Green Chemistry

Cutting-edge research for a greener sustainable future

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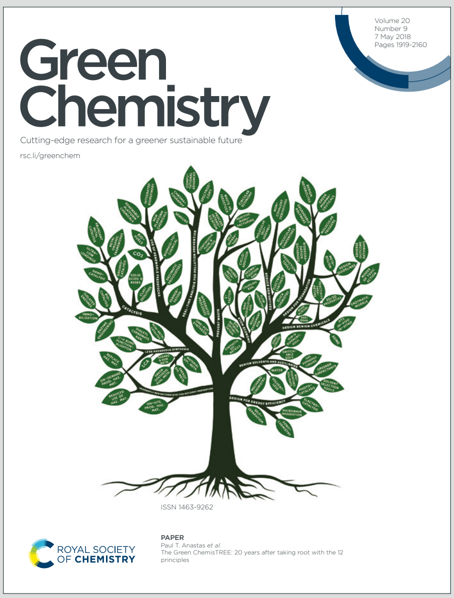

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Green Foundation Box for perspective article:

Situated Green Chemistries:

a Starting Proposal

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1. The main advance in green chemistry discussed in this article is an original route for acknowledging and addressing values and perspectives embedded in green chemistry research. The route will strengthen the scientific rigor of green chemistry, and offer more robust solutions, because more diverse and contextually grounded.
2. The "situated green chemistries" proposal is of significant wider interest because it addresses a pressing blind spot of research practices in the current era: the need to learn how to scientifically handle contextual and experiential dimensions of knowledge production. Such need is pressing due to the "great acceleration" which characterizes the current Anthropocene era, thus continuously shifting research boundaries.
3. If successful, the field of situated green chemistry is unprecedented. The foundational paper on situated Knowledges (Haraway,1988), cited 8900+ times overall, has not yet spawned an operational methodology in chemistry.

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Situated Green Chemistries: a starting proposal

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Abstract

Green chemistry has long benefited from interdisciplinary collaborations, integrating insights from disciplines such as toxicology, environmental science, economics, computer science, earth system sciences, and engineering. This paper further extends this approach by arguing that, due to the rapid changes of the Anthropocene, scientific methods must adapt to shifting conditions by integrating methods from social sciences. Since we have to produce research even when there is no time for ideal consensus-building, in the pressing circumstances where shrinking human habitability on the planet is a legitimate source of concern, we would benefit from acknowledging the value-driven, cultural and historical contexts that influence non-ideal current outputs. By integrating a contribution from the social sciences, specifically Donna Haraway's situated knowledge concept, the « situated green chemistries » framework proposes to do so by explicitly situating core drivers framing the research, such as local sustainability and robustness against severe environmental and social disruptions ("+5°C Fighters"), addressing imbalances affecting the Global South ("North-South" driver), developing technologies that are designed to be simple to use, repair and make ("Low-Techs"), pursuing science for the intrinsic value of knowledge ("Intrinsic Value of research"), environmental and societal stewardship ("Do No Harm"), business and governmental leverage ("Global Forces"), and treating research as a creative endeavor akin to art ("Research as Art"). By more explicitly framing research around these and others drivers of diverse desirable futures yet to be identified by the community of green chemists it is argued that green chemistry research can expand its scope, embrace complexity, and offer more robust solutions, because more diverse and contextually grounded, to some of the challenges for research during the Anthropocene.

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Green Foundation Box (perspective article)

What advances in green chemistry have been discussed?

The main advance in green chemistry discussed in this article is an original route for acknowledging and addressing values and perspectives embedded in green chemistry research. The route will strengthen the scientific rigor of green chemistry, and offer more robust solutions, because more diverse and contextually grounded.

What makes the area of study of significant wider interest?

The "situated green chemistries" proposal is of significant wider interest because it addresses a pressing blind spot of research practices in the current era: the need to learn how to scientifically handle contextual and experiential dimensions of knowledge production. Such need is pressing due to the "great acceleration" which characterizes the current era, which the term "Anthropocene" currently proposed by some can help characterize, thus continuously shifting research boundaries.

What will the future of this field hold, and how will the insight in your review help shape green chemistry science?

If successful, the field of situated green chemistry is unprecedented. The foundational paper on situated Knowledges (Haraway,1988), cited 8900+ times overall, has not yet spawned an operational methodology in chemistry.

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1. Introduction.

Green chemistry aspires to contribute to global improvement through man-made chemical transformations while at the same time minimizing their negative environmental and human impacts; it does so by emphasizing sustainability of chemical transformations and processes through design,[1–4] and integration of system thinking.[2,5–8] Over the years, green chemistry has benefited from interdisciplinary alliances with fields such as toxicology,[9] engineering,[10] and environmental sciences.[11] These partnerships have enriched green chemistry by enabling the integration of scientifically informed methods for assessing and reducing unsustainable impacts and suggesting avenues of sustainability.

The urgency of global challenges,[12,13] from climate change and biodiversity loss to resource depletion and socio-economic inequities,[14–17] their complexity and systemic nature[18,19] have further reinforced existing calls to strengthen interdisciplinary approaches.[7,20] As already listed elsewhere,[8] several sustainability-driven systemic frameworks for chemistry or by chemists have been proposed as for example “Green & Sustainable Periodic Table”,[3] “One-world Chemistry,[6] “Circular Chemistry for Circular Economy”,[21] system thinking connected to the molecular basis for sustainability,[5] and more recently chemistry’s mission of material stewardship[22] and “Weaving Indigenous Knowledge with Green and Sustainable Chemistry”.[23] This paper is a further proposal in that direction; its distinctive feature is the resolute use of social sciences concepts to change our practices in research.[8,23,24]

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This paper argues that importing social sciences elements into green chemistry is required by the increasing pace, complexity and interconnectedness of global changes, which will be collectively evoked by mobilizing the term "Anthropocene".[12,13,25] The accelerating pace of the Anthropocene,[18] and the connected continuously shifting conditions of research context, probably render early uncertain stages preceding scientific consensus increasingly prevailing.[20] Ignoring this risks embedding hidden biases, values and perspectives into our research.[8] Indeed, as history and sociology-based studies about dynamics connected within scientific knowledge production show,[26,27] and as a study in political psychology can help illustrate (see Figure 1),[28] who we are, and in particular our values, biases, and perspectives, contributes to shaping the way we, as scientists, interpret evidence especially in the early stages of data analysis or when « values are in dispute, stakes high and decisions urgent».[20] By acknowledging and addressing such biases, values and perspectives embedded in our current research, we can strengthen the scientific rigor of green chemistry. Integrating social science methods relevant to these aspects into our research can provide green chemistry with methodological tools needed to uncover and mitigate these biases, and to cope with embedded values and perspectives thereby enhancing both the quality and relevance of our research. This paper suggests a way to integrate one of such tools.

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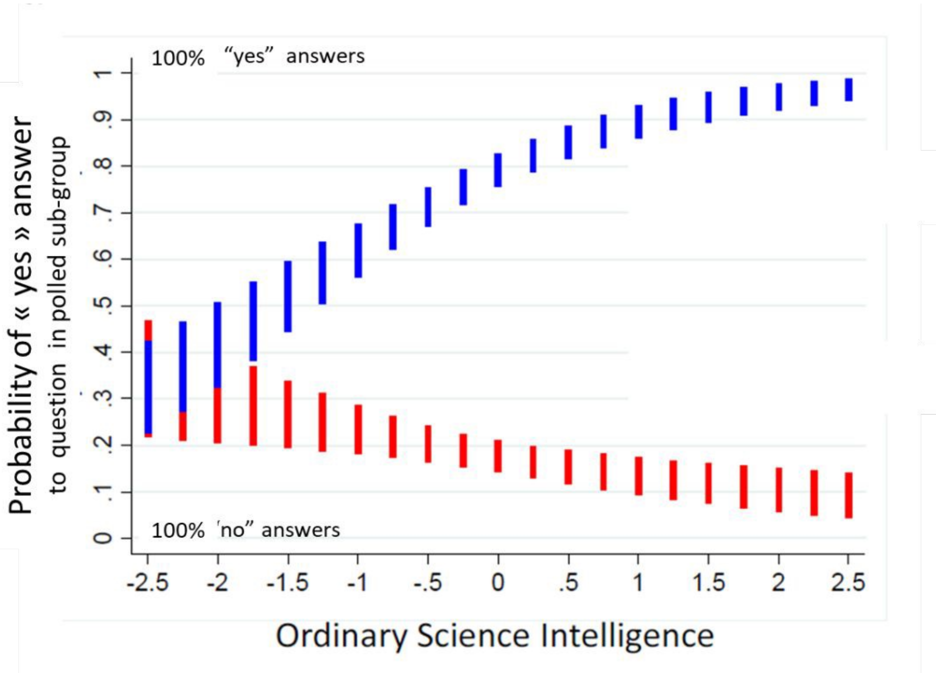

Figure 1a. Distribution of answers to a question related to choosing the main cause of climate change vs. the result of the polled person's ordinary science intelligence test in D. M. Kahan (2015).[28] Blue : poll responses from people who self-identified with political group A; Red: poll responses from people who self-identified with political group B. Visual adapted from ref 28 : Kahan, D.M. (2015), "*Climate-Science Communication and the Measurement Problem*" **Political Psychology**, 36: 1-43, with permission from John Wiley and sons, copyright 2026. See original paper for more information. Note how the polarization among the two groups interpreting the data increases with ordinary science intelligence : the high performing individuals on this scale appear to use their reasoning proficiency to selectively conform their assessment of evidence to the position that predominates in their group.

This paper argues that integrating Donna Haraway's concept of situated knowledge[29] —which recognizes and accommodates context-based factors during the production of scientific knowledge— into how we perform green chemistry research can be a way to produce better and more diverse research outputs. By adding pertinent contextual and experiential dimensions of

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knowledge production into green chemistry research, this approach aims to make green chemistry more accurate, robust, just and responsive to the pressing challenges of the Anthropocene.[25]

2. Let's embrace it: Situated Knowledge

2.1 Risks of Non-Situated Green Chemistry

One example from my experience as an academic researcher in this field illustrates how green chemistry research can exhibit undesirable—yet possibly pervasive—issues. These issues arise from a lack of acknowledgement of the situated nature of knowledge production. The example concerns a way of framing research around "peak load shaving strategy", which involves exploiting fluctuations in electricity prices, potentially making expensive technology economically viable under certain conditions (see Figure 2a).[30] Peak shaving strategy has been mobilized in energy transition research and in green chemistry, since it provides pertinent framing for research findings relevant to grid electrification, a climate mitigation strategy. Nevertheless, its uncontextualized presentation at a conference vividly revealed a possible disconnection. Figure 2b underscores the broader reality: 9% of the global population (750 million people) lack access to electricity altogether.[31] The application of the research presented is not as universal as the problem it tackles, global warming. While the research addresses a legitimate green chemistry approach and research, the universality of its framing does not translate to the universality of the research output's relevance. The disconnect was made more vivid by the very fact that the presentation occurred at a conference taking place in the very

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continent having the most limited access to electricity (See figure 2b) and that the conference itself had as specific overarching objective the development of materials research capacity in Africa.

Global warming is planet-scale, pressing and a recognized research-orienting target; at the same time, the chosen research avenue of investigation -peak shaving strategy for over solicited electrical grids- is context specific; in other words, the research avenue is situated and its relevance is limited to a subset of the global population. Presenting such a strategy as an ill-contextualized solution to a global problem is misleading. By failing to acknowledge the specific contexts for which it emerges, that is by being non-situated by the very researchers who produce it, such knowledge can unintentionally prioritize some contexts while marginalizing other possible avenues of research that could be relevant in other contexts for the issue at hand, global warming.

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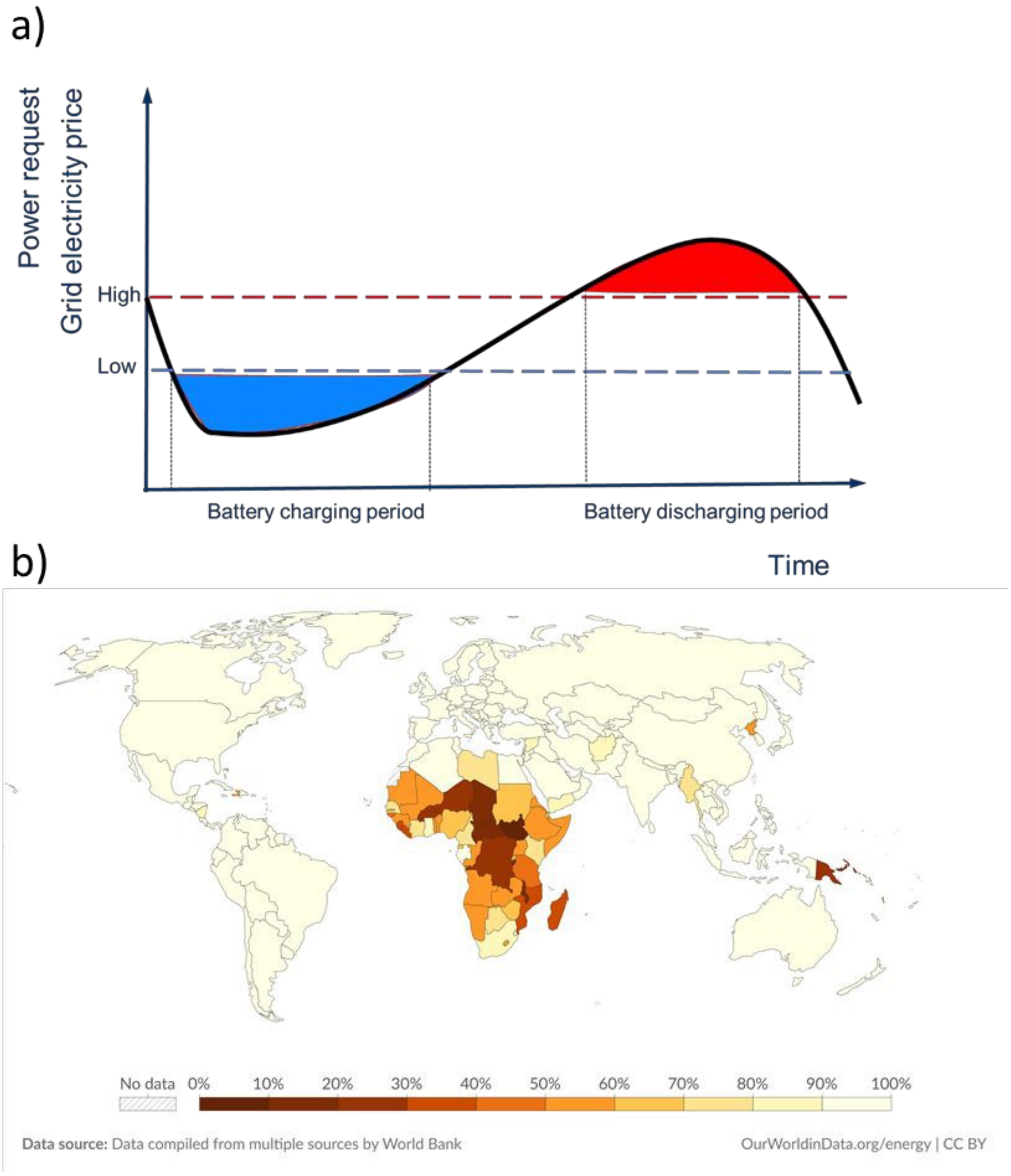

Figure 2. **a)** Schematic representation of the peak load shaving strategy for overloaded electricity grids. adapted from ref 30 : [30] Uddin *et al.* "*Review on peak load shaving strategies*" **Renewable and Sustainable Energy Reviews**, 82 (Part 3), 2018, 3323-3332, with permission from Elsevier, copyright 2026. **b)** Share of population with access to electricity (2023). Data source from ref 31 ourworldindata.org/energy (CC BY) compiled from World Bank data. .[31]

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This anecdote exemplifies the importance of recognizing the partiality of knowledge production. Non-situated green chemistry —that is green chemistry which fails to explicitly acknowledge the context of its validity and the perspective from which it is built, or at least attempts to share relevant elements in these directions, see later—can be scholarly, well-intentioned and useful in certain contexts and at the same time marginalize other relevant research avenues in green chemistry. This marginalization occurs because non-situated green chemistry implicitly dismisses other relevant research avenues by portraying its particular perspective as the neutral one (the one which does not need to be contextualized, the one which implicitly "works for everyone, everywhere"), hence no other research avenues are perceived as absent. Indeed, by increasing the perspectives from which green chemistry research is built, situated green chemistries can become more diverse and less partial and hence lead to a more objective knowledge production. The plural form of "situated green chemistries" is chosen to convey such increase in diversity of perspectives.

Integrating situated knowledge into green chemistry is not only a methodological necessity but also an ethical opportunity.[29,32] Non-situated approaches, which trivialize the assumption of universal applicability of their perspective, tend to ignore the specific contexts of their relevance, and therefore risk perpetuating inequalities by addressing questions and research topics relevant to that one perspective and thus, de facto, marginalizing other legitimate ones.[33,34]

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2.2 Foundational Insights from Situated Knowledge

This section aims at offering a primer of the concept of situated knowledge[29] for readers in the field of green chemistry who are not familiar with it. For interested readers, some more elements can be found in supplementary material. To the best of my knowledge, the concept of situated knowledge has not been explained from within the chemistry community before, even if important work explicitly using situated knowledge in green chemistry or adjacent disciplines such as in chemical education,[35] toxicology and environmental chemistry,[36 37] or critiques of lab practices[37] exist.

2.2.1 Focus on "situated"

The adjective situated wants to convey the following points which are applicable to all forms of knowledge :

- All knowledge depends on the context in which it emerges
- Knowledge and context shape each other and co-evolve
- Recognizing these connections is not optional but part of producing accountable and robust science

Centrally to situated knowledges, these unavoidable connections -- we cannot produce robust science without being "entangled" with the context, without participating to the mutual changes- require that those who produce science remain accountable for how they frame it, how they describe its reach, and how they respond to its effects.

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The task for scientists is to trace these interactions and to remain answerable for how their research participates in shaping its conditions. Therefore, responsibility (or in Harawayan terms response-ability, see SI) is not an optional ethical layer but part of how valid knowledge works.

This preliminary statement is necessary to say, as Donna Haraway does,[29] that all knowledge is situated, whether we acknowledge it or not. The choice therefore is not whether knowledge is situated- it always is, but whether scientists acknowledge and work with that situatedness, or not. As examples, fruitful situatedness acknowledgements from within scientific practice can be found in Liboiron, [37] Barad[38], or Suchman,[39] for environmental science, physics and computer science, respectively. One counter-example is given in the example given in the previous section: by omitting to address the situatedness and specificity of their research area (some questions addressed by the researcher could have been : where does it apply and where does it not ? Who does it benefit? What material resources does it need? What does this research changes, how can I remain in contact with the changes it elicits? Why and how do I care?...), the knowledge produced actually loses part of its validity, because it omits to share important aspects that make a scientific knowledge reliable. Like calibration, contextual parameters do not pollute the measurement : they co-define it, they make it possible for others to repeat, verify, or build upon it. Publish experimental data without reporting temperature, pressure, or instrument specifications renders the publication critically flawed. Stripping away those contextual details, those "meta-data", creates the illusion of universality while in fact weakening the result. Haraway's proposal is similar. Scientific knowledge does not emerge in isolation: it is made

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possible by instruments and practices (that orient what can be observed and how), values and institutions (that orient priorities and limit what should be investigated), norms and languages (that shapes what can be communicated), which all concur at giving scientific knowledge shape and meaning. Knowledge becomes trustworthy not when it pretends to be detached, but when it gains transparency about the circumstances that make it possible and the specificity of its pertinence. Completely ignoring these social, historical, professional and material conditions does not make science more objective, it makes it less reliable, because some of the very details that co-define it are erased.

But Harawayan situated knowledge is more than the argument just laid out. To situate knowledge is not only to trace where it comes from (see above and paragraph on constructivism in SI) but to remain responsive to what it does. The knowledge-making process is part of the situation, not separate from it. Scientific knowledge is active: it helps bring new realities into being, shaping materials, organisms, human and ecological systems, communication and interaction modes which in turns change the "meta-data" that shape research which in turn, looking to understand its role in this dynamic, adapts and changes, … This inter-play, this co-construction, make knowledge an action which requires scientists producing robust and reliable science engaged and responsive to the world to which they connect with their research and responsive to the effects their knowledge produces. In this view, scientific work is not just about producing scientific knowledge for something (understanding how it works or providing new solutions, new materials, new approaches) but is the inseparable action of knowing, doing, looking for the

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effects and being responsive to them. Because it is produced within those relations, scientific knowledge also carries a form of specificity and care (in the philosophical meaning of "care" see SI) for the effects: scientific knowledge does not simply act on a world "out there," but it participates in maintaining and transforming the very connections through which it emerges in the specific situation it is embedded in.

In this sense, the aspect of situated knowledge aligns very well with green chemistry. The response-ability of the situated scientist is in echo with the stance of green chemist, since by definition green chemists consider the implications of their work beyond the immediate confines of the specific project (can I decrease the risk of accidents ? when the new molecule developed in the laboratory enters the « real world » will it degrade safely ?) and this ability has increased with system thinking in green chemistry. Conversely, the ability of acknowledging in which terms the knowledge producing process in green chemistry is not neutral or universal but partial (because connected to specific practices, infrastructures, values and other aspects some of which detailed above) and in which ways we remain responsive to the effects of our research is not well developed. Such gap leaves room for improving green chemistry. This manuscript aims at suggesting a way such gap in green chemistry research could be addressed and reduced. The central approach around which this proposal hinges is the "partial perspective" concept, which is part of the situated knowledges conceptual tools and is exposed in the next section.

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2.2.2 Focus on "partial perspectives"

One of the most immediate consequences of understanding the "situatedness" of scientific knowledge explained in the previous section is that, since :

a) context is thus not just a backdrop but an active part of how scientific questions are framed, which data are collected, how results are interpreted,

b) there is no single perspective that can capture all the relevant aspects of the problem raised (relevant to whom? problematic for whom ?) nor all the scientific questions to be asked,

and yet c) the knowledge-making process participates in making the world, or to use the mirror phrasing, participates in stifling some possible ways of shaping it, if the process is not diverse enough,

then :

more objective scientific knowledge - and thus more robust knowledge and thus more robust ways of handling the interdependence the knowledge has with the world it helps co-create - requires several perspectives, all of which are partial. For the interested reader, more formal definitions of some terms used above as well as some connected terms central to situated knowledge (position, positionality, and perspective) are proposed in SI.

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Centrally, a core tenet of situated knowledge for guiding research is that the path toward better science, in this view, is not through unattainable detachment (an inexistent universal or neutral position)[29,40,41,42] but through integration of different perspectives, each with its limitations, and each with its distinctive attention and implications *for* a certain aspect of the situation. This necessity of different perspectives to increase the quality of the science produced is central to situated knowledge.

In summary, the existence of a perspective when producing scientific knowledge is not a surmountable hindrance, a bias, but a defining feature of science that, when embraced, can enhance the robustness of our scientific endeavors.

When relevant differences in perspectives are missing, important questions are not asked, relevant data are not collected, and pertinent changes in the situation which the knowledge co-produces do not occur.

Therefore, situated knowledges and standpoint theory (a relevant connected body of philosophical work, see SI) offer suggestions on how to nourish ongoing discussion about adding “missing voices” in our communities,[35,42] with ways to increase the kinds of questions, categories, and values green chemistry research addresses and with which it decides to be connected. The goal of this paper is to propose the “green chemistry core drivers”, defined below, as simple (probably simplistic but at least operational) ways to create space for diverse individual researchers’ perspectives while performing research. The goal is to use the drivers as stepping stone to facilitate the emergence of more diverse standpoints among the green chemistry community. Noteworthy, a standpoint (a collective achievement, see SI), an important term

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theorized by stand point theories in dialogue with situated knowledges,[43] builds upon or goes beyond a perspective, which is at the individual level. This addition is critical here because research is a collective achievement : the creation of standpoints, rather than individual perspectives, is necessary to the emergence of more diverse collegial research advancements (for example : an individual pursuing research from a peripheric but possibly relevant perspective cannot and should not alone generate the shift in evaluation paradigms or funding opportunities that such perspective would require in order to thrive). This paper aims at proposing perspective as a stepping stone for practical standpoint emergence (ex. parallel session in conferences organized around different drivers, collective discussion on evolution of evaluation criteria capable of not unduly dismissing uncommon perspectives,…).

This does not mean that "anything goes." Situated knowledges is a scientific practice and as such it is not relativism: not all opinions carry the same weight as scientific evidence. Situated knowledge is, rather, a commitment to defending and improving science by making it better because "connected with different contexts and values, where all positionings are partial and open to critical reexamination, where they interact and shift, leaving room for dialogue, contestation, and change"[32] and they remain responsive to the situation they co-create. A formal definition of situated knowledge in a language common in our community is proposed in SI.

For scientists, including chemists, this means paying attention also to the conditions, assumptions, and perspectives that shape research-learning to acknowledge the context in which and the context *for* which the research is performed -and checking that the knowledges developed

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are pertinent for the situation addressed. This attention strengthens rather than weakens scientific practice. Situating green chemistries, or rather researchers acknowledging the situated nature of their research in green chemistry and working with such situatedness, therefore, become an asset rather than a liability, fostering better science through examination of how their methods, tools, and assumptions shape what becomes visible. The integration of diverse contexts and standpoints that are presently absent and potentially useful for the context at hand is one of the expected consequences of this work. This consequence makes the following two goals closer: an overall more objective scientific production and a more robust overall research production. Since critical viewpoints possibly missing or underrepresented now could emerge and thrive, and since current viewpoints would become more scientifically grounded, the research would overall better prepare to the shifting conditions of the Earth system.

2.3. How to situate green chemistry research: the power of imagining desirable futures for situating research

This paper's proposal is to situate the research perspective by explicitly stating a salient aspect of the desirable future which the researcher aims at enabling through their research. Aspirations and value-infused shared visions for the future- also called imaginaries-[44] serve as the "social-sciences-meet-physical sciences" junction concept on which this paper is hinged. While rooted in the human-component that contributes to the situatedness of knowledge production during research, aspirations and shared visions do also drive collective efforts, shaping technological and scientific trajectories, becoming powerful catalysts for change. A compelling example, cited

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by Beltran and Carré,[45,46] is Anne-Françoise Garçon's analysis of the early 20th-century competition between electric and internal combustion vehicles in Paris. On top of technical, economic and organizational factors, the eventual dominance of combustion-engine vehicles was driven, Garçon says, by a shared cultural narrative- an imaginary-[44] that framed the automobile as a symbol of personal freedom and long distance travel. This shared vision shaped urban mobility, revealing the power of imagination in guiding technological trajectories and societal transformations.[46] Today, green chemistry research topics are similarly distinguished by the invitation to align research efforts with aspirational visions. Today, an example of such effect is how the widespread desirability of fossil-neutral electrification for a sustainable future is performatively shaping research agendas around electrification,[8,15,47,48] and can be insightfully analyzed through the socio-technical imaginaries lens.[49]

These examples tend to show the importance of shared narratives in mobilizing change and align efforts to a common desirable future. Such imaginaries offer a pathway for green chemists to learn how to explicitly connect the scientific advancements with a diversity of transformative societal goals and aspirations, as proxy for the Harawayan perspectives mobilized by the situated knowledge concept.[29,41,43]

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3. The situated Green Chemistries framework

3.1 Introduction on the method used to define the ten "Situated green chemistries" drivers

The "Situated Green Chemistries" framework aims at inviting researcher to connect their green chemistry research with community-shared aspirations for the future. The goal is to increase legitimate research perspectives and thus produce overall more robust and objective research in green chemistry. The mean is to propose community-inspired diverse key drivers as stepping stones to explicit community-shared aspiration for the future

Already formalized set of aspirations for the future such as socio-technical imaginaries, STIs, for mapping diverse visions of energy transitions, for example, exist.[49] Their layered structure mobilizing social science concepts (with, for example, " four dimensions co-produced in each vision: meanings, knowings, doings, and organizings" for STIs) can be very insightful. At the same time, the scholarly depth connected to STIs[49,50] require a learning curb that might stifle this effort to spark the reflexive approach around situatedness in the green chemistry community. The general exposure of green chemistry community to STS tools and concepts remains largely untapped.[8,23,24] Pre-existing categories like STIs might therefore be less adequate to the budding reflexive approach proposed here, than community-inspired self-defined ones as the drivers below.

The methodological route followed here is to develop a set of drivers that come from within the lived experience of green chemists and use it as a starting set to be refined by future collective

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discussion if the current proposal is embraced by the community. The starting group of 10 core drivers presented below (§ 3.2.) was constructed by me, the author, based on : 1) the analysis of the published literature and of conferences' contributions by the green chemistry community and 2) informal exchanges with colleagues and peers over my 30 years practice of academic research in chemistry. Below, I outline 10 initial drivers (see figure 3), acknowledging that this framework is a work in progress, subject to ongoing refinement through community feedback. I have chosen these drivers with the goal of proposing enough drivers to try to cover in a practical way a significant portion of the variety of aspirations toward desirable futures that I have perceived in the research community, as more fully explained in SI..

Some characteristics of the possible researcher perspectives' drivers present in the community were inferred from the analysis of the papers and communications, mostly from the introduction and conclusions of the papers (ex. interest in increasing technology-readiness levels, see for example drivers "Global Forces" (#1) and "Start-Up and small businesses" (#2), or interest in being "benign by design", #5). Such analysis lead to propose core drivers #1-to-#6 (see below), that appeared sufficient to cover most abstracts presented in a Green chemistry conference, sampled as a preliminary test for drivers' set completedness.[51] The informal discussions with colleagues over my career and in particular with peers during green chemistry-related events confirmed the pertinence of drivers #1-to-#6 chosen by inference from published literature. These informal exchanges also uncovered aspirations which were not common in the literature I perused and lead to hypothesize further drivers. Once such driver hypothesized in these informal exchanges, I searched for representative academic peer -reviewed papers in one of the most established collection of databases that indexes the world's leading scholarly scientific literature.

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Four more drivers (drivers #7-to-#10) were thus added to the framework. Follow-up discussions with peers suggest that these (and maybe others to be added through community refinement) might be worth exploring because meaningful to a portion of the green chemistry community.

A situated core driver is more akin to a programmatic declaration of intent by green chemists themselves rather than a characteristic of the published work. Therefore, the method used here (analysis of the literature and informal exchanges with practitioners rather than declaration by practitioners) is just a way to make a reasonable starting proposal. At the same time, omissions or redundancy in this starting proposal should not be necessarily critically problematic, since the starting proposal herein is intended to be modified by the practitioners themselves.

3.2 Core Drivers of the Situated Green Chemistries Framework

The proposed initial core drivers to situate green chemistry researchers are listed here below, their number is not a ranking. For each driver a short explanation and potentially representative academic works are proposed. While the intended process for pairing a driver with their body of work will be self-determination by authors, the fact that this manuscript associates a work with a driver without the authors' input, is because situated green chemistries approach does not exist yet in a formalized way and the intended process cannot be implemented.

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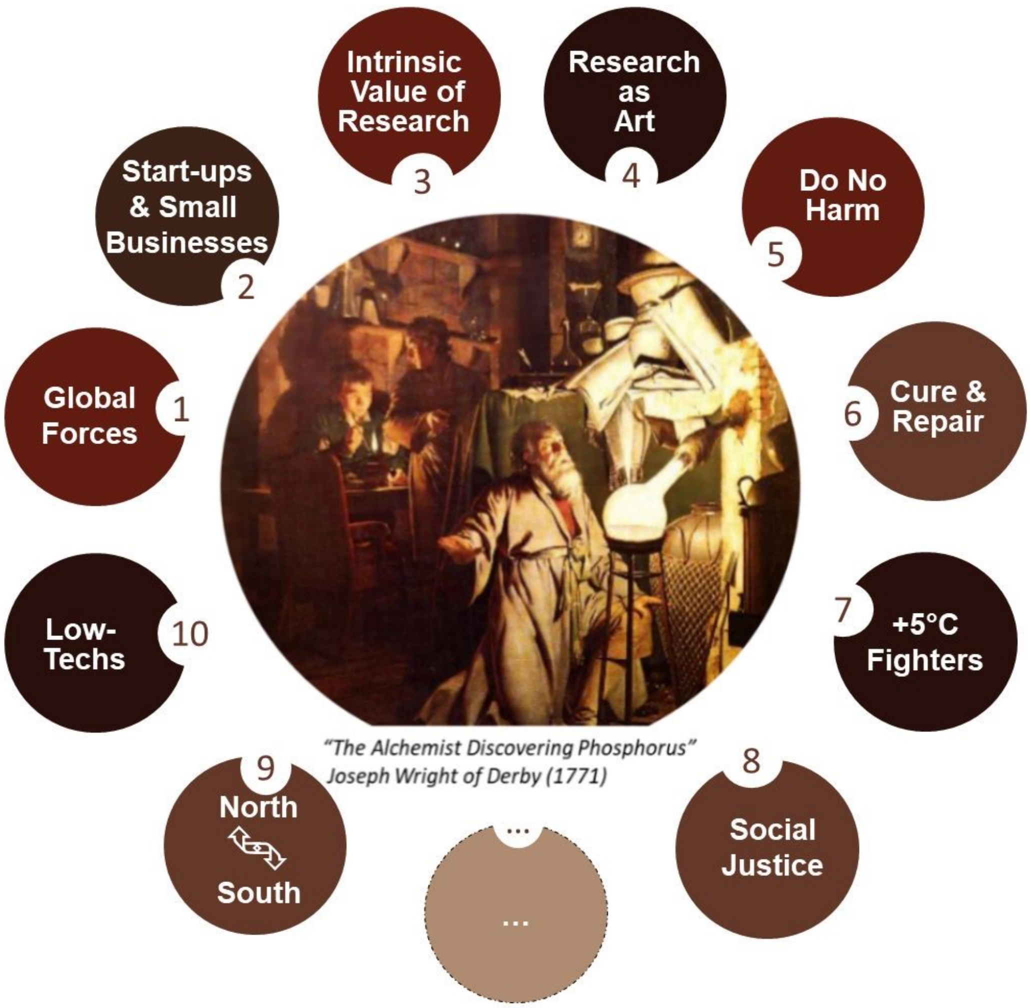

Figure 3. Pictorial representation of the initial ten core drivers proposed in this manuscript for the *Situated Green Chemistries* framework and described in the text. An additional potential driver has been deliberately left unspecified ("…") to underscore the evolving character of the framework, depending on future community input.(CC BY NC)

Driver 1: Global Forces. Green chemistry can provide solutions of global or even "geological magnitude", to echo Crutzen's work.[12] The ambition to tackle global issues through scalable solutions to be eventually connected to –or developed since the start with– large socio-economic

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stakeholders can be a key driver for research. A researcher situated through the "Global Force" driver trusts that the best way forward for their research is to have such ambition, to aim for the greatest possible contribution toward sustainability by interacting with the stakeholders of the moment (corporate, institutions) capable of tapping into substantial economy of scale. The following papers can illustrate this perspective:

- Example : Contributing to sustainable industry: *"Products and processes for a sustainable chemical industry: a review of achievements and prospects*" by J. F. Jenck, F. Agterberg and M. J. Droescherc in *Green Chem.* (2004).[52]

- Example : Chemistry-based approaches that contribute to advancing geoengineering as those cited in : "*Stratospheric solar geoengineering without ozone loss*" by D. W. Keith, D. K. Weisenstein, J. A. Dykema, and F. N. Keutsch in *Proc. Nat. Ac. Sc.* (2016).[53]

Driver 2: Start-ups & Small Businesses. Research in green chemistry can lead to marketable value-added goods through startups, circumventing large corporate groups' risks of inertia, while simultaneously retaining the capacity to eventually deploy at global scale. Green chemists situated through the "Start-ups & Small Businesses" driver connect research with entrepreneurial spirit trusting in startups to develop green chemistry innovations with strong commercial potential. The following paper can illustrate such perspective :

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- Example: "*Separation of Bio-based Glucaric Acid via Antisolvent Crystallization and Azeotropic Drying*". by H. Choi *et al. Green Chem.* (2022).[54] The work involves Kalion Inc, one of the U.S. Environmental Protection Agency (EPA)'s "Small businesses" Green chemistry Challenge awardees.[55]

Driver 3: Intrinsic value of research. Green chemistry researchers mostly situated in core driver 3 advocate above all the advancement of knowledge regardless of the uses and applications that might be derived from it. One of the arguments used in this context is that, since the knowledge produced by research and the innovations to which it will lead are unpredictable, it is unrealistic to assess the relevance of research on the basis of its putative impact, and therefore futile to attempt to govern this activity, except maybe to ensure that its diversity is preserved. Indeed, there are several historical examples of discoveries stemming from fundamental, knowledge-driven research later becoming drivers of applied innovation. In fields relevant to green chemistry an example can be lasers, famously dismissed in the 1960's as 'a solution looking for a problem' when they were reported,[56] which now underpin spectroscopic investigations present throughout out chemical sciences, green chemistry included. To rephrase the definition of this driver with terms that can connect to an abundant literature in human sciences, researchers situated in this driver trust in the *intrinsic value* of scientific knowledge (hence the name of the driver), regardless of the *instrumental value* that such knowledge can have, and get their main motivation to perform research from this trust.[57,58] From this perspective, science's way to contributing favorably to society is self-evident.

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Driver 4: Research as Art. Some researchers in chemical sciences see their profession akin to artistic activity, because they create their own object. This posture can be their driver. Some literature and op-ed inspirations that exemplify such posture are *"What Is a Beautiful Experiment?"* by M. Ivanova,[59] *"Can aesthetics contribute to chemistry?"* by V. Seifert in *Chemistry World (2023),*[60] *"Beauty in Chemistry : Artistry in the Creation of New Molecules"*[61] and *"The epistemic significance of appreciating experiments aesthetically"* by G. Parsons and A Rueger in *the British Journal of Aesthetics (2000).*[62,63]

Driver 5: Do no Harm. The "Do no harm" driver advocates the precautionary principle and prioritizes a "benign by design" approach to chemistry as the driver to their work.

- Example: "*Going All In: A Strategic Investment in In Silico Toxicology" by* J. Kosta and A. Voutchkova-Kostal in *Chem. Res. Toxicol.* (2020).[64] The authors embed absence of toxicity from the start in computer-aided drug design to ensure absence on toxicity in the drugs resulting from their work.

- Example: The fairly recent concept of exposome, which is the life-course cumulative environmental exposure of an individual to several health-relevant factors,[65,66] can be connected to *"do not harm"* green and sustainable chemistry.[3] The development of analytical chemistry research aiming at improving the definition of exposome

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measurement could be an example of "do no harm" driven researchers. A possible paper exemplifying research performed by researchers steered by this driver is "*EISA-EXPOSOME: One Highly Sensitive and Autonomous Exposomic Platform with Enhanced in-Source Fragmentation/Annotation" by* J. Xue *et al.* in Anal. Chem. (2023).[67]

The two "do no harm" examples given above target human health. This core driver can also target more broadly, even with potentially disruptive ethical and political definitions of whom are we taking into account (and whom we are not taking into account) in the targets of benign care (human beings, non-human beings, non-living?), thus extending the precautionary principle into questions about whom do we choose to "make kin" with,[68] about care,[69] and about opening to non-Eurocentric ontologies.[23,70–73]

Driver 6: Cure and Repair. The "Cure" driver focuses on health applications, while the "Repair" driver seeks environmental remediation, both addressing urgent needs within their respective and interlinked domains.

Driven by the "Cure" core driver, this green chemist develops research that contributes to new knowledge that is directly relevant to the medical field.

- Example: "*Continuous-flow synthesis of the anti-malaria drug artemisinin*" by Lévesque, P. H. Seeberger in *Angew. Chemie* (2012).[74] In this paper, a new process abiding green engineering principles is developed for the synthesis of an important drug.

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The "Repair" core driver moves researchers in green chemistry interested in repairing environmental damage. Even though "end-of-the-line" remediation solutions are not the principal target of green chemistry, some interesting examples come from our community:

- Example biomass-based catalytic remediation processes (such as phytoextraction, rhizofiltration, and biosorption) for the restoration of polluted ecosystems as in *"Ecocatalysis, a new vision of Green and Sustainable Chemistry"* by C. Grison and Y. Lock Toy Ki in *Current opinion in green and sustainable chemistry* (2021).[11]

- Example: The development of 'OleoSponge' adsorbing materials to clean up oil spills in open waters. "*Filtration membranes* " by S. B. Darling, J. W. Elam, R. Waldman, US patent. No.: US 2019/0054426 A1 Pub. Date: Feb. 21st, 2019 and "*Montmorillonite Membranes with Tunable Ion Transport by Controlling Interlayer Spacing*" by Liu *et al.* in *ACS Appl. Mater. Interfaces* (2023).[75]

As stated above, core drivers #1-to-#6 have been inferred mostly from green-chemistry literature. The next core drivers, drivers #7-to-#10, are proposed to account for drivers not encountered in my peruse of the literature (see § 3.1 and SI for more details on their origin); the proposed representative papers below therefore are for the most part from academic journals outside the green-chemistry fold.

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Driver 7: +5°C Fighters. The name of this driver references the extreme "+5°C" scenario that is the highest temperature taken into consideration for 2100 by the 6th IPCC assessment report,[15] to stress the "brace-for-the-worst" state of mind underpinning this core driver. It is to be intended more broadly than "just" preparing for climate disruption. This driver characterizes researchers mostly motivated by producing research in green chemistry helpful to face worst-case scenarios, such as the extreme disruptions due to global warming or other natural catastrophes such as the collapse of biodiversity, or due to profound social unrest or to other causes of drastic reduction in the world's habitable areas. In the scenario where the world become substantially disrupted in the next decades, what new green chemistry knowledge do we need to develop now in order to cope with this possible future later?

- What drugs do we need if the 5°C (or lower or other than climate-related) severe disruption occurs? And how can we produce them? Necessary drugs are just one of the aspects. The example of the paper reporting DYIbio insulin[76] below can be used for this driver. What about access to water? To other resources? Scientific knowledge-production connected to material circularity for a severely disrupted world might have a definition of circularity that is not the same as the one presented in most papers now. The experimental section of "+5°C fighters" research papers would probably not begin with "purchased from a commercial source". This latter comment underlines again that different drivers for green chemistry research create green chemistries with distinct primary objectives, distinct means and distinct practices.

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Driver 8: Social Justice. This driver leads to research aimed at addressing perceived social injustices. It aims at producing scientifically-informed knowledge in the field of chemical sciences which is relevant to grounding the debate around a topic related to social justice. For the connections of green and sustainable chemistry with justice-seeking topics, see for example several items in Anastas and Zimmermann's "*Periodic Table of the Elements of Green and Sustainable Chemistry*", such as "Element 37 : Ensure Environmental Justice, Security and Equitable Opportunities", "Element 4 : Design to Avoid Dependency" or "Element 72 : Benefits Distributed Equally", among other relevant elements.[3] The following papers can illustrate the perspective for which research can enrich a social or societal debate.

- Example: *"Is Lithium Brine water?"* by M. Ejeian, A. Grant, H.-K. Shon, A. Razmjou in *Desalination* (2021).[77] The DFT calculations reported therein help understand if brine is more akin to water or to a mineral. Methodologically, the work follows scholarly procedure in the field of theoretical chemistry. Less conventionally, the framing of the introduction directly exposes the authors' interest in contributing to the ongoing point of social tension around some brine fields, where environmental issues linked to water access have been connected to brine collection practices. Scientifically advancing knowledge whether such brines behave like water solution or as solid has implications for this debate,[77,78] and can thus be associated to the "*social justice*" core driver.

- Example: *"The Open Insulin Project: A Case Study for 'Biohacked' Medicines" by* J. E. Gallegos, C. Boyer, E. Pauwels, W. A. Kaplan, J. Peccoud in *Trends in Biotechnology*

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(2018).[76] The paper reviews how biochemists, considering that prohibitive prices in their country make access to vital medicine socially unjust, organized in community biolabs and a DIYbio movement to develop and share useful scientific knowledge to counteract this situated injustice.

- Example: The chemistry research performed as part of a citizen science project to measure air pollution in "*A critical air quality science perspective on citizen science in action*" by D. Booker, G. Walker, P J. Young and A. Porroche-Escudero in *Local Environment* (2023),[79] or to report microplastic pollution in water in "*Reporting Guidelines to Increase the Reproducibility and Comparability of Research on Microplastics"* by W. Cowger and 19 co-authors in *Appied Spectroscopy* (2020).[80] This line of research is connected to the "science undone" concept,[81] when groups of people perform research to defend their interests and overcome a lack of official data (or their suppression, underfunding or defunding, or malicious discredit) in established arenas, there included academic ones. This "social justice" driver could therefore also help introduce topics into the academic arena, particularly topics that are, for various reasons, on the fringe.

<u>*Driver 9: North ↔ South*</u>. This driver aims at performing research in green chemistry for addressing or correcting global inequalities and the inherited injustices between the global North and global South. More specifically, this core driver is relevant to those, like me, who feel that

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any desirable future will have to have ridden itself of these dynamics and consider this task a priority.[8] From this « *North* ↔ *South* » perspective, it is essential to develop research in chemistry that can both correct the existing effects of global inequalities and of inherited injustices and propose new routes. Some literature inspirations around this driver are reported below and they tackle possible aspects of North-South injustices such as denying right to access, extractivism and epistemicide.

- Example: "*Simultaneous CO_2 capture and metal purification from waste streams using triple-level dynamic combinatorial chemistry*" by J. Septavaux, C. Tosi, P. Jame, C. Nervi, R. Gobetto and J. Leclaire in *Nature Chem.* (2020).[82] This paper focuses on using CO_2-triggered combinatorial chemistry to help recycle metallic elements from spent batteries. This paper is an example on how to find resources in end-of-life waste produced in the global North; this approach can therefore reduce global North common extractivist reliance on resources from global South, and can therefore be seen as a research strategy contributing to address historical North ↔ South dynamics.[83–85]

- Example: The previously discussed "*Is Lithium Brine water*?" by M. Ejeian *et al*.[77] can also be used as a possible example here, if the motivation of the authors to perform their research were connected to criticism which sees colonial dynamics in current electrification of global North.[84,85]

- Example: *"In Vitro Characterization of a Nineteenth-Century Therapy for Smallpox"* W Arndt, *PLoS One*, 2012[86] can be seen as a scientific contribution to curb ongoing

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epistemicide regarding knowledge produced in the global South.[87] In this case too, as discussed at the end of "Driver 7: +5°C Fighters" section, the way we practice research, and not just the scientific results by themselves, emerges as one of the relevant features that must be co-developed during the research to align with the core driver. For example, new knowledge produced can provide advancements on several fronts, not just in the "pure" level of knowledge. The production of new knowledge can help, for example advance someone's career, and such advantage can materialize in subtle yet important practices like authors' order in the paper publication, for example. If we limit the discussion here to academic capital generated by research (rather than, say, financial benefits) one question relevant for this driver attentive to north south disparities is how this academic capital is distributed: How does the list of co-authors reflect the value represented by the core driver? Are the original "owners" of the knowledge considered? Does the knowledge produced proportionately benefit the North ↔ South dynamic?[88] These types of questions reveal one of several directions for future refinement of this preliminary "Situated green chemistries" framework proposal and the several layers simultaneously relevant for its deployment.

Driver 10: Low Techs, that is technologies that are designed to be simple to use, make, repair and eventually disassemble,[89,90] and which do not require sophisticated or harmful supply chains. For « Low Tech » - driven researcher, desirable future needs simple tools developed and maintained by a community of users, with a low overall environmental burden, possibly at a local

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rather than at a global level, so with no need for centralized scalability and most likely specific to the community and its environment. The aversion for complex infrastructures and sophisticated supply chains is one important difference between this driver and driver 1 "Global Forces".

- Example : Several research in the field of energy transition are reported in the low tech communities[91] and can thus be considered (at least *in pectore*) green-chemistry-related research. The solar concentrator is a featured technology in the low tech community.[91] The paper *"Towards solar metallurgy: Iron ore reduction by ammonia under concentrated light flux"* by M Luu *et al.* in *Solar energy (2025)*[92] shows a chemistry-related research in this area. The senior researchers of the *Solar Energy* article clearly explain why and how their aspirations toward a "low tech" future, nourished by the sustainability concept of conviviality,[90] has guided their research topic choice,[93] offering an example of how researcher can situate themselves via explicit mention of some socio-technical characteristic of their desirable future and from there "retroplan" adequately aligned research projects

- Example: The insulin project [76] presented in driver 8 *"Social justice"* above could be an example also in the low tech section. This goes to show that it is not necessarily the work itself that decides the classification in the "*Situated green chemistries"* framework, but also the intention of the authors. In this sense, most of the examples that are given throughout this manuscript are really just attempts to illustrate what the starting proposal,

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since the authors rarely explicitly share diverse “shared vision for desirable futures”, the fulcrum of situatedness considered as relevant here.

- Example*:* A low tech solution specifically developed for removing arsenic well water in Bangladesh is reported in *“ Development of a Simple Arsenic Filter for Groundwater of Bangladesh Based on a Composite Iron Matrix”* by A. Hussam and A.K. M. Munir.[94] Tellingly, the local-sourcing of the most of the components is stressed in the paper (see Table 1 thereon). Indeed, the need for a simple supply chain embedded in the low tech goal, often leads to favour situation-specific over globally-deployable one-fit-everywhere research goals and practices. For some, desirable futures do not rhyme with scalability[95] which is a common implicit quality of the findings sought by researchers driven by the « global forces » driver exposed above.

- Unlike the three examples just mentioned, the next two examples pitch low tech as a necessity for some parts of the world which, according to the authors, cannot attain the “state-of-the-art” or that are “developing countries” or “low and lower-middle income” countries: [96] *“Comparison of Different Pretreatment Strategies for Ethanol Production of West African Biomass”* by S. T Thomsen, J. E. G. Londoño, J. E. Schmidt and Z. Kádár. in *Appl. Biochem. Biotechnol.* (2015)[97] and *“Local manufacturing of perovskite solar cells, a game-changer for low- and lower-middle income countries?” by* B. Roose, E. M. Tennyson, G. Meheretu, A. Kassaw, S. A.; Tilahun, L.; Allen, and S. D. Stranks *in Energy Environ. Sci.* (2022).[98] The points of view that can be inferred from the articles’

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introduction and opening statements which revolve around the incapacity to attain the "state-of-the-art" by these "developing" or "low and lower-middle income" countries,[96] suggest that *Low tech* is not the best desirable futures which the authors' envision but rather an *ersatz* of desirability tailored for not-fully-there-yet "developing" countries". This positioning suggests that low tech is not the authors' "core driver". The discussion on hierarchy of values[8,96] that such type of introductions suggest is beyond the scope of this paper. Their presence here adds another layer to the "situated green chemistries" framework. Indeed, inspiration for green chemistry associated with one core driver can come from wide sources. Situated green chemistry is open to cross-fertilization and dialog or confrontation between distinct visions of desirable futures.

- Driver …: Yet to Be Determined. This placeholder underlines the evolving nature of the framework, leaving room for future drivers that may emerge through community dialogue and acknowledging that the current ones are only starting suggestions and need to be refined or removed if not relevant after exchange with the community. They also allow me to materialize the filiation from and show gratitude toward the "twelve green chemistry principles" foundational work within the green chemistry community.[1]

The "Situated Green Chemistries" framework has the potential to engage the community, and facilitate a wide range of opinions and drivers present within the community become more visible and operational. Community engagement is the goal of this manuscript. The contribution from social sciences and philosophy into green chemistry and the usefulness of concept from social

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sciences (such as social imaginary or situated knowledges, for example) for this work also point to the opportunity to co-construct such dynamics with social scientists.

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4. Conclusion

Green chemistry, like all scientific disciplines and sub disciplines, is constructed through ongoing interactions among the social, physical, and ecological worlds. These interactions shape research trajectories. Some of these interactions and trajectories can lead to avenues of research that are narrower than what they could be. In the Anthropocene, limiting or neglecting potentially relevant research avenues becomes especially perilous.

The "Situated Green Chemistries" framework draws on Haraway's concept of "situated knowledges", as a route to more epistemically robust, ethically adjusted and politically less unduly restricted knowledge production. In this way, the framework attempts to help rid our current practices from two pitfalls: poor handling of context-based factors during the production of knowledge and harmful narrowness of research themes. To favour the wider and fairer exploration of research avenues and the more robust overall production in research through strong objectivity,[40,41,43] the "Situated Green Chemistries" framework offers a practical approach: researchers are encouraged to identify a core driver—whether it be social justice, low techs, +5°C fighters, or another among the current proposed 10—and to use it as a foundation for building their research toward desired futures.

This project can also help structure our identities differently in these changing times. Building research communities around our main core drivers (social justice-driven green chemists, "do-no-harm"-driven green chemists, economic growth-driven green chemists, etc.) rather than —as is often the case—around our disciplinary area of expertise (catalysis, synthetic chemistry, biomass conversion, etc.) can offer a new layer of motivation and creativity, and a new

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framework allowing constructive synergies to emerge. This reframing has the potential to foster new motivations and provide a broader sense of purpose, creating an environment where diverse approaches to green chemistry can thrive for a more robust bid to preparing for sustainable futures. In all these regards the "situated green chemistries" approach is an ambitious one.

At the same time, the "Situated Green Chemistries" framework is still a rough initial proposal which requires expansion. The proposal is rough because, firstly, while researchers at the individual level are responsible for aligning the research they perform with their ethics—and we must reclaim this agency where we have lost it—the choice of research orientation cannot be left solely to individual researchers or to self-organized groups of researchers alone (which is where the current version of the "Situated Green chemistries" framework stops). Research orientation is political, and as such, the framework requires consideration at a level that is larger than academia. Secondly, the current framework is rough because it remains "down-to-earth" (code for "unsophisticated") since it operates within the familiar ontologies -what we consider real- and epistemologies – what we can know and how we can know it- familiar to most chemists in the academic arena I am familiar with. As my ongoing readings suggest, the deeply ingrained chemical perspectives of many chemists—including myself—will inevitably need to expand and intertwine with other ecological and social understandings. This evolving journey promises to reshape how we think about green chemistry, and its role in broader ecological and societal systems. I am looking forward to intra and transdisciplinary encounters and hope that the invitation to engage in this journey, which this manuscript conveys, will be heard.

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While looking forward to these and other necessary improvements to be achieved collectively, I still believe in the merit of this starting unrefined proposal—choosing a core driver and applying the tools and methods of contemporary green chemistry that are still very much part of today's green chemistry territory — because it is an operational invitation : this is where we are now, and we will build more diverse, including necessarily substantially different[100] green chemistries from here.

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A verse of poetry. Attempts to let my own distinctive voice slowly emerge through more academically recognizable rhythms. As attempts to narrate and produce academic knowledge from a visibly different perspective. As an invitation to accept the unfamiliar territory into which academic research has to embark, amongst these Anthropocene-laden uncertainties. Unprecedented bibliographic conventions to challenge the common ways. And challenge the common ways of formatting bibliography because the usual ways are not adapted to transformative interdisciplinarity which is pointedly needed. These, similarly perilous style- and content-related experiments, as well as other issues in the text itself lead to an experimental version of this paper being rejected. As a different statement about style, situated knowledge, yearnings, permission to narrate and scholarly language, this version has used generative artificial intelligence to shorten the original text and rephrase sentences in less personal manner and more scholarly language. The original version is available to interested readers.[101]

The original version also contains more elements on “from where I speak” or “lieu d’énonciation/locus of enunciation/lugar de enunciación”.[33,34] Some of them take under the form of an extended explanation on why I would like to express my sincere gratitude to the many colleagues whose support or guidance have been crucial in shaping this work. Their names are Dimitris Papadopoulos and Patrick Degeorges, María-Grace Salamanca González, Michel Lussault, Jérôme Canivet, Samir Boumediene, Fabrizio Li Vigni, Mélanie Gourarier, Jérôme Santolini, Pablo Jensen, Natacha Krins, Manon Guille-Collignon, Emmanuel Landrivon, Paul

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Data Availability Set

For

Situated Green Chemistries: a starting proposal

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As a Perspective article this manuscript does not have data relevant for a DAS