Decision-Making under Environmental Complexity: The Need for Moving from Avoided Impacts of ICT Solutions to Systems Thinking Approaches

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***Abstract* — The indirect impacts of Information and Communication Technology (ICT) on the environment (whether positive or negative) have been extensively discussed in academic and industrial literature, particularly within the ICT4S community. However, a lack of consensus exists in academia on how to assess them, especially in the context of decision-making processes. This paper examines whether 'net impacts accounting' methods are suitable for decision-making and suggests alternative approaches. We begin by clarifying different scenarios within the context of environmental decision-making. Then, we assess their relevance across those different decision scenarios. We emphasize their inadequate response to uncertainties, their focus on solutions rather than problems, and their inability to inspire a range of decisions compatible with an environmental transition. Drawing insights from systems thinking, we finally suggest methods and tools that could be combined to better address the complexity surrounding environmental decision-making. Throughout the paper, we develop the case study of Vinted – a second-hand clothing resale platform – to illustrate our arguments. The contribution advocates for a more systemic approach that embraces complexity by employing mixed methods, encompassing both qualitative and quantitative perspectives.**

Keywords—avoided emissions, ICT, environmental decision-making, complexity, indirect effects, systems thinking

I. INTRODUCTION

Planetary boundaries represent critical thresholds beyond which the safe operating space for human development becomes uncertain. Recent research posits that six out of nine planetary boundaries have been surpassed [1]. Scientific literature has shown the escalating influence of human activities on the ecosystem [2]. While most sectors are concerned, recent attention has been given to the direct impacts of Information and Communication Technologies (ICT). Freitag et al. [3] estimated the greenhouse gases (GHG) attributable to the digital sector between 2.1% and 3.9% in 2020. In addition, the sector consumes rare metals and produces wastes that are difficult to recycle [4, 5]. Nevertheless, the sector is often presented as an important catalyst for mitigating the environmental impacts of other high-impacts sectors such as mobility, buildings or industry, especially within the industrial literature [6]. However, as pointed out by [7, 8], this assertion lacks robust support from rigorous scientific studies and cannot be considered reliable. The sector is also associated with negative environmental externalities including rebound or induction mechanisms [9, 10, 11, 12]. All these indirect effects, whether positive or negative, are particularly complex. Although the indirect impacts of ICT have been extensively discussed in, *inter alia*, economics, computer sciences, and environmental sciences [13, 14, 15, 16, 17, 18], to date, there is no consensus in academia on the aggregated net effects of ICT.

The ICT community recognizes that accounting standards and tools are needed to assess the footprint of entire value chains and to track emissions over time. It appears that some accounting tools also aim at evaluating whether specific solutions may help in achieving emission reductions by substituting, optimize existing products or enable new processes or services with lower footprint [19] and thereby "*avoid emissions*" compared to a reference situation. As shown by Mission Innovation's history of avoided emissions [20], ICT has been the first and main sector pushing the idea that, beyond the scope of their own carbon footprints, companies may play a role as low carbon solutions providers. To standardize the assessment of "*avoided emissions,*" generic frameworks as well as ICT-specific frameworks have been proposed. This topic has also received increasing attention from the ICT4S research community [7, 21, 22, 23].

In principle, avoided emissions frameworks enable the quantification of both direct and indirect effects of ICT solutions, and are intended for decision-making as explained in Section II. In this article, we aim to study the relevance and the limitations of these avoided emissions methods within the context of environmental decision-making, and suggest a combination of alternative practical approaches, methods, and tools that could enhance decision-making in several contexts. We support our arguments and proposals through the case study of Vinted, a second-hand clothing resale platform who recently published a net impact study conducted by Vaayu [24]. We begin by clarifying the different environmental decision-making scenarios we

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address and show to what extend net impacts frameworks are intended to address them. Subsequently, we analyze the main challenges of using avoided emissions methods for decision-making through a quick review of existing avoided emissions methods. Finally, drawing on systems thinking, we suggest insights, methods, and tools better suited for a systemic approach to environmental decision-making.

II. NET IMPACTS ACCOUNTING METHODS AND THEIR POSITIONING IN RELATION TO DECISION-MAKING SUPPORT

'Avoided emissions' methods are designed to produce a quantitative result describing the difference in impacts between a scenario where the solution of interest is deployed and a "*reference scenario*" where the solution is absent. In this contribution, instead of 'avoided emissions' we will mostly use the term 'net impacts' to encompass a broader consideration of impacts, recognizing that other environmental impacts could also be considered. Additionally, unlike 'avoided emissions', 'net impacts' insists on the fact that the net result is not necessarily negative: an ICT solution could increase - instead of reducing - global impacts. The nine methods selected in this paper (selection criteria and list of selected methods can be found in Section III) share fundamental mechanisms, notably the utilization of a reference scenario and the objective of producing an aggregate figure whose sign and value is intended to enable decision-making. These methods are all associated with at least one decision-making objective. Although the primary purpose of most methods appears to be the construction of environmental claims, it should not be considered as a final objective, as claims take part in a strategy to support — or influence — decisions. In TABLE I. we distinguish five decision-making situations in which net impacts methods are said to be applicable. These scenarios reflect current power dynamics in digital consumption and production (at least in Western economies with high levels of digitization) and are illustrated by the Vinted case study. We distinguish between the external decisions taking place outside the organization developing the solution, and the internal decisions taking place inside it.

At an external level, environmental claims can be targeted toward customer to influence their purchase decisions (A), by "*enabl[ing] customers to differentiate products*" [25]. Moreover, claims can be directed toward public and private investors or shareholders (D) to "*enable [them] to assess company risk and opportunities for investment decisions*" [25] especially in the context of a growing interest in green investments. These methods are also tailored to impact political decisions (E). For instance, [26] is explicitly designed to support political decision-making, while [25] mentions an objective to "*inform policymakers about the potential consequences of policy and regulatory choices*."

Internal decisions at organization level are also addressed in net impacts methods. The guidance on avoided emissions [27] emphasizes that organizations can "*include these assessments and claims in their decision-making processes.*" In [25] the method can "*inform portfolio planning — the determination of which products to develop and which to retire*" and can even go as far as "*reinventing the company's business model*" in [28]. In this context, organizations are mostly seen has a portfolio of projects. Decision occurs at a financial level, where decision makers are internal investors driving a budget (C). But an organization can also be seen as a collection of processes. In this context, these methods could serve as tools to help organizational processes such as design processes (B). [25] mentions the objective to "*guide product benchmarking and product research and development (R&D)*" while [27] states that "*avoided emissions can also be used as a powerful tool to [i]nnovate.*"

TABLE I. DECISION-MAKING SITUATIONS CONSIDERED

	Decision makers	**Scale of decision**	**Type of decision**	**Example in the context of Vinted practical case**
A	Consumer	Product / service	Purchase / use	Deciding whether to buy/sell or not on the Vinted platform based on the environmental and social impacts of this service.
B	Designer	Product / service	Product / service design	Identifying product design levers to mitigate direct and indirect effects, comparing scenarios, defining a strategy.
C	Organi-zational decision maker	Organi-zation portfolio	Strategy design	Deciding to adapt the business model to reduce environmental and social impacts while maintaining the viability of the company. Investing more in products from the portfolio with the best impact.
D	Investor / shareholder (public / private)	Invest-ment portfolio	Investment	Deciding whether to invest or not in Vinted to green the investment portfolio.
E	Political decision maker	Society / market	Policy design (regulations, incentives, etc.)	Introducing regulatory mechanisms for companies or consumers to create conditions that enable a reduction in the environmental and social impacts of the clothing sector (regulations, taxes, information, quotas, tax reductions, etc.).

Unlike a physical measurement conducted in natural sciences, the effectiveness of an environmental accounting method used in a decision context cannot be judged solely on its ability to accurately describe a portion of reality. It must also enable the best decisions to be made to reduce the absolute environmental impacts under analysis. According to Ekvall [29] such methods should be *feasible* to give results, *accurate* to give information that faithfully describe the portion of reality investigated, *comprehensible* to provide knowledge for the targeted audience, *inspiring* to give incentive for taking (good) decisions and finally *robust* to avoid misuse. In this paper, we aim to explore net impacts accounting methods through this decision-making perspective by addressing the following questions: (Q1) Are net impacts accounting methods appropriate to environmental decision-making? (Q2) What alternative or complementary approaches, methods, or tools, could enhance decision-making support?

III. METHOD

A. Literature review

We conducted a literature review encompassing academic, industrial and normative sources that delineate net impacts accounting frameworks. Avoided emissions and net

impacts have been discussed since at least the 2000's across various sectors [20]. To narrow the study's focus to contemporary methods applicable to ICT, our analysis primarily centered on the ITU-T L.1480 [30], the latest IT-specific net impacts accounting method, and its associated references. Among this selection, we identified nine methods pertinent for net impacts accounting in the IT sector. Eight methods are published in the industrial and normative literature: ITU-T L.1480 [30], QuantiGes [31] (replaced by Empreinte Projet [32]), section 5.6 of ETSI TS 103 199 [33], the Policy and Action Standard [26], the Avoided Emission Framework [34], the B2 pillar of the Net Zero Initiative (NZI) [28], the guidance on avoided emissions [27], and the 2019 working paper "*Estimating and reporting the comparative emissions impacts of products*" from the World Resource Institute (WRI) [25]. One method is detailed in two academic papers: "*Methodology for assessing the environmental effects induced by ICT services*" Part I and II [7, 22]. While our selection process was not systematic and as such does not cover all recent net impacts accounting methods, it captures those discussed in the ICT4S community. This includes the three available methods discussed in ICT4S23 workshop on indirect effects assessment [23] and two academic papers published in ICT4S20 [7, 22]. Our analysis focuses on the inherent limitations of all these methods. When relevant, we detail some mechanisms specific to a particular method.

B. Case study

To illustrate our arguments in Section IV and elaborate on the proposal in Section V, we develop the case study of Vinted net impacts assessment published in 2021 [24]. Established in 2008 in Lithuania, Vinted is a leading second-hand clothing resale platform currently operating in Europe and Northern America. Beyond enabling cost savings for customers and additional income for vendors, the company emphasizes its environmental benefits as a key commercial argument. Vinted claims to reduce GHG emissions by encouraging the purchase of second-hand clothing thereby avoiding the production of new clothes. This assertion assumes that the emissions avoided compensate for the additional emissions due to the transport of parcels and the operation of the Vinted platform and organization. Unfortunately, these gains are accompanied by other indirect effects (documented by [24, 35]).

In 2021, Vaayu, a consulting firm specialized in the environmental assessment within the textile sector, conducted a net impact study (focusing on GHG emissions) on behalf of Vinted [24]. Based on WRI's working paper [25] and using primary data collected through survey and transaction analysis, the study states that Vinted has avoided 453 kiloton CO2eq. in 2021. This figure is obtained by comparing, for each transaction, a scenario where items are purchased on Vinted platform with a scenario involving the acquisition of new items. The study claims that rebound effects were included through a "*consequential life cycle assessment.*" In particular, they evaluated the fraction of purchases that were considered additional ("*impulsive*" [24]). This case is particularly relevant as few net impacts studies have been carried out to date. Moreover, this study stands out for the scale of the data collected (350,000 users surveyed), its compliance with the WRI's guidelines, and its transparency. While its objectives are not clearly stated, we can assume that its main aim is to convince customers (A), as avoided emissions are seen as "*a valuable calculation for comparing one choice's impact to another.*" However, such claims could also be leveraged externally for investors/shareholders (D) or political decision makers (E). Notably, the study does not seem to target internal decision-making (B, C) as it does not provide recommendations such as mitigation measures.

IV. Challenges of using net effects methodology to support decision-making

This section outlines key challenges associated with employing net impacts accounting in decision-making. We not only discuss whether net impacts methods produce *accurate* knowledge (sub-section A), but also to what extent this knowledge offers *inspiring* and *robust* representation for making decisions aligned with an environmental transition (sub-section B).

A. Challenges in accurately representing reality

a) Uncertainty - Net impacts methods insufficiently acknowledge quantifiable and unquantifiable uncertainties: Environmental accounting methods are expected to yield accurate knowledge to guide decision makers in "*the right direction*" [29]. In the context of net accounting, accuracy implies that, at least, when the estimated net impacts of a solution are negative, its implementation should effectively decrease global environmental impacts compared to not using it, and this reduction should reasonably align with the computed value. However, guaranteeing such accuracy is a real challenge due to uncertainties which emerge at various steps of net impacts assessment (e.g., data collection, choice of parameters, evaluation's scope) and can take different forms (e.g., aleatoric, epistemic), like in Life-Cyle Assessment (LCA) upon which net impacts accounting methods are commonly grounded [36, 37]. As shown by [38], the proper analysis of uncertainties is often overlooked even in the academic LCA community.

The methods under analysis introduce substantial sources of uncertainty, especially with the definition of scenarios which are "*non-verifiable fictional situation[s]*" [28], in a similar manner to the "*avoided burden*" approach of LCA recognized to be intrinsically very speculative and uncertain [39]. For example, the reference scenario in the Vinted study [24] is counterfactual, representing what would have occurred if buyers "*had not found [their product] on Vinted.*" Being built from customers' self-reported data, it is prone to social desirability bias, potentially leading to overly optimistic results. Another source of uncertainty when building scenarios is related "*to how a new technology affects the use of the incumbent technology, as well as the interactions of these technologies with the broader economy*" [25]. In other words, it lies in the complexity of the dynamics induced by the deployment of the solution under consideration, including indirect effects such as socio-economic transformations at various scales [13] which are by nature highly uncertain.

To qualitatively characterize the quality and completeness of assessments, net impacts methods may consider several evaluation levels (e.g., [28] and [30] considers three levels, and [32] has five levels) depending on, *inter alia*, the nature of the data and the completeness of the modeling approach. They also address uncertainty through numerous principles and techniques such as conservativeness, transparency, computing a best and a worst-case scenario, employing ranges or conducting sensitivity analysis. According to Vinted [24], its study relies on "*a conservative approach [...] wherever possible to avoid overrepresenting the emissions-saving potential,"* although we note that this principle is not systematically applied throughout the study and that no global

uncertainty analysis is provided. Most of the aforementioned techniques treat, at best, uncertainty within the frame of "*risk analysis*" through probabilistic approaches quantifying the likelihood of assessed values to deviate from reality. However, as noted by [30] "*usually uncertainties are uncertain,*" that is, they fall within the notion of Knightian uncertainty [40] and are thereby unmeasurable. Face with this type of uncertainty, [40] advocates for "*plural and conditional methods*" to reflect the range of possibilities and the diversity viewpoints [41, 42], and to avoid "*that policy makers are denied exposure to dissenting interpretations and the possibility of downright surprise*" [40].

b) Complexity - Net impacts methods are reductionist and solution-oriented: There is pressure from the various decision-making levels for simple answers to complex problems [43]. However, as stated by Stirling, to whom we align [40], "*When knowledge is uncertain, experts should avoid pressures to simplify their advice. Render decision-makers accountable for decisions.*" Given the complexity and intricacy of consumption and production practices (1), and the complexity of the effects of an intervention (e.g., the introduction of Vinted in the clothing sector) within socio-technical systems (2), it would therefore be appropriate to use non-reductionist (3) approaches and tools [44], in opposition to net impacts methods which often reduce the complexity to a single value. Net impacts frameworks offer limited guidance on comprehending the complexity of the problem (1), placing more emphasis on solution analysis. Depending on practitioners, the reference scenario identification phase and step 4 in [32] could serve this purpose. The reference scenario of the Vinted study [24] focuses on the brand-new clothes that are displaced by purchases on Vinted, aiming to mitigate the impacts on the textile sector. Yet, the dynamics of the textile sector's unsustainability and its connection to increased purchases of new clothing are not discussed. Without a thorough understanding of the context surrounding a technical solution, the analysis of its effects appears limited.

Complexity also arises from the dynamics resulting from actor's actions (2). In particular, changes occurring from the introduction of a new technology constitute a complex phenomenon involving socioeconomic transformations at various scales of society. Among those phenomena, substitution and optimization effects are included by all methods, as they generally represent the desired outcomes. Computing *"the sum of all system-wide changes in emission [...] occurring because of [the solution]*" requires including also all its "*extraboundary effects*" [25]. Beyond substitution and optimization effects, rebound effects (i.e. an increase in consumption caused by an optimization, e.g., economic or temporal savings [9, 14]) are cited in all methods. In [27] and [28], they are considered as negative externalities that should be reported, without making it mandatory in the assessment. Empreinte Projet [32] gives a list of indirect effects including rebounds but excluding indirect rebounds from the assessment. The ITU-T L.1480 [30] considers more broadly "*higher order effects*" in accordance with Hitly's framework [13] offering a list of effects and guidelines for qualitative identification and magnitude assessment for direct and indirect rebounds. The heterogeneity in the scope of indirect effects included in methods highlights the practical challenge of conducting a comprehensive quantitative analysis. The Vinted study attempts to evaluate direct rebound effects but considers only Vinted purchases that might not have substituted for new clothes due to "*impulsive*" (i.e., unplanned and opportunistic) buying [24], overlooking other additional purchases of clothes, not necessarily on Vinted, due to, e.g., the re-spending of economic savings and money from sales made on the platform. Moreover, indirect rebounds and structural and systemic effects induced by Vinted (see TABLE II.) are not part of the evaluation. Their inclusion could drastically change the results, but their quantification is challenging, if not impossible. The analysis of Vayuu tends to hide those difficulties.

TABLE II. EXAMPLES OF INDIRECT EFFECTS OF VINTED

Type of Indirect Effects [9, 14]	**Examples of Indirect effects**	**Included in [24]**
Direct rebounds (clothes)	Additional purchases of clothes induced by Vinted [24] (notably fast fashion [35])	Only partially
Indirect rebounds (other products)	Additional purchases of other products than clothes induced by Vinted	No
Structural & systemic	Long-term transformations of production and consumption patterns induced by Vinted, e.g., shift in sellers' practices towards a "*consu-merchant"* [35] (i.e. blur between consumer and vendor status)	No

Net impacts methods might suggest to decision-makers that evaluating whether a solution is environmentally relevant could be reduced to a single figure, even when dealing with complex phenomena (3). Several methods propose less reductionist complementary results such as consequence trees [26, 30, 32]. While these complementary representations offer a more dynamic representation of the complexity, they remain centered around solutions (the roots of the consequence trees) rather than the problems they seek to address. The choice of a tree representation also limits the modeling of feedback loops, which are not mentioned in the methods (this concept will be detailed in Section V.D), and as a result fails to fully capture the dynamics involved. Relying on a single figure also raises issues when these methods are applied to impacts beyond climate change [32]. Indeed, mapping different impact criteria or different impact localizations on a one-dimensional scale implies some ethical choices [45, 46].

Faced with simple dynamics, we could be satisfied with simple results. Unfortunately, the dynamics analyzed by net impacts accounting are usually complex, and even when net impacts figures can be considered reliable, which is probably not the typical case, it limits the comprehension of the conditions or reasons for the expression of positive effects.

B. Challenges in providing useful representations for environmental transition

a) Inspiring - Net impacts methods are more appropriate for claims than for exploring decisions compatible with environmental transition: Environmental accounting methods should produce knowledge that results in action [29]. According to [27], "*avoided emissions can be the right incentive for companies*" as they are believed to identify solutions with the greatest environmental benefits allowing companies to act on the most relevant levers. Claiming avoided emissions or more generally avoided impacts may take different forms but would result in the "*allocation*" of net impacts to one or several entities. While some methods are explicitly designed for producing environmental claims [27, 30, 34], [26] and [32] attribute net impacts to the action (or solution) investigated and not to the entities in the value chain of the solution. In this context, no allocation guidelines are required.

The main difficulty in net impacts allocation is that it "*reflect[s] the collective efforts of multiple partners along the entire value chain*" [25]. As such, allocation rules will either try to avoid double accounting by partitioning net impacts along the value chain, accept double accounting by attributing the total net impacts to several actors of the value chain [27] or make a hybrid approach [28, 30]. The WRI working paper [25] leaves the question open, recommending that the allocation mechanisms be discussed among the stakeholders of the value chain (also in [34]). As every stakeholder in a value chain could claim net impacts when double accounting is allowed, [27] limits the attribution to solutions "*that directly and significantly improve or optimize systems.*" Justification remains in the hands of the entity carrying out the study. In [28], the final vendor of the solution can claim all the avoided emissions. Entities contributing to the solution, however, can claim a share of the avoided emissions based on the proportion of direct emissions from the component they provide over the total emissions of the solution. In an appendix that does not form an integral part of the recommendation, [30] presents a possible approach for a multi-level allocation method previously introduced by [22]. In this approach, three levels of allocation are considered, each allocating the same net impacts but to different types of stakeholders (Level A: ICT service stakeholders, Level B: Service specific building blocks, Level C: Common ICT devices, services, and infrastructure). Within each level, no double counting is authorized. In its study, Vinted claims all avoided emission but considers that its report "*reflects the collective effort of the entire value chain*" in accordance with WRI's guideline [25].

Claims from organizations suggest that they are responsible either totally or partially (when responsibilities are distributed across the value chain) for avoided impacts. However, in general, those claims do not discuss how solutions are embedded in environmental transition scenarios [21], which imply a multitude of stakeholders both inside but also outside the value chain, including policymakers and consumers/citizens. Those stakeholders are never considered in the context of claims even if they are essential entities of the environmental transitions. They can be regarded as external factors [32] or contextual factors [30] mentioned by certain methods. However, these factors are portrayed as mechanisms beyond the influence of the entity conducting the study, but determining the conditions in which the solution is deployed. In decision contexts A, C and D, this approach narrows the decision space to binary outcomes (e.g., financing a solution or not, buying a solution or not) instead of identifying broader levers such as lobbying or collective actions (considered as necessary by certain scholar for environmental transitions [47]) which could have influence on external factors. In decision contexts B and E, net impacts methods do not support the exploration of decisions (e.g., through an eco-design approach). It functions as a method applicable once a solution is established to justify (or deny) its environmental benefits.

Finally, "c*laiming avoided emissions does not necessarily mean that the products and services sold by a company are relevant in a carbon-neutral world*" [28]. Indeed, achieving transition objectives may have two consequences: *(i)* diminishing the imagined positive effects, and *(ii)* rendering a solution incompatible with other measures taken. For example, a scenario where the number of clothing items per person has been reduced, and the remaining items are eco-designed, will diminish Vinted's avoided emissions (consequence *(i)*). Alternatively, a transition scenario where the transportation of goods is constrained makes the continuity of Vinted's service more challenging (consequence *(ii)*). This implies that the aggregation of individual avoided emissions, materialized through environmental claims, does not constitute a transition scenario which needs to deal with known non-linearity of socio-environmental transitions. To address those issues, the NZI proposes to complement avoided emissions with "*a new indicator aimed at measuring the alignment of a [solution] with low-carbon transition*" [28].

b) Robustness - Net impacts methods safeguards may be insufficient against greenwashing: Environmental accounting methods shouldn't be used to justify a decision that would go in a misleading direction. One main motivation behind the development of some of these methods stems from the need to standardize industry's avoided emission or net impacts claims, some of which have been criticized for lacking rigor and robustness [7, 9, 25]. All methods introduce numerous principles for robustness emphasizing transparency, relevance, completeness, consistency, accuracy, and conservativeness. The guidance on avoided emissions [27] introduces the concept of "*gates*" which entities must pass to claim avoided emissions. These gates are designed to ensure companies claiming avoided emission have "*Climate action credibility,*" and that the solution is compatible with "*latest climate science alignment*" (involving no direct application on mining or fossil fuel sector) and its contribution to decarbonizing is significant. Additionally, guidelines regulate claims' communications to prevent misrepresentation. Some methods highlight the importance of disclosing the portion of revenue brought by a solution to the organization to fight cherry-picking solutions in company' portfolio [27, 28, 30]. Others mandate the communication of a set of elements alongside results, like the consequence tree, the assumptions, or the data sources [26, 30]. In this perspective, Vinted provides a high level of transparency in its study, allowing the audit of results and a certain reusability of collected data.

Overall, each of these methods attempts to put in place safeguards to prevent abuse. However, "*managers often make decisions which involve preference and which may not always be rational*" [48]. The safeguards should therefore focus not only on modeling aspects but most importantly on the subjectivity of the stakeholders involved. Moreover, as reminded by [49], any environmental accounting comprises risks of reappropriation by companies which will always try to promote "*increasingly seductive claims.*" In the industrial publications investigated by [25], "*no examples were found where companies explicitly included negative impacts in their assessments,*" and, more problematically, "*that companies almost universally based portfolio-wide estimates on a subset of products known or predicted to offer positive impacts.*" Imposing a plurality of perspectives could be a way to limit abuses without having to anticipate all their possible forms [41]. More generally, inherent threats are associated with decision-making led by numbers. They have been well documented by the sociology of quantification and include, *inter alia*, "*enhance[d] knowledge and power asymmetries*" [50]. To reduce such threats, some authors propose to rely on interactive approaches in which participants can examine, question and modify the underlying assumptions of quantification processes [42, 51]. This necessity of multiple perspectives from a variety of stakeholders is rarely observed

in net impacts accounting methods. In the Vinted study, clients were involved for statistical purposes during the data collection phase. However, neither the clients nor the other stakeholders impacted positively or negatively by Vinted's activities took part in the study, resulting in an asymmetry of power in the creation and interpretation of the results.

In this section, we identified important weaknesses of net impacts accounting methods in supporting environmental decision-making (summarized in TABLE III.). In conclusion, we argue that the final aggregated figure ("*avoided emission*" or "*net impacts*"), which is a central representation of the methods, hides from decision-makers the complexity and uncertainty inherent to the analyzed dynamics. This is due to reductionist and best effort approaches that are used to justify "*science-based"* decisions and create the illusion of "'*definitive' policy interpretations"* and knowledge [40], even when dealing with large areas of uncertainty, ambiguity, and ignorance. The approach tends to prioritize solutions over problems and overlooks the importance of including a diversity of stakeholders.

V. Alternatives and Avenues for Decision Support with a Systemic Approach

To address the above-mentioned challenges, we discussed the necessity for a plurality of approaches and methods (qualitative and quantitative), diversity of stakeholders and perspectives, and transparency regarding complexity and uncertainties [40]. In the ICT literature, there have been multiple calls to approach the complexity of indirect effects with a systems thinking perspective [52, 53], but with few practical examples beyond quantitative modeling of dynamic systems [54]. In this section, we propose to apply a combination of best practices, methods, and tools to the Vinted case study. We believe that these alternatives (or enhancements) to net impacts methods, mainly inspired by systems thinking, are promising avenues of research to address the identified challenges, although they are not without weaknesses. The optimal combination of these methods according to the needs (in terms of *feasibility*, *accuracy*, *inspiration*, *comprehensibility*, *robustness* [29]) is an area that requires further investigation.

Systems thinking is both an interdisciplinary research field and a worldview that opposes reductionism and acknowledges the importance of interactions within a system, non-linear behaviors, and emergent phenomena. We align with Critical systems thinking, which advocates for combining qualitative and quantitative approaches [55]. Furthermore, we refer to complex thinking [44], systemic design [56], and futures studies [57].

A. Stakeholder diversity and expression of their values

Requisite variety [58] is a cybernetics law that has been translated into a principle of team diversity in management science. In systemic design, the idea of requisite variety has been popularized as "*bringing the entire system into the room*" [59]. Representativeness of stakeholders and diversity (of values, positions, affiliations, levels of power, etc.) promotes a comprehensive view of the situation and minimizes the risks of bias, thereby enhancing *accuracy* and *robustness*. **Value Sensitive Design** (VSD) [60] is one of the value-oriented approaches to the design of technological systems, that aims to integrate human values into the design process. It is based on the idea that technological systems are not neutral entities, but instead reflect the values of their designers. In VSD, the design team identifies values that are important to users and stakeholders and designs solutions that consider the potential impacts of the system on the identified values. Integrating different perspectives and explicitly describing values could prevent (un)intentional misuse (*robustness*) of the methodology and enable the team to evaluate decisions considering these values (*inspiring*). While VSD was criticized for leaving too much agency to the designer, other, more prescriptive approaches have been proposed, such as the Value-based engineering for ethics by design [61]. The need for stakeholder diversity and the explicit expression of their values has also been discussed in the context of LCA [42, 62].

In the example of Vinted, it would have been interesting to involve various stakeholders in the analysis of the situation, such as designers, decision-makers, academics, policy-makers, and users. Some stakeholders could be highly sensitive to the price, or the economic viability of the company, while others would be more concerned about the working conditions of employees in the textile industry, climate change, or local pollution. The diversity of perspectives could ensure that certain impacts are not overlooked. For instance, an academic with expertise in second-hand clothing platforms, such as E. Juge [35] would likely have identified indirect effects not considered by Vayuu in their calculations, such as the indirect rebound effect, as well as hardly quantifiable systemic effects, like the structural shift in consumption practices (see TABLE II.). Negotiations among stakeholders with divergent interests may be more time consuming but could facilitate the construction of a more comprehensive and therefore *less reductive* view, along with enhanced transparency regarding *uncertainties* and better *robustness* against greenwashing.

B. A critical view of the present, desirable future(s), and transition pathway(s)

Causal Layered Analysis (CLA) [63] is a critical futures research method designed to explore the root causes of issues by examining four levels, described in the left-hand side of Fig. 1. The purpose of this method is to question a current problematic situation and its construction, thereby challenging assumptions from the past and present, and thus opening up broader possibilities for the future. Futures studies research distinguishes several types of scenarios [64]: predictive, exploratory and normative. Predictive scenarios seek to define the most probable futures, based on current trends (forecasting) or on the condition of certain specific events (what-if). **Normative scenarios**, at the other end of the spectrum, can be built using a **backcasting** method. The first step is to define one or more desirable futures [65], before working backwards to build trajectories that lead to the desired outcomes. In the context of sustainability planning, backcasting has been illustrated in a study on smart lighting in Wallonia [66]. To influence the behavior of a complex system, system thinkers and systemic designers typically use **Meadows' twelve leverage points** [67]. These "*twelve places to intervene in a system*" are grouped into four categories that resonate with the CLA (see right-hand side of Fig. 1). They are arranged from the shortest-term but less effective measures (parameters) to the longest-term and most powerful strategies (mental models). To address various time scales, encompassing both urgency and sustainability, it can be valuable to combine leverage points at various levels.

In the context of Vinted, CLA could facilitate a multilevel analysis of consumption (and production) practices and the underlying assumptions (see examples in Fig. 1). This could

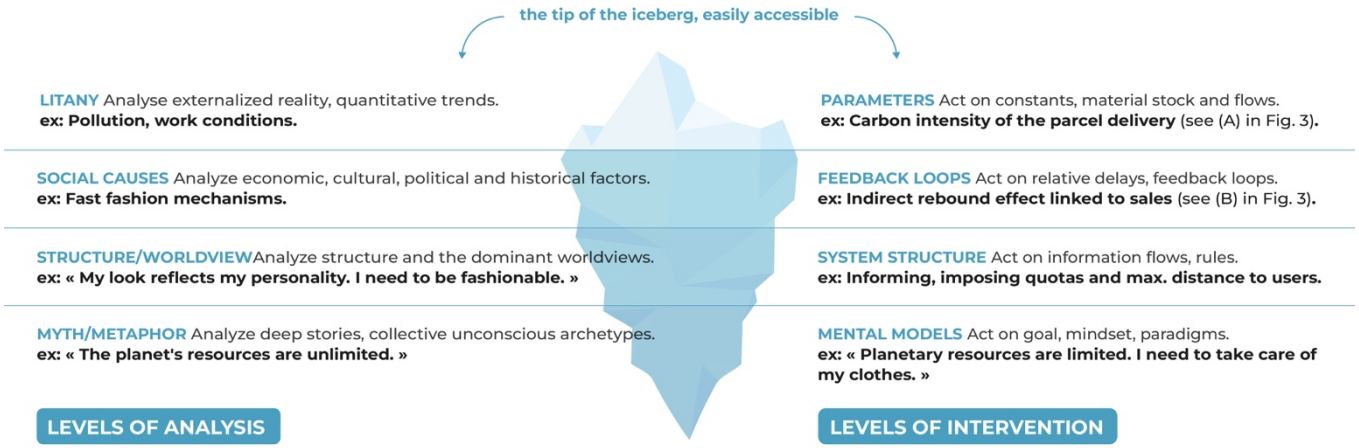

Fig. 1. Causal Layered Analysis levels (left) and Meadows' leverage points categories (right), illustrated by Vinted examples (in bold).

lead to a better understanding of the factors that cause certain consumers to decrease their consumption, providing a *less reductive* understanding of the situation. Reflection on desirable futures and the trajectories to achieve them (backcasting) could enable situating each decision within a broader context and verifying that it aligns with the construction of the desired future (*inspiring*). In our example, a desirable future could be, for instance, a world where people are attached to their clothing and renew them very infrequently, leading to a reduction in textile-related waste and pollution. The identified pathways to this (desirable) future could be compared relatively to guide decisions, rather than compared to a baseline (which introduces additional *uncertainties*) to claim avoided emissions. For product/ service designers (B in TABLE I.), it would involve combining and comparing design ideas. For policymakers (E in TABLE I.), it would mean comparing policy strategies (population awareness, business regulations, quotas, etc.).

C. *A qualitative and quantitative process supported by Collaborative modeling*

Group Model Building (GMB) [68] is a modeling process that involves a diverse group of stakeholders working collaboratively to develop a conceptual model of a complex situation. The process typically starts with identifying the problem or issue of interest and defining the boundaries of the system being studied. The participants then engage in workshops to construct causal loop diagrams, system dynamics models, or other types of models. It enables participants to test various scenarios, simulate the behavior of the system under different conditions, and explore the potential consequences of different interventions or policy changes. In general, GMB is initiated by a comprehensive, qualitative representation of the situation. Subsequently, it may transition to a dynamic model, which represents a quantifiable subset that can be executed and simulated. It is noteworthy that, in net impact frameworks, broader, systemic, and/or societal qualitative issues are often considered afterward, as an afterthought (*e.g.*, [27] or [28]).

In our practical case, stakeholders could have explored the indirect effects of Vinted on charitable donations, its contribution to fast fashion, consumerist practices, and addictions before quantifying the direct effects, the magnitude of substitution of new clothes, and rebound effects. This approach ensures that higher-level and challenging-to-quantify elements, which are nonetheless highly relevant, remain at the forefront throughout the entire project, revealing *complexity* and some of the unquantifiable *uncertainties*. Consequently, stakeholder participation in the construction and exploration of a dynamic model (especially feasible for situations B, C, and E in TABLE I.) can enhance the understanding of study results and limitations (*comprehensible*). A research perspective, based on GMB, could aim to maintain a balance between the qualitative and quantitative aspects in decision-making processes, preventing the quantitative aspect from becoming the dominant factor.

D. *A comprehensive qualitative representation*

There are various types of comprehensive qualitative representations in systems thinking and systemic design [69] ranging from the very informal, such as gigamapping [70], to the relatively formal, like causal loop diagrams [71]. **Causal loop diagrams (CLD)** illustrate the causal relationships (depicted by arrows) among variables within a system. These diagrams differ from the consequence trees described in Section IV by allowing for the representation of feedback loops (closed paths of causal relationships). They enable the formalization and communication of more complex hypotheses about the causal mechanisms of a system, moving beyond a focus on the solution and enabling the identification of potential leverage points. Although CLD can be used in many ways, they generally represent the initial problematic situation. They invite a *less reductive* and solution-oriented approach. Fig. 2 illustrates a CLD representing the dynamics of Vinted's impacts, built from secondary material and workshops with designers. This type of diagram could help provide a *comprehensible* qualitative overview of the environmental and societal impacts of Vinted, such as indirect effects on charitable donations, its contribution to fast fashion, consumerist practices, and addictions (A, B, C, and D in TABLE I.) as well as systemic mechanisms in the clothing market as a whole (E in TABLE I.). In situations B and E (TABLE I.), they can aid in identifying intervention levers contributing to a more *inspiring* analysis.

E. *A quantitative modeling for understanding dynamics and comparing strategies*

Quantitative modeling requires focusing solely on quantifiable data. It narrows its scope compared to qualitative representations (which can capture societal phenomena). However, dynamic models allow for representing a system's state [72] over time and comparing scenarios.

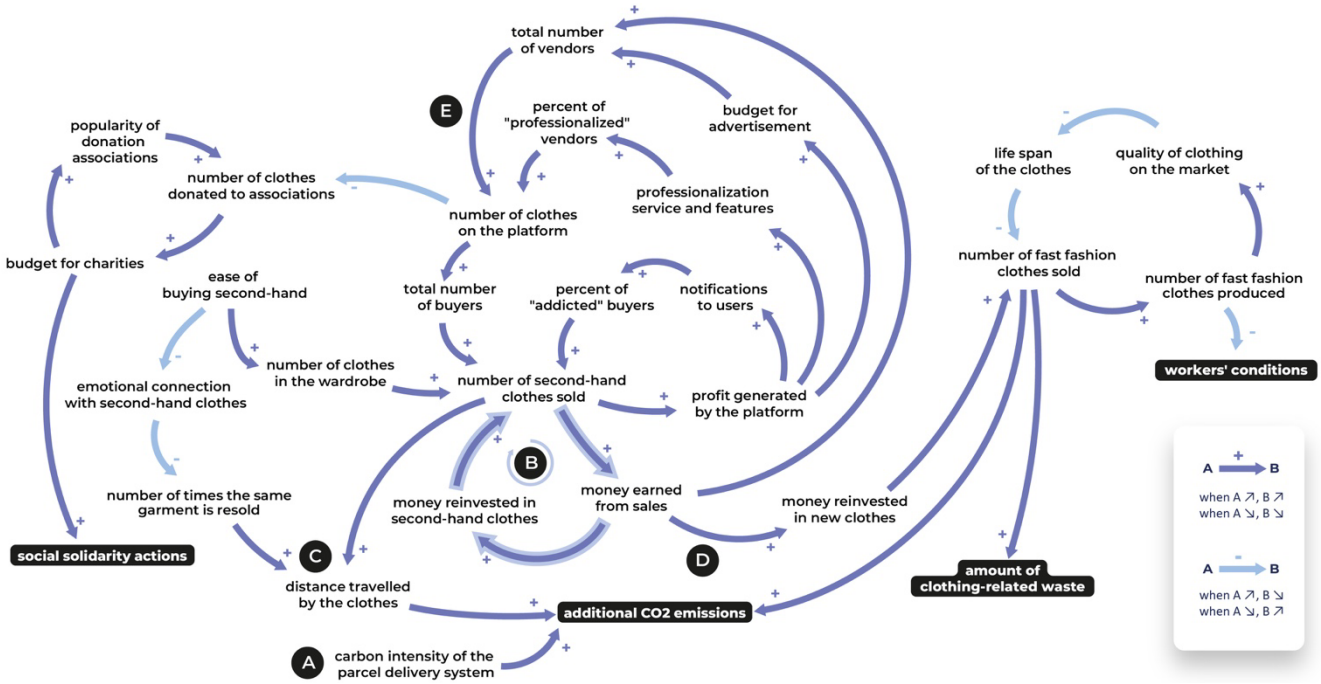

Fig. 2. A simplified causal loop diagram of Vinted platform dynamic behaviors (adapted from [73])

Certain studies have advocated for the integration of LCA with dynamic quantitative modeling [74]. This can be a valuable support for decision-making, providing an understanding of magnitudes and dynamics, as long as it does not override a comprehensive qualitative approach (e.g. CLD). In general, the dynamic models used to describe sociotechnical systems are either stock and flow models (top-down approach, relying on a system-level description), or agent-based modeling (bottom-up approach, focusing on describing the individual's behavior) [75]. Both types of models have inputs and outputs. The initial values of the inputs are generally set by the modeler, while the outputs are calculated during simulation. They can be explored manually, through trial and error, or systematically, using tools like OpenMole [76]. Model exploration can reduce quantifiable *uncertainties* and provide *inspiration* by identifying intervention points and discovering input values that yield satisfactory output values. Some are detailed below with the example of Vinted. Involving stakeholders in the construction of the quantitative model (Group Model Building as described in Section V.C) could enhance their understanding of its limitations. This allows for a critical examination of the results, which decision-makers may sometimes lack. In fact, most net impacts methods already involve a significant quantification effort that could be leveraged for decision making if it were fed into a model that could be exposed, simulated, explored, and critiqued.

For example, based on [73], we built a quantitative model[1] adopting a systemic approach to simulate direct and indirect effects of Vinted platform and services. This model is based on secondary sources including [24, 35]. Some approximations were made to simplify the model. It uses average values for certain model parameters (e.g., distance traveled by parcels, carbon intensity of transportation, carbon impact of garment production, etc.), as the primary focus is on orders of magnitude and dynamics rather than exact figures. Indeed, instead of aiming for a precise single aggregated "*net impact*" figure, this model enables stakeholders to manipulate variables and influences to compare multiple scenarios. This approach allows comparing the impacts of different design strategies, business models, and integrating the effects of regulations (B, C, E in TABLE I.) over time.

While the model is imperfect, it considers significant mechanisms overlooked by [24], in particular the rebound effect linked to the use of money from sales. Interestingly, this alternative modeling, utilizing the findings from [24] with some different assumptions, yields different results. Indeed, emissions turn positive (additional emissions surpass avoided emissions) in certain conditions. This illustrates the issue of making claims based on a single, definitive aggregated figure.

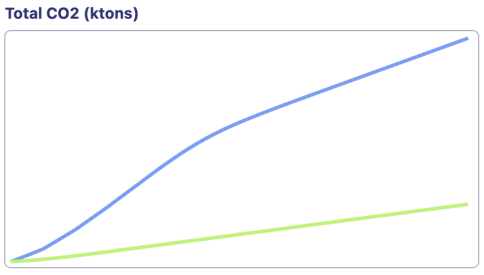

Fig. 3. Comparison of GHG emissions (in CO2eq) between two design strategies for Vinted (based on [73]). The values are intentionally not displayed in order to focus solely on identifying trends and the magnitude.

With the use of this model, one can compare the impact on GHG emissions (see Fig. 3) between arbitrary design strategies (B and C in TABLE I.). The violet (upper) curve illustrates a strategy primarily focused on reducing transport-related emissions (halved over the 8 years of the simulation, see (A) in Fig. 2) and encouraging sellers to spend their

[1] The model is accessible here: https://lii.enac.fr/projects/magnitude/

earnings on low-carbon options (to limit the impacts of indirect rebounds, such as (B) in Fig. 2). The green (lower) curve depicts a second strategy where a filter is used to limit the distance packages travel (C), a virtual currency forces sellers to spend their earnings on second-hand items (D), and a maximum quota is imposed on sellers (E).

In this model, certain inputs can be considered as data parameters that may require more precise definition to accurately represent reality. For instance, the influence of the number of sales on the platform's attractiveness. Other inputs can be viewed as tunable parameters, subject to influence through design interventions, strategic decisions, or regulatory measures. For example, in the scenario depicted by the green curve: the average distance traveled by garments could decrease with the implementation of a distance filter; the percentage of income from sales used to purchase new items would drop to zero due to a virtual currency; and the frequency of purchases and sales per person per month would decrease due to imposed quotas. Finally, among the significant outputs, we can mention carbon emissions, as well as the number of sales per month. Model exploration can help identify inputs that, when varied slightly, will have a substantial impact on outputs (Global sensitivity analysis). If these are data parameters, it implies potential sources of *uncertainty*, requiring further refinement through additional studies. If they are tunable parameters, it means they could be powerful levers (*inspiring*). For instance, a slight change in the percentage of sellers' money reinvested in new items can significantly decrease the emissions. Optimization could help identify combinations of input values that minimize GHG emissions and maximize sales, such as the rate of new clothes on the platform, the rate of compulsive purchases, and the rate of sellers using sales money to buy back on the platform. Regardless of the type of quantitative approach, involving stakeholders in the construction and exploration of the model is essential to critically evaluate the results.

VI. Discussion

This article emphasizes the necessity of presenting *complexity* and *uncertainties* to decision makers. However, this approach is in tension with several aspects of the decision-making process such as the availability of human and financial resources or the human cognitive limitations [43]. In alignment with [29], these tensions are characterized as a balance between the pursuit of *accuracy* and the practical considerations of *feasibility* and *comprehensiveness*. As the method's accuracy and complexity increases, the more challenging its application becomes (*feasible*) and the more difficult the results they yield can be explained and understood (*comprehensive*). Such "trade-offs" are inherent to decision making tools especially in environmental decisions [45] and should be made explicit and adapted depending on the level of decision-making whatever methods or tools are to be used.

Section IV emphasizes that net accounting methods are not designed for, and if used in isolation do not allow, the assessment of the compatibility of a solution with a sustainable future. The research field of absolute sustainability seeks to address this critical issue by developing methodologies that integrate top-down sustainable goals (typically planetary boundaries) with bottom-up indicators derived from LCA [77, 78]. However, they typically do this through environmental budget allocation, which implies that they operate in an attributional framework, whereas net impact methods operate in a consequential framework, making the two approaches incompatible [79]. This supports the argument that the consequences of a solution cannot be qualified as sustainable per se, but should be considered in terms of their level of compatibility with an environmental transition scenario.

Section V.A introduces the notion of values in the context of decision-making [41, 62]. It may be interesting to question the values underlying the construction of net impacts

TABLE III. Synthesis of net impacts methods challenges and alternative methods and tools

Challenges	**Recommendations based on our analysis**	**Suggested alternatives**
<u>*Uncertainty*</u>: Illusion of definitive knowledge Existence of unquantifiable uncertainties, which often make it impossible to reach a definitive conclusion	Embrace *uncertainty* (including non-quantifiable): building a comprehensive panorama	Requisite variety (stakeholders' diversity), Causal Layered Analysis, Group Model Building
	Expose *uncertainty*	Qualitative representation (Causal Loop Diagram), systems dynamics, model exploration
<u>*Complexity*</u>: Reductionist and solution-oriented approach	Enable *comprehension* of the *complexity* of the problem instead of a solution-oriented vision	Group Model Building, qualitative representation (Causal Loop Diagram).
	Enable *comprehension* of the *complexity* of the systems dynamics	Systems dynamics, simulation
<u>*Inspiring*</u>: Limited decision space, not allowing the exploration of different designs Cannot assess the compatibility of a decision with a transition scenario	Define an overall objective, follow a trajectory to achieve this objective	Normative scenarios and backcasting (future thinking)
	Identify levers and anticipate the direction and magnitude of their effects	Causal Layered Analysis (levels of analysis), Causal Loop Diagram, Meadows' twelve leverage points (levels of intervention), quantitative modeling.
	Support decisions rather than claims	Comparing several scenarios rather than comparing one to a hypothetical baseline (B, C, E in TABLE I.)
<u>*Robustness*</u>: Focus on modeling aspects and do not consider the involvement of heterogeneous stakeholders	Impose a plurality of perspectives to limit misuses without having to anticipate all their possible forms	Requisite variety, Value Sensitive Design

methodologies. These methods focus their efforts on the positive contributions of a solution (usually a technology-based product or service) rather than a profound understanding of the problem. Because they reason by iso-functionality, they are not appropriate to question needs (e.g. reducing the volume of wardrobes). As such, we might say that net impacts methodologies carry techno-solutionist visions, even if those are not shared by all stakeholders involved. While it is tempting to think that presenting a numerical value can guide consumers, public and private investors "*in the right direction,*" and that the sum of their individual actions will help achieve global goals related to planetary boundaries while maintaining free-market logic, some scholars argue that it may have the opposite effect [80]. Bond et al. [81] even argue that environmental impacts assessment "*supports neoliberal agendas by facilitating economic development.*" In fact, the term "*right direction*" is closely linked to the values and the vision of the transition paths considered implicitly or explicitly by stakeholders. It is to be mentioned that, in writing this paper, we have explicitly brought together our values and visions of a desirable future, including respect for social boundaries. Social boundaries are absent from net impacts methods, proof of their narrow conception of sustainability. As explained by Gray [49], the notion of sustainability is both equivocal and hardly appropriate to organizational levels, and he suggests "*the development of multiple and conditional narratives that [...] explicitly challenge the hegemonic claims of business movements in the arena of sustainability and sustainable development,*" which net impacts frameworks do not address.

The decision framework (TABLE I.) we used is open to criticism as it aligns with the current system and does not directly question power dynamics. It would be interesting to challenge the results of our article by envisioning alternative consumption and production systems, as in Community-based environmental decision-making [47]. Additionally, the decision-making situations are presented separately, which is a simplification we made to ensure clarity in reading. In fact, decisions at different levels can interact and be interdependent, for example, in the case of corporate lobbying with the government or when the company's strategy influences service and product design choices.

Finally, frameworks under discussion in this paper share a common objective of bringing knowledge to decision-makers. One of the main underlying assumptions, also present in Ekvall's framework [29], is that good decisions depend on the quality and the shape of the knowledge brought to decision makers. Yet, the performativity of the accounting methods (i.e. the capacity of methods to transform reality) cannot simply be analyzed through a methodological lens. Some authors suggest that the environment in which the methods are embedded should be also studied [82]. Even if managerial theories could be relevant, only a few authors have investigated this path [45].

CONCLUSION

This article examines the limitations of using net impacts accounting methods for decision-making at various levels, using the case study of Vinted as an illustration. We suggest that by overly focusing on aggregated figures these methods fail to represent on their own the inherent *uncertainty* and *complexity* of the dynamics they aim to model. From the perspective of consumers, external investors or shareholders, and policymakers, this may result in a partial and simplistic, when not misleading, *understanding*, as well as serious risks of misuse and "*greenwashing*." For designers and internal decision-makers, relying solely on aggregated figures allows, at best, to compare results from different solutions. This seems unsuitable for decision-making as this does not identify action levers or facilitate the exploration of multiple strategies. Moreover, the net impacts methods, if used in isolation, fail to determine the compatibility of the solution with a transition scenario, questioning their relevance when used for claiming positive environmental impacts.

To address these challenges, we propose a combination of alternative or complementary methods, tools, and best practices drawn from systems thinking, complex thinking, systemic design, and future studies, and applied them to the Vinted case study. To ensure the *robustness* of the methodology, we suggest building in the diversity of stakeholders and the explicit expression of their values, rather than imposing safeguards on the calculation methods. We advocate for a critical examination of the present (CLA), defining one or more desirable futures (Normative scenarios), and planning a trajectory to achieve them (backcasting and Meadows' leverage points). We recommend collaborative modeling (Group Model Building) for a complex *comprehension* of the situation, with a complete qualitative view (Gigamapping, CLD) and a complementary dynamic quantitative perspective (Systems dynamics). Some of these approaches represent avenues of research, either building on the foundations of net impacts methods, complementing, or even replacing them.

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