mining and visualization techniques, was conducted on this corpus.

The second stage involved identifying relevant dimensions and topics of DT and sustainability by using topic modelling, keyword extraction, clustering, and trend visualization. We developed a taxonomy to characterize sustainable and regenerative digitalization dimensions and topics using a hybrid approach that combines manual and automatic methods. Furthermore, this framework is currently undergoing further refinement and will be validated through expert elicitation. Ultimately, the findings will inform the development of a Report Card [17], serving as a monitoring tool in the subsequent stage of the research (forthcoming).

TABLE 1. Overview of the research approach followed.

| | |
|---|---|
| **Framework Review:** *(desktop research and literature review)* | • Review of pertinent scientific literature in Scopus, Web of Science, Google Scholar.<br>• Review of relevant grey literature frameworks through desktop research (346).<br>• Mapping of key measurement frameworks for DT and SD.<br>*N.B. Publication years: 1995-2023; Scale: micro, meso, macro; Coverage: worldwide, regional; Main Language: English; Keywords: combinations of sustainability, environmental, social, ethics, ecological, regeneration, SDGs, digital transformation, digitalization, assessment, monitoring, impact, measurement, indicators, metrics, index.* |
| **Corpus Creation** | Selection of the most relevant frameworks for creating the corpus of the study |
| **Comprehensive Analysis** | • Qualitative analysis of dimensions and metrics from the selected frameworks (155).<br>• Text Mining of the corpus combining diverse techniques: Topic Modelling (Latent Dirichlet Allocation, LDAvis); Keyword extraction (TF-IDF Term Frequency-Inverse Document Frequency, mBERT); Document/Word Embedding (FastText); Network Exploration; Clusterization.<br>• Clustering of documents by key themes<br>• Analysis and visualization of document clusters in the corpus using Voyant Tools. |

| | |
|---|---|
| **Design of the framework** | • Rationale and logic definition.<br>• Identification and classification of key dimension, subdimensions and features.<br>• Formulation of the Taxonomy. |
| **Refinement and validation** *(underway)* | • Expert Elicitation: survey and semi-structure interviews.<br>• Subsequent qualitative analysis and quantitative statistical analysis.<br>• Refinement and validation of the Taxonomy classification. |
| **Report Card** *(forthcoming)* | • Selection of the most relevant topics and related metrics for a Report Card (monitoring and awareness framework). |

TABLE 2. Methodology Pathway Components and References

| Methodology Component | References |
|---|---|
| **Literature Review** | [6] Vom Brocke et al. (2015). |
| **Desk Research & Framework Selection** | [5] Lai et al. (2022); [7] CISL (2022); [8] Mohamad et al. (2023); |
| **Qualitative Analysis** | [9] Saldaña (2013); [8] Mohamad et al. (2023). |
| **Taxonomy Development** | [10] Nickerson et al. (2013); [11] Hermman et al. (2023); [8] Mohamad et al. (2023). |
| **Text Mining and Topic Modelling Techniques** | [12] LDA (Silge and Robinson, 2017); [13] LDAvis (Sievert et al., 2014); [14] FastTEXT (Grave et al., 2018). |
| **Text Visualization** | [15] Sinclair, Stéfan, and Geoffrey Rockwell (2016); [16] Gregory et al. (2022) |
| **Report Card Framework** | [17] Carter et al. (2023) |

## III. REVIEW INSIGHTS

Our research encapsulates key core ideas to illuminate the intricate relationship between digital transformation and sustainability and delve into the repercussions of existing limitations in the pursuit of SRDT. We scrutinize impacts and controversies of digitalization, unveiling the inadequacy of extant assessment frameworks, the divides amid disciplines, the emergence of green hypocrisy, along with the unreal perceptions, including techno-utopias and illusions of dematerialization, which are critically examined.

Emphasizing the need to bridge such caveats and divides, our research advocates for a digital orientation for sustainability [4], aligning with the pluriverse paradigm beyond disciplinary boundaries, for inclusivity and systemic mindset. We discuss he imperative evolution towards regenerative sustainability (RS), anticipating the impact of novel trends. The challenge of enhancing assessment and measurement frameworks for SRDT is acknowledged, contributing to the ongoing debate on paths for improving the 2030 Agenda and upcoming post-agenda. These core ideas offer nuanced insights into the complex interplay between DT and sustainability, guiding current and future research and practical applications in the pursuit of a sustainable future.

### *A. Overview of the sustainability and digitalization caveats*

The future trajectory of digitalization is critical for global development, necessitating alignment with the 2030 Agenda's values and the sustainability trends, such as regeneration. Certainly, DT presents vast opportunities for advancing regenerative sustainability, fostering positive change in both nature and society.

Besides, DT offers new data, capabilities, and communities that could address complex sustainability challenges and promote positive outcomes for people and the planet [18], [19]. As argued by [18] numerous initiatives demonstrated the power of DT in protecting nature, tracking poverty, enhancing urban landscapes, and contributing to climate education (e.g. AI4Good, UN Global Pulse Labs, GeSi, DataPop Alliance, ITU SDG Acceleration Agenda). Pioneering studies emphasize the need for regenerative design, innovation, and democratic participatory processes focused on renewing natural ecosystems and promoting social cohesion [20], [21]. Nevertheless, despite its potential, the regenerative philosophy has not fully embedded the digital realm, with scarce and fragmented literature, and limited understanding of sustainability trends. Better integration regeneration within DT is essential [22].

Furthermore, regarding DT measurement, existing governance structures fall short in capturing the multifaceted dimensions of such transformation, rising controversies and lively ethical debates. The absence of a comprehensive taxonomy of SRDT, integrated impact assessment tools, metrics, together with the divide amid disciplines, underscores the need for novel perspectives. The environmental “net impact” of DT, particularly in Artificial Intelligence (AI) and Quantum Technologies remains uncertain. Understanding the social impacts is even more intricate, with incomplete clarity on how DT either promote inclusion and well-being or exacerbate divides. Moreover, a thorough comprehension of the interplay between DT and responsible governance is essential, but current frameworks necessitate evolution for tackling regenerative development. Despite initial explorations, SRDT lacks standardization, with shattered literature along with open debates, and contradictions. Ongoing research is crucial to shape the field.

In parallel, the landscape of sustainability is suffering a severe erosion of trust. [23] critique the misunderstanding of the sustainability concept, leading to "green hypocrisy" and propose its rehabilitation based on systemic thinking on the interdependence of ecological, social, and economic factors. Wiek et al. [24] stress the importance of collaboration and transformative change for bridging gaps between science and society. Samuel et al. [25] identify the ambiguity of sustainability, cautioning against equating it with ESG aspects. The literature acknowledges the deficiency in conceptual frameworks and the insufficient understanding of the complexities of sustainability.

Bremer et al. [3] underscore the vast and uncertain digital impacts, both positive and negative, with highly fragmented studies providing divergent results. They also advocate for active involvement of all stakeholders, together with improved measurement methodologies, robust data, and standards. Indeed, a multidisciplinary approach is deemed essential to address systemic impacts. As elucidated by Becker [26], society navigates a landscape shaped by opaque algorithms, subtly nudging humanity towards misinformation and unsustainable consumerism. DT appears to be “insolvent” to the ideals of sustainability, urging a paradigm shift. Pérez-Martínez et al. [27] underline controversies regarding the actual potential of DT to mitigate climate change, with

believers in favour and detractors against. Furthermore, positive environmental benefits to decarbonize may be offset by rebound effects and growing consumption [28][29]. So far, DT has not been able to decouple economic growth and environmental damage, and its impact remains unclear due to its multivariable nature [27].

Besides, the literature falls short in covering indirect effects, spillovers, and changes in human behaviour [30]. Diverse perspectives influence the nexus between DT and SD depending on the stakeholder [31]. Verhoef et al. [32] outline DT impact on organizations, individuals, and society. [25] caution against a "carbo-centric" approach and advocate for a broader ethos of sustainability. [33] explore hidden environmental impacts of AI through a Life Cycle Assessment (LCA), emphasizing the need for a comprehensive taxonomy. In the challenging realm of AI impacts, [34] underline the substantial environmental footprint and introduce the concept of carbon lock-in, while [35] support the integration of sustainability into AI discourse. [36] expands the discussion to intergenerational justice. Additionally, [37] proposes a framework aligning AI impacts with SDGs, and [38] stress societal and ethical implications of rapid AI integration. [39] suggest a comprehensive approach to AI ethics, and [40] highlight AI's transformative impact on societal and environmental aspects. DT, as a transformative force resolving global environmental challenges, is challenged due to indirect rebound effects [30], while [41] highlight the controversies on the impact of digital and environmental orientations on innovation.

Moreover, the prevalence of greenwashing, or preferably “green hypocrisy” (meaning the widespread of deceptive environmental claims [42]), has garnered significant attention due to its detrimental impact on sustainability. The digital domain exhibits high prevalence of greenwashing and parallel deceptive practices, such as "machine washing” or “ethics washing” [43]. The "decoupling" phenomenon is particularly noted in the digital realm, where organizations disclose information for legitimacy without genuine sustainability efforts harming society [44],[45],[46], and leading to customer distrust [47]. Machine-washing, coined by Wagner [48], is a deceptive strategy in AI and algorithms, fabricating an illusory façade of positive change, evading scrutiny, and potentially influencing regulations [49]. The "ethification of ICT governance" is analysed by [50], while [51] emphasized the proliferation of non-genuine ethics and misleading “responsible principles”.

Scholars stress the importance of genuine corporate social responsibility, regulation, standards, transparency, and penalties for misinformation [46],[52],[53]. Thus far, regulation efforts [54] (e.g. EU Green Claims Directive) are perceived as insufficient. Nevertheless, even governmental organizations and regulators are criticized for deceptive claims [55] and hidden agendas influenced by big corporations. Unexpectedly, the rise of ESG reporting obligations raise concerns due to greenwashing practices [56]. [57] highlight challenges in resisting digital pressures across various domains introducing the concept 'digital disengagement'. Navigating the complexities of green/ethics hypocrisy for assessing green claims [58] with sustainability-oriented innovation has been proposed [59], but further advances are needed. Amidst this debate, there is an urgent need to cultivate novel imaginaries that steer digitalization towards a genuinely sustainable trajectory. Pansera et al. [60] raise concerns about the alignment of digitalization with degrowth principles and democracy, while [61] advocate for interdisciplinary collaboration and a 'pluriversial' conceptualizing degrowth as a radical niche innovation. [24] emphasize a shift towards transformational science through stakeholder collaboration, while [62] stress the significance of interdisciplinary for tackling complex impacts of DT.

Moreover, [63] explore connections between cooperation and eco-innovation. [64] delve into the nexus between lean practices, green initiatives, and sustainability-oriented innovation. Haklay et al. [65] promote the co-creation of digital tools fostering a pluriverse of pathways to the future. The triple planetary crisis, demanding a decoupling of economic growth from resource consumption, is also acknowledged. Elkington [66], [67], [68] propose transformative frameworks and complex systems thinking for a sustainable future. [69] analyse synergies and trade-offs in the triple transition, while [70] highlight the need for synchronizing green and digital transitions. Caro Gonzalez et al. [71] also advocate for a 'triple transition' approach guided by eco-centric and systemic principles. A shift towards regeneration is proposed as a “net-positive,” stakeholder-centric ethos [20]. [72] establish foundational pillars for regenerative design, while [73] encourage a purpose-driven approach for the convergence of digitalization and the regeneration paradigm. Besides, [74] links the circular economy to restoration and regeneration.

The literature also reveals a gap in understanding change management pathways for a sustainable DT [75], based on responsible leadership, effective communication, and inclusion [76]. Ambidexterity is identified as crucial for navigating DT [77], promoting the coexistence of exploration and exploitation [78].

Regarding the integration of SDGs into digital initiatives, [79] underscore the risks of decoupling DT and sustainability, while [80] and [81] emphasize the imperative and the challenges of such "dual transformation." However, previous research has exposed the caveats of the 2030 Agenda regarding the integration of potential digital impacts [18]. We anticipate novel efforts, such as the underway Global Digital Compact (GDC) [82], which aims to establish an effective governance of the DT, analogous to the Global Compact for sustainability. However, the integration of sustainability in the GDC process has been criticized [83].

Thus, our research underscores a salient disconnection and the importance of understanding interlinkages and co-dependencies between DT and SD strategies to decoupling human well-being from adverse consequences.

### *B. Gaps of frameworks for assessing digital and sustainabilitytransformations*

Evaluating impact requires assessing transformative changes in both scalability and depth among beneficiaries. When addressing DT, RS and SD, two significant breaches are evidenced: a salient divide between environmental and digital spheres, along with a divide between social and environmental domains. Addressing these disparities calls for a more integrated approach that harmonizes the interconnections between these dimensions.

*B.1 Digital Transformation Frameworks*

Vial et al. [84] define DT as a disruptive process prompting strategic responses from organizations, extending to "Sustainable Digital Transformation" within the planetary and social boundaries. Certainly, literature and practice characterize DT as inherently disruptive, impacting behaviour, reshaping business models, and bringing novel actors. Our review exposes challenges in extant frameworks for governing and assessing DT, namely: fragmentation, lack of definition and awareness, absence of approaches for comprehensively assessing sustainability and ethical impacts [84], [85]. International organisations and prestigious institutions (e.g., OECD, UN Agencies, the World Bank, WEF, the European Commission) have provided a plethora of frameworks for measuring socioeconomic DT impacts. For instance, the EC's Digital Economy and Society (DESI) Index [86], the OECD reports on measuring DT [87], among others. However, caveats persist in finding a more holistic perspective of DT by integrating regenerative sustainability. Moreover, scholars caution against extant naive views and divergent opinions on the challenges around sustainable digitalization [88], [3], [18], [26]. While recognizing outstanding benefits of DT, our review stresses the need for comprehensive, dynamic, and regenerative perspectives, agile governance, and leadership, along with a paradigm shift from a static to a dynamic vision of the triple transition.

The literature highlights significant shortcomings regarding metrics for measuring the impact of DT on sustainability. [89]. Scholars emphasize the inadequacy of current indicators and methods, which often focus solely on either the "information society" or sustainability, overlooking their interconnected dynamics [90]. There is a call for a robust set of metrics that address the ecological, social, and institutional implications of digital solutions on sustainability [22], along with lean and reliable methodologies to navigate complexities effectively [91]. Additionally, relevant organizational performance metrics are also lacking [92]. Experts suggest the development of an index combining ICT adoption with sustainability [93], and the prioritization of sustainability in methodologies and indicators [94]. Novel quantifiable indicators are essential for DT in regenerative design [20]. Furthermore, we evidence that the measurement frameworks lag behind the rapid changes in digital and sustainability phenomena, resulting in an incomplete reflection of societal and environmental disruptions.

Taylor [95] and [91] also underscore methodological challenges in measuring societal aspects like the digital divide, due to their intangible nature. International organizations like ITU and OECD have developed integrated models to include the social context, but indicators exhibit weaknesses, conceptual imprecision, and measurement issues. Policy interventions are recommended to guide DT towards positive societal impacts, encouraging inclusive participation and risk mitigation. For instance, the EC put forth in 2021 the "Digital Decade" communication [96], emphasizing a human-centred, sustainable digital future. Yet, so far, policies or principles remain as unfulfilled promises. Nevertheless, there is hope in the promising work of novel alliances such as CODES [97], which brings together stakeholders to unify efforts in the fragmented landscape to promote environmental sustainability in DT.

Furthermore, we ascertain a divide between social and environmental domains, urging more integrated approaches and further dialogue amid disciplines. For instance, the Human Development Index (HDI) has been criticized for neglecting the environmental dimension, rewarding major polluters based solely on income. Hickel [98] and [99] argue that narrow social approaches (e.g., improved HDI) may fall short of planetary boundaries and claim for stronger approaches. Certainly, studies evidence that prioritizing development solely with socioeconomic lens and dismissing connection to biophysical systems, has led to adverse environmental effects, contributing to biodiversity loss, ecosystem damage, and climate change [27], [100], [101]. Gupta et al. [102] and [103] advocate for integrating environmental targets with justice considerations, emphasizing the interconnectedness of social and ecological issues for successful transformation.

Qualitative assessment approaches like the "Sustainability Awareness Framework (SUSAF)" or "Corporate Digital Responsibility (CDR)", while intriguing, also have limitations. They lack comprehensiveness and robustness to fully covered DT impacts on RS, particularly regarding complex intangible aspects beyond organizational boundaries. SUSAF is highly subjective and relies heavily on the analyst's sustainability expertise [104], often limited in ICTs. CDR lacks a consensus definition for digital responsibility and focuses on the corporate sphere. Both lack indicators for objective evaluation [105],[106].

We argue that collaborative and multidisciplinary efforts to integrate social and planetary boundaries are essential for realising a triple transition. Nonetheless, the literature still ignores that DT is neither a cure-all nor a lineal phenomenon but entails complex societal changes. Thus, governance challenges in digital ecosystems demand an inclusive approach combining top-down and bottom-up inputs from all relevant stakeholders and contexts. Glocal networks and helix ecosystems [107] could create the atmosphere for the convergence towards the triple transition. A full adaptation of institutions to the decentralized nature of DT is crucial for intergenerational success and knowledge exchange.

Hence, our review shows significant gaps in literature with dispersed and fragmented studies, unsuitable assessment frameworks and lacking metrics, failing to fully incorporate sustainability and regeneration systematically, which in our view, contribute to the deficient awareness about DT and RS impacts. Thus, research calls for comprehensive, integrated, and mindful approaches, broader measurement scope, institutional reforms, along with tools for navigating the complex interplay between DT, RS, and societal changes.

*B.2 Sustainability Frameworks*

The sustainability domain boasts a rich tradition of frameworks to assess economic, governance, social, and environmental impacts across sectors, including principles (e.g. IFC), indices and indicators (e.g. Global Sustainable Competitiveness Index, SDG Index, EPI Index), standards (e.g. GRI, SASB), along with ratings and benchmarks (e.g. MSCI). However, they also evidence gaps in meso-level coverage, present dominance of summative approaches [7] and weak integration of DT. We also found a significant gap

in the coverage of regenerative approaches, even in advanced frames for circularity (e.g. EAP, WBCSD).

Furthermore, we discovered that environmental frameworks exhibit stronger alignment with social aspects than social frameworks with ecological issues. Notable frameworks, like GSCI [108], EAP indicators [109] emphasize planetary boundaries and human well-being but lack coverage of digital aspects. The CISL Index [7] introduces nuanced metrics for competitive sustainability including digital elements, but the ecological focus is weak, based on resource productivity. Additionally, the [110] MSCI "Sustainable Impact Metrics Taxonomy" covers environmental and social impacts, with the "empowerment dimension" addressing connectivity and digital divide. The [111] MSCI ACWI IMI "Sharing Economy Index" comprises companies fostering a circular transition, spanning sharing economy, smart mobility, e-commerce, social media, digital payments, among others.

The notion of "Double Dynamic Materiality" [112] with support of AI analytics underscore the need for a holistic perspective in assessing the evolving landscape of ESG factors amidst ongoing controversies and trade-offs, which could be useful in the DT realm.

Therefore, we conclude that the expected environmental benefits of digitalization, particularly in dematerialization, efficiency and decarbonization, have not materialized as expected. Besides, regenerative aspects are merely testimonial. The perceived positive effects on material consumption and carbon emissions may be offset by complex factors, indirect rebound effects or spillovers not included in current measurement frameworks. Thus, the net contribution of DT necessitates a critical reassessment with enhanced frameworks able to scrutiny dynamically the intricate and evolving dynamics of SRDT. We contend that, despite the diversity of frameworks and progress made, there exists no comprehensive framework addressing all dimensions of SRDT in an integrated manner and across all relevant scales. Consequently, our research will provide insights and tools for better understanding and bridging some of these gaps.

### *C. The relevance of Taxonomies.*

Formulating taxonomies in the intersection of sustainability and digitalization is significant. A taxonomy is defined as a scientific process of classifying things based on shared qualities for organizing entities. Initially exclusive to biology, taxonomies now extend to categorizing various concepts and phenomena. They have become crucial tools in environmental monitoring, offering structured frameworks for classification and governance, thereby enhancing understanding and informed decision-making. They are useful in classifying circularity indicators [113], and sustainable finance activities (e.g., EU Green Taxonomy), enhancing accountability [114]. In the realm of digital innovation, taxonomies, though more recent, also aid in understanding projects [11], classifying AI approaches in Industry 4.0 [115], aligning methods in knowledge organization systems for objects [10], open government data [8], and smart mobility services.

Drawing from existing literature, our research proposes that the intersection of sustainability and digitalization can significantly benefit from taxonomies as structured classification systems, contributing to enhanced understanding and governance. Notably, the academic literature has yet to provide a taxonomy in this context, making our contribution relevant and novel.

## IV. FINDINGS.

### *A. Overview of findings*

After an exhaustive examination of the most relevant frameworks pertaining to DT, sustainability, and their convergence, key insights have emerged. Our study revealed that 60% of DT frameworks overlook sustainability, with only 25% explicitly designed to address sustainability aspects. In the sustainability-focused frameworks, 20% concentrate on climate, 40% on general environmental considerations, and others touch on various dimensions. Frameworks primarily target the macro scale (global or European), with limited representation at the meso (sectorial) and micro (ESG standards, circular indicators) levels (see table 3). Most indices (94%) are global, but lack diverse representation, from the Global South. Hence, a critical gap exists in the literature, highlighting the disconnect between social and environmental priorities. Despite some inclusion of social dimensions in DT frameworks, their interconnectedness with environmental aspects is often overlooked. Our study emphasizes the urgent need for a more comprehensive approach to address the invisible nexus between digital and sustainability transitions in policy and research agendas.

TABLE 3. Overview of Digital Transformation and Sustainability extant frameworks across the micro, meso, and macro scales.

| Scale | Digital Transformation | Sustainability | Sustainable Digital Transformation |
|---|---|---|---|
| MACRO | STRONG | STRONG | WEAK |
| MESO | MODERATE | MODERATE | VERY WEAK |
| MICRO | MODERATE | STRONG | VERY WEAK |

### *B.Taxonomy development*

Our Taxonomy underscores the significance of the classification system in bringing together the realms of digital and sustainability transitions. It lays groundwork for future theoretical, practical, and policy advancements, offering a conceptual foundation to navigate this evolving landscape.

Encompassing 6 principal dimensions, further dissected into 46 subdimensions and 255 topics, our taxonomy reflects a comprehensive approach, a fusion of conceptual and empirical insights, derived from a meticulously structured literature review [8], [11]. Aligned with current literature, our taxonomy adopts a more holistic, up-to-date perspective, since it captures the essence of the ongoing evolution toward the Triple Transition and regeneration concept. It outlines a DT designed not only to minimize potential negative impacts, but also to actively promote positive societal and environmental opportunities. Its primary goal is to provide prospects to revitalize, restore, and regenerate nature and society. In essence, the framework embodies the principle of regenerative sustainability, pursuing a positive contribution for both people and planet.

The taxonomy's primary dimensions are rooted in the five key pillars of the SD 2030 Agenda: people (social dimension), prosperity (socioeconomic dimension), planetary sustainability (environmental dimension), peace (governance dimension), and partnerships (cooperation). This alignment ensures coherence with global sustainability objectives. Additionally, we introduce a sixth dimension centred on preparedness, since it is acknowledged in literature as a

cornerstone for successful DT transformation [116]. These dimensions encompass various aspects crucial for navigating the triple transition landscape (see Table 4).

Given the complex and interconnected nature of this realm, certain topics may span multiple dimensions Therefore, we position them where they exhibit the greatest affinity, effectiveness, and impact. Additionally, we emphasize that regeneration is embedded across societal opportunities, particularly in making positive contributions to protecting and revitalizing the environment. Figure 1 portrays a Sunburst diagram encapsulating the main dimensions, subdimensions, and topics of the taxonomy for a comprehensive depiction of its structure and components.

Hence, gaining a holistic understanding of the various dimensions of DT which could impact RS and SD, whether positively or negatively, is essential for informing effective decision-making. We acknowledge that monitoring a framework comprising 255 elements would be impractical, requiring the prioritization of topics. Therefore, following steps will help identify the most relevant topics with the support of expert elicitation. Subsequently, we will populate a Report Card Framework, which will serve as a flexible monitoring and awareness tool. By prioritizing relevant topics for each specific context, we can better address "glocal" needs. Consequently, this taxonomy and the forthcoming Report Card will offer a holistic and pluriversal tool, to concentrate our efforts where they are most needed.

TABLE 4. Dimensions and Subdimensions of the Taxonomy for SRDT.

| Dimension | Subdimension |
|---|---|
| PEOPLE | Human Rights, inclusiveness, fairness, equitable development, participation, safety, societal opportunities, resilience, culture, creativity, social acceptance, responsible use. |
| PLANETARY SUSTAINABILITY | Regenerative sustainability principles, environmental impacts (direct, indirect, rebound), supply chains effects, ICT-based mitigation strategies, positive contributions (i.e. "handprints"). |
| PROSPERITY | Responsible digital innovation, jobs, taxation, inclusive financing, ethical business models, fair competitiveness, responsible uptake technologies. |
| PARTNERSHIPS | Digital cooperation, pluriversal communities, collaborative ecosystems, digital diplomacy, multilateralism, capacity building, technological cooperation programmes, crowdsourcing. |
| PEACE | Mindful governance, ethical and inclusive governance, responsible regulation, digital ethics, responsible leadership, fair competition, digital commons, Internet governance, risks management, e-government. |
| PREPARADNESS | Digital readiness, resilience, meaningful connectivity. It entails possessing the necessary means, skills, and organizational mindset necessary to fully harness the digital opportunities. |

## V. DISCUSSION

### *A. Opportunities and caveats for SRDT and the triple transition*

The pervasive influence of digitalization is transforming every aspect of society, while prompting discussions about its impact on sustainability. Certainly, we concur with the literature about the potential of DT to advance regenerative sustainability, benefiting both nature and society. However, the regenerative philosophy has yet to fully infiltrate the digital domain, and the research landscape remains nascent. Aligning with [22], we recognize the need of integrating DT into the regenerative journey to effectively tackle contemporary challenges. To fully capitalize on these opportunities, full understanding of SRDT is indispensable.

Besides, we exposed the limited convergence of DT and SD agendas, surrounded by techno-utopian narratives, misleading claims, and a lack of awareness regarding impacts. We underline the inadequacy of current assessment frameworks and metrics to reveal true sustainability impact. Moreover, we advocate for a transition from silo-based thinking to holistic mindset and pluriverse approach, integrating digital, environmental, and social perspectives, for genuine sustainability efforts. We also claim for the rise of the triple transition, encompassing digital, ecological, and social dimensions, which necessitates a paradigm shift toward regeneration. While sustainability and regeneration should be intrinsic values guiding all human activities, we perceive a significant gap in understanding and measuring SRDT, urging a more comprehensive approach and practical tools to raise awareness and spark dialogue toward navigate broader societal and ecological impacts.

While diverse experts from myriad fields offer perspectives on steering the DT, often their voices are not universally selected. Meanwhile, a stark reality bit us: regulation remains elusive, digital rights are barely endorsed, greenwashing permeates all sector and actors, and digitalization pitfalls are inadequately tackled aggravating the planetary and social crisis. Can we, then, gather the audacity to craft a sustainable digitalization paradigm?

As we contemplate the remaining scant 6 years to meet the 2030 Agenda's deadline, an essential query arises: Do we possess the necessary objectives, metrics, and systems in this endeavour? Is it feasible to promote a triple transition or is it a utopia? These queries remain unanswered in literature and across experts. A profound understanding of the hallmarks of SRDT is urgently needed to illuminate the path ahead.

In light of the prevailing trend to discredit sustainability, there is a risk of promoting green hypocrisy and embracing an elastic and harmful interpretation of RS. While acknowledging the need for potential renewal of the concept, it is crucial to recognize that sustainability remains an imperative for humanity and regeneration emerges as the paradigm shift after a sustainability winter.

In addition, our analysis exposes a glaring absence of a suitable framework for the assessment of DT with a specific focus on RS. Aligning with the observations of [3], [5], [66], [90], [94], we concur on the inadequacy of existing frames, emphasizing the imperative need for enhanced methods, standards, and data to track progress. The research and policy landscape of SRDT remains highly fragmented, lacking cohesive vision. We evidence an invisible nexus amid digital and ecological transitions beyond pleasant words in policy agendas. The inadequacies also extend to SD frames, revealing carbon centric approaches, capitalists' perspectives on resource productivity, poorly integrated digital risks, and infertile disputes amid social and ecological realms [98],[99].

The outstanding opportunities of DT for regeneration need to be unlocked and scaled beyond pilot initiatives, all the while mitigating potential negative impacts. However, progress toward SRDT cannot be achieved if techno-utopias and green hypocrisy persist, along with political indifference, hidden agendas, and missing programmes or funding. We advocate

for a more comprehensive and holistic perspective that seamlessly integrated social, environmental, and digital factors with regenerative approaches for pursuing the triple transition. Consequently, we encourage for a transformative shift towards a regenerative mindset that not only acknowledges risks but also highlights opportunities in the DT landscape. Nonetheless, ongoing initiatives often focus on integrating a confined set of indicators into existing indices, with unclear merit. We stress the imperative for policy bodies and international organizations to evolve the measurement framework in tandem with the pace of DT, aligning with the triple transition in dialogue with all stakeholders. Moreover, we caution against overly optimistic assumptions based on pilot projects unable to mainstream. Comprehensive understanding and effective mitigation strategies are imperative. Understanding the dynamic and evolving nature of transitions by providing tools for awareness and agile governance are crucial steps. Considering this, it is crucial to recalibrate both digital and sustainability ethos, necessitating a taxonomy on SRDT, as presented in this work. It is essential to dispel illusionary thinking and fallacies surrounding digitalization, portraying it as immaterial, efficient, and magically steering us toward climate neutrality. As argued by [3], [26], [30], unintended consequences, real impacts, and untamed rebound effects must be factored into the equation.

Finally, our research marks a modest yet necessary initial step in confronting challenges and propelling the triple transition forward. It entails a deeper exploration of the dimensions and features associated with digital, ecological, and just transitions. Emphasizing the importance of novel monitoring and awareness tools, we offer a structured framework for the classification and analysis of the hallmarks to navigate the convergence of DT and regenerative sustainability.

*B.Strategies for Enhancing the Convergence of DT and RS*

The existing 2030 Agenda incorporates only a limited scope of digital dimensions, encompassing connectivity, basic Internet usage, mobile ownership, and basic skills. E-waste is also partially addressed. Indeed, literature highlighted severe deficiencies in formulating targets and metrics for the SDGs, as well as data lack and lags [18]. Thus, there is a pressing need to explore ways to enhance the Agenda to better encompass DT and RS critical trajectories. In this section, we delve into diverse strategies aimed at that purpose, echoing some intriguing ideas gaining momentum at international fora discussions (not yet translated into the literature) and propose novel strategies towards a future enhanced post-agenda 2030. Several approaches have been deliberated:

- Cross-Cutting Transformation [1]: Recognizing the pervasive influence of DT across societal domains and SDGs, challenges arise in materializing and assessing progress due to the absence of specific metrics/targets.
- Enhancement of current ICT-based SDG Targets: while offering broad coverage of macro aspects, this approach may overlook relevant risks and opportunities.
- Integrating further digital-based targets across SDGs: Supplementing with specific digital targets could address short-term concerns but may complicate the monitoring process and raise efficiency concerns.
- Formulating a Novel SDG18 for SRDT: it facilitates addressing a wide range of risks and enables more granular monitoring but necessitates a complex global consensus. Besides, it demands novel indicator design and data availability. Attention to the capacities of the Global South is crucial to avoid unattainable approaches.
- Parallel Agenda: Initiatives like the Digital Global Compact [82] pursue a separate agenda for DT. However, current drafts maintain existing divides and lack a truly systemic perspective on SD, impeding genuine integration with sustainability efforts.
- Achieving SRDT through a Sextuple Helix Innovation Model (6HIM) [107]: Recognizing the pivotal role of innovation, this approach envisions digital, ecological, and social transformations as key actors shaping a sextuple helix ecosystem. While offering potential in policy formulation and use cases, it necessitates further empirical research, along with stakeholder dialogue.

Therefore, these strategies represent diverse pathways toward enhancing the alignment of DT and RS/SD trajectories, each with its own opportunities and challenges. Continued exploration and collaboration are essential to navigate these complexities and advance the integration of digital and sustainability agendas effectively. Based on these findings, we recommend a twofold roadmap, urging for additional research and collaborative policy development with global stakeholders to address the identified gaps. The overall strategy needs to be flexible to address immediate and future needs, set realistic goals, and aligned with the evolving dynamics of sustainable digitalization and the triple transition.

In the short term, it may be suitable to enhance existing frameworks with better ICT indicators, sustaining seed funding for SRDT programs, and gradually building capacities toward more ambitious pathways. To the best of our knowledge, there are no specific programmes for this purpose. In the medium to long term, as a new SD Agenda will need to be established in the coming years, it is advisable to raise ambition and incorporate a dedicated goal for SRDT. Additionally, promoting the 6HIM model for ecosystem and policy development through a global institution and appealing global goals would be compelling. This will enable the convergence and co-evolution of not only the Digital and Sustainability agendas but also the innovation agenda, which shares remarkable synergies with both.

Our proposed taxonomy represents a preliminary guiding tool for developing more elaborated frameworks. We align with CODES [97] recommendations, regarding the pertinence of a World Commission on Sustainability in the Digital Age and Standards for providing guidelines and building literacy. We also argue that specific programs and funding dedicated to the regenerative triple transition would be useful to start pilots and develop capacities. We also recommend integrating, at least, a simplified ESG risks evaluation, based on available standards, into digital projects and publications, to combat impacts and misleading discourses. We likewise underscore the need for collaboration, interdisciplinary and multistakeholder dialogue, to advance the collective understanding of the interconnected realms of digital, sustainability and innovation. Thus, our research represents an initial step in addressing challenges and advancing the regenerative triple transition, towards gaining a deeper understanding of the dimensions and characteristics of digital, ecological, and just transitions.

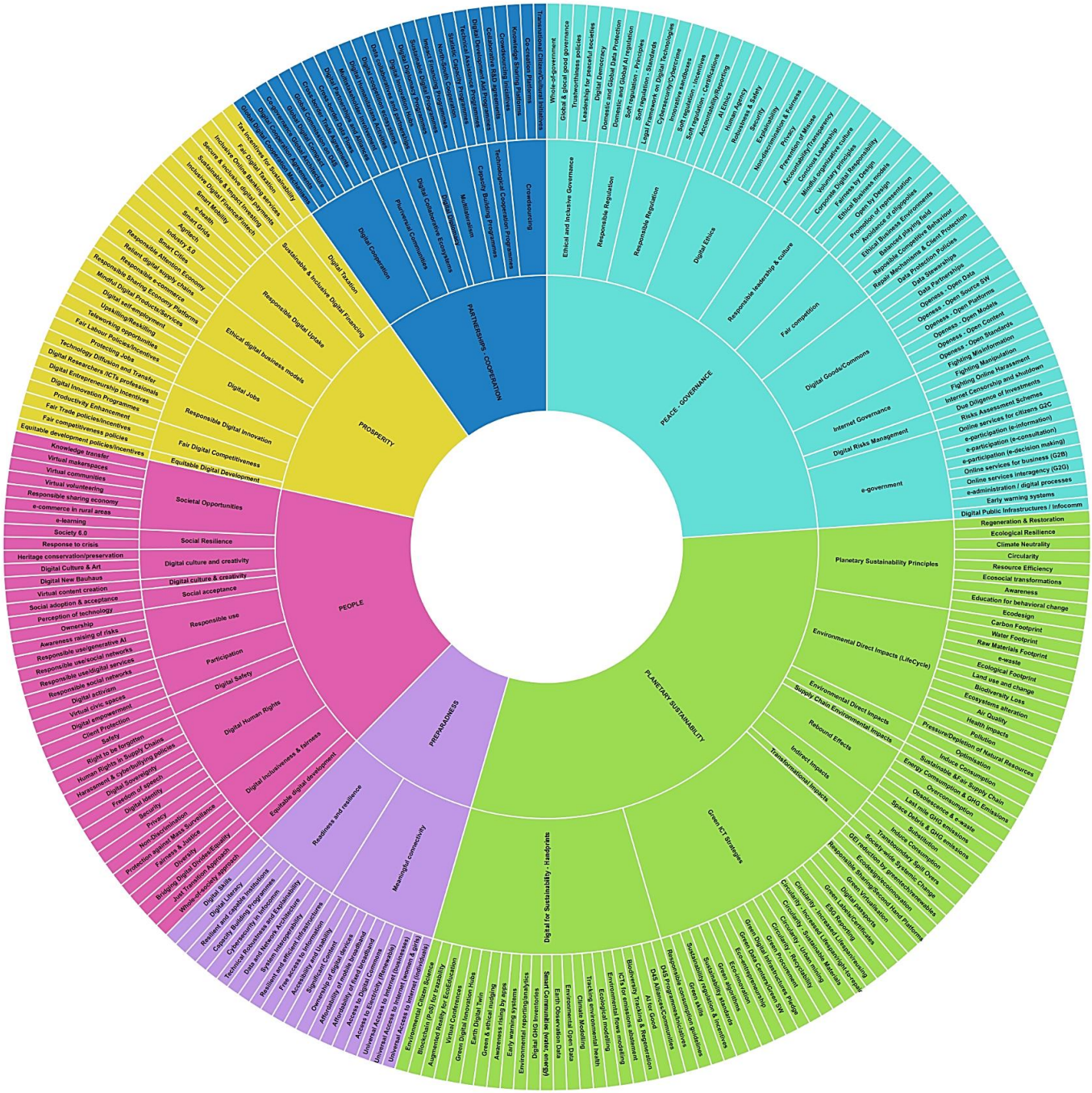


Figure 1. Sunburst diagram representing the dimensions, subdimensions and topics of the taxonomy for SRDT.

## VI. CONCLUSION

This ongoing research, forming part of a broader Ph.D. dissertation, delves into the complex interplay between digital and sustainability agendas within the triple transition and regeneration context. The preliminary findings presented in this conference, while evolving, mark an initial step in addressing identified gaps at the intersection of DT and RS. The research contributes to provide novel insights and practical tools to navigate the unveiled challenges.

In response to RQ1, the study introduces a comprehensive taxonomy outlining key dimensions and features of a sustainable digital transformation with regenerative qualities. For RQ2, valuable insights and practical tool are provided for the responsible use of digital paradigms for sustainable and regenerative development. Therefore, the research provides a contribution in advancing the understanding and implementation of SRDT. This includes a thorough critical review of existing frameworks and the introduction of a comprehensive taxonomy, which serves as unified classification, providing a foundational understanding for the pursuit of the triple transition and the convergence of both SD and DT agendas.

The research holds implications across theoretical, practical, and policy realms for all stakeholders. Theoretical implications encompass the conceptualization and

taxonomy of SRDT, ensuring that sustainability, inclusivity, and ethics are integral to DT. Practical implications arise from the guidance offered by this taxonomy, assisting organizations in understanding and prioritizing the implications of digitalization on sustainability. Furthermore, policymakers can utilize this science-informed insights to enhance their awareness and prioritize RS in digitalization policies, and programs.

Acknowledging limitations, the study notes the underdeveloped nature of the research sphere and literature in this field and the challenges posed by the rapid pace of digitalization. We also recognize divides amid disciplines, inherent biases in qualitative analysis and expert judgment, and limitations in text analysis tools. Nevertheless, we employ a sound combination of techniques for achieving optimal results.

The next phase of the research will include validating and refining the proposed taxonomy through expert elicitation (currently in progress). Additionally, experts' input will aid in prioritizing the most relevant topics within the taxonomy to construct a lean and efficient Report Card framework. This supplementary framework will serve as a user-friendly monitoring and awareness tool, adaptable to various contexts to accommodate diversity, and comprehensible for stakeholders from any discipline.

In conclusion, the research illuminates theoretical underpinnings and translates insights into practical guidance, advancing the understanding and governance of the intersection between digital and sustainability transformations with a regenerative lens. We encourage the scientific community to take bold action and facilitate dialogue among stakeholders to shape the evolving digital landscape towards regeneration.

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