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Editorial
Technology Assessment for Addressing Grand Societal Challenges

***Abstract*—Emerging technologies are both a cause of many grand societal challenges (GSCs) facing twenty-first-century societies and an integral part of some of their most promising solutions. As an element of the GSCs, technology becomes intertwined with several interrelated issues that constitute the GSCs. This calls for approaches to Technology Assessment (TA) that account for the paradoxical role of technology in the GSCs, and the imperative and complexity of pointing technological innovation toward addressing the GSCs. In this introduction to the special issue, we identify three major streams in TA research and practice, namely TA as a policy instrument, a deliberation process, and an issue field. These streams highlight tensions between relying on experts and on the inclusion of various stakeholders in TA processes, and between a TA framing around the technology and framing around critical issues, such as those constituting the GSCs. We discuss the advantages and challenges of each stream. We also outline and discuss key principles for conducting TA in the context of GSCs. We end by introducing the four papers that constitute this special issue.**

I. Introduction

The rapid acceleration of technological developments and the widening scope of technological transformations are challenging our ability to assess existing and emerging technologies' social, economic, and environmental consequences. Public and academic discourses increasingly recognize the need to better understand and evaluate the role of technology in major societal challenges facing humanity in the twenty-first century [10]. Addressing these "*grand societal challenges*" (GSCs) requires the creation of shared visions of the desired futures that can be embodied in organizational strategies, innovation programs, and policy frameworks [28]. Technological innovations can be part of the causes underlying the GSCs by perpetuating historical patterns of social inequality and environmental degradation, but can also be integral to solutions for addressing the GSCs in the article. This paradoxical effect of technology as both an enabler and a constraint to the achievement of a more sustainable human future highlights the need for effective approaches to technology assessment (TA) that can support the evaluation of both the risks and the opportunities embodied in new and emerging technologies [27]. Yet, despite the critical need for appropriate TA frameworks to address the GSCs, little research attention has been paid to the forms that TA needs to take in relation to the imperative of addressing GSCs [8], [25], [26].

The origins of TA have been linked to the formation of the US Office for TA in the 1970s as a means of assessing the impacts of technology on society [25]. However, this expert-based approach has been challenged by alternative perspectives that challenged its assumptions of technocracy and emphasized the emergence of technology's societal impacts from intertwining technological and societal factors [22], [24]. Subsequent approaches to TA have responded to these challenges by advocating the inclusion of a wider group of stakeholders in the TA process, resulting in what has been dubbed participatory TA [9], [25]. Such deliberative processes [28], align with new forms of innovation governance commonly referred to as responsible innovation [21]. These forms of "inverted TA" move away from a limited reliance on expert assessment of potential impacts towards an assessment that is built around the public response to new technologies [6, p. 108]. In addition, TA has been moving from a preventative to a prospective stance, from passive responsibility based on duties or liability to active responsiveness based on quality.

The recent developments in TA are particularly important to analyze in relation to their suitability for addressing GSCs. GSCs reflect multiple complexities and multilevel, multidimensional problems that require concerted efforts by various actors— public, private, and nonprofit. In addition, the boundaries of GSCs are often hard to define as the challenges are interrelated and difficult to isolate. Thus, addressing GSCs requires coordinated and collaborative efforts [10] in which multiple perspectives and approaches are integrated, including those of the poorest and disenfranchised. Typical examples of GSCs include scarcity of materials, climate change, aging societies, poverty, pandemics, and digital inequality. Often GSCs contain a number of interrelated issues which might evolve in different ways and require diverse forms of response. Multiple public values need to be considered when addressing GSCs, and there are often tensions between values, which need to be resolved to enable collective action in the face of GSCs [7].

Yet, despite the significant developments in TA, assessment of technology in relation to GSCs remains problematic. This is particularly true for emerging technologies, such as those commonly subsumed under the term "fourth industrial revolution" [e.g., artificial intelligence (AI), distributed ledger technology, blockchain]. TA is complex in these cases because of the high levels of uncertainty associated with the evolution of such technologies, including their entanglement with the GSCs through rapidly changing cultural norms and socioeconomic relations (Lin, 2011). Thus, while many look to emerging technologies for addressing GSCs [27], the processes through which we can collectively engage with both their positive and negative consequences require further conceptualization and analysis.

Digital Object Identifier 10.1109/TEM.2022.3233460

II. Streams of TA Research and Practice

The TA literature presents three different streams that define the field's evolution over the past few decades: TA as a policy instrument, a deliberation process, and an issue field. Initially, TA was based on input from experts to inform the development and implementation of technology-related policy. However, new approaches that require broader participation from multiple stakeholders emerged as complementary or alternatives to the expert-based approach. More recently, the focus in many TA circles has shifted toward interorganizational and multidisciplinary processes that crate shared imaginaries of the future.

A. TA as a Policy Instrument

The first stream emerged with the practices and discourses that gave rise to the early forms of TA institutionalization. This approach uses TA to describe the deployment of different processes and tools to determine the potential impacts of emerging technologies. It draws heavily on expert knowledge from science and engineering for delivering advisory and precautionary recommendations to organizations and society. This approach continues to develop and remains an integral part of public policy apparatus, such as the design and implementation of early warning systems. It builds on the premise that technology's impact can be quantified and projected.

As a public policy instrument, TA seeks to draw on expert knowledge from science and technology-based disciplines. It is expected to bridge science/technology and politics through the exchange of technical knowledge. However, adopters of this approach to TA need to grapple with the paradox of expert independence [13]. On the one hand, experts are supposed to provide impartial and objective knowledge; on the other hand, their expert advice is supposed to be relevant and responsive to political needs. This makes it difficult for TA to claim its neutrality or impartiality, particularly when policy making institutions fund TA to provide policy makers with an evidence base for their policies. In addition, expert-based TA faces the challenge of the inherent biases in using existing science/technology to deliver oversight over emerging science/technology.

The exclusive reliance on experts' assessment can have two unintended consequences. First, it bolsters the legitimacy of the technologists as the vanguards in shaping the future of our technology-infused societies [29]. In effect, it redistributes power to members of an unelected group and moves our institutional environment towards conditions in which technological risks are detached from the institutional processes that created them [3]. Second, technologists are likely to adopt an instrumental perspective of responsibility, seeking to avoid any legal sanctions and financial penalties, rather than adopt a more normative approach that would widen consultation to include a broader spectrum of stakeholders in co-shaping the role of technology in society.

B. TA as a Deliberation Process

A second approach to TA emerged in the 1980s when questions were raised regarding the role of experts in the process and the importance of public participation in shaping the socio-technical systems that constituted the infrastructure of modern societies. However, several tensions arose when seeking to align lay contributions with expert knowledge. While the objective of this approach was to enhance inclusivity and to create more integrative views of technological questions, it tended to underemphasize the political dimension of TA processes [8]. A stream of practices and studies that have advanced this approach, particularly in Europe, is the responsible research and innovation (RRI) framework and its accompanying literature. This approach tackles GSCs by addressing the procedural aspects of technological change [4], [17].

This approach appeals to the capacity of the organizations involved in technological innovation to achieve socially-valued impact. However, the processes for determining what impact is socially valued can be contentious. The TA literature points to various principles that these processes need to uphold, such as anticipation, reflexivity, inclusion, and responsiveness. However, making deliberation processes more inclusive remains a challenge for multiple reasons, such as the fact that it often requires sharing proprietary knowledge and information, which business organizations tend to resist. In addition, most technological fields reflect high levels of power differentials and information asymmetries, making it difficult to envisage broader applications of deliberative processes beyond the remits of basic research programs and publicly funded universities [23].

C. TA as an Issue Field

The issue field approach organizes TA processes around issues, such as one of the many issues that constitute the GSCs. An issue concerns members of multiple sectors who borrow elements from their respective institutional infrastructures and logics as they shape the issue field (Zietsma et al. 2016). **Q1** Issue fields are often fragmented, particularly in their emergent stage when field identity is ambiguous and open for contestation. GSCs, consisting of several issues, are often not recognized by all actors or not found to be problematic.

TA as an issue field draws upon contributions from a transdisciplinary set of actors who interact and draw on each other's perspectives to build a shared vision of desired technological futures. Each field actor engages with their own means to conduct TA around aspects of the issue that matter to their distinctive motives (Grodal & O'Mahoney, 2019). The boundaries of the issues are contested, and the practices are regularly challenged based on commitments to diverse institutional arrangements [14].

In this approach, the functions of TA are tempered by the types of imaginaries that become dominant within a field comprising multisectoral actors [15]. In contrast to the first two approaches, there is less emphasis on reducing risks. Instead, proponents of this approach extrapolate from the present to construct imaginaries of the future that are afforded by emerging technologies [18]. In some cases, such as in geoengineering (the use of technology to control the Earth's climate through manipulation of its processes), the assessment involves hypothetical technologies that do not yet have concrete applications but are

TABLE I
OVERVIEW OF TA APPROACHES

Stream	Public Policy Instrument	Deliberation	Issue Field
Main Objectives	Bridging science and politics (anticipatory and precautionary functions)	Enabling the co-evolution of society and technology (innovation policy and programmes)	Creating shared visions of technological futures (mobilizing issue field actors)
Main Principles	Neutrality of expert knowledge	Inclusion, RRI	Multisectoral coordination, normativity, resource mobilization
Type of Technology	Existing technologies	New and emerging technologies	Emerging and potential technologies
Boundaries of TA practices	Boundaries are defined by science and engineering	Boundaries are permeable	Boundaries are contested, leading to shifting practices based on the scope of the issue
Level of analysis	Policy level	Policy and organizational levels	Field level
Sources of authority	Expert knowledge grounded in science and engineering; political authority	Participation in public deliberations	Centrality in the issue field
Main Contentions	Transparency and accountability Neutrality/politicisation of TA	Re-distribution of responsibility	Competing meanings and future imaginaries

TABLE II
OVERVIEW OF PRINCIPLES

Principle	Brief description
Openness	Broaden our imagination of multiple futures and involvement of diverse stakeholders
Neutrality	Organizational and financial independence of TA institutions and the pursuit of objectivity in the assessment processes
Duality	Technology as a source of the GSC and solutions for addressing them
Interrelatedness	Address the dependencies among various technologies and solutions
Behavior	The behavior of people can be a source of the GSC, and addressing GSC might need a change in people's behavior
Depth	Take first, second and third-order effects into account
Reflexivity	Anticipate actions to avert undesired and unintended consequences

being explored for future implementation. TA in this stream is not limited to the analysis of present trends; it focuses as much on potentialities as it does on probabilities [1]. Instead of simply forecasting the future from current conditions, it is equally based on *backcasting*, which involves "working backwards from a particular desired future end-point or set of goals to the present" [20: 842]. As such, this approach to TA is intentionally normative and, therefore, openly political. The different actors in the issue field can be open about their policy motives and do not need to claim impartiality as a condition for contributing to TA.

III. PRINCIPLES AND CHALLENGES OF TA FOR ADDRESSING GSCS

GSCs represent a set of wicked problems that defy simple definitions and are not amenable to single solutions [5]. Wicked problems are characterized by: a lack of definitive formulation, no immediate and ultimate test of a solution and by being unique [19]. Wicked problems cannot be solved by only considering a part of the problem, but require an integral and transdisciplinary approach. Therefore, TA processes that are aimed at addressing GSCs need to follow principles that reflect the nature and complexity of these challenges. The TA literature across the three streams suggests various principles that TA processes need to uphold in order to be effective in having a positive influence on the role of technology in society. We discuss here some of the main principles for TA in the context of GSCs and summarize them in Table II. This list of principles is not meant to be comprehensive but seeks to push the discussion on TA for addressing GSCs.

Openness: Given the nature of GSCs as wicked problems, TA, in this context, needs to avoid premature closures that freeze the process in outcomes that limit the adaptability of the field. In this article, TA needs to aim to broaden our imagination of multiple futures instead of seeking to identify the one future that will deterministically result from current technological conditions or a single ideal future that we need to pursue based on those conditions. It needs to avoid "closing down the future space of options without sufficient evidence and thereby becoming blind to alternatives or spaces for shaping future developments in other directions" [12, p. 98]. This also requires the involvement of people having diverse view.

Neutrality: Neutrality is expected to limit the effect of TA participants' self-interests on the development and outcome of TA processes. Neutrality in TA has both an organizational and an epistemological dimension. From an organizational perspective, the principle of neutrality calls for the organizational and financial independence of TA institutions. From an epistemological lens, neutrality involves the pursuit of objectivity in the assessment processes. However, some TA researchers have questioned the attainability, and even the desirability, of neutrality as a guarantee of objectivity [8]. TA processes are understood as inherently political, so assuming or aspiring for a demarcation between their technical and political dimensions often conceals the power dynamics that shape their evolution. In addition, accepting the political nature of TA process enables TA actors to adopt normative stances that are more conducive to the realization of transformative agendas.

Duality: The paradoxical nature of technology as both a source of many societal problems underlying the GSCs and an element of major approaches to addressing the GSCs makes its assessment complex. For example, taking this dual nature of technology when conducting GSC-oriented TA calls for evaluating or imagining the impact of applying technology, but also that of not applying it. For example, if technology is expected to save lives (as is claimed by the proponents of various medical technologies or self-driving cars) or to enhance inclusion (as is claimed for example by the proponents of digital identification systems), the duality principle would call for consideration of the costs of delaying adoption and implementation along with the risks of premature implementation.

Interrelatedness: GSCs are often related to each other and to multiple technologies. This makes it hard to establish clear boundaries for the set of factors that need to be considered in a TA process. The wickedness and complexity blurs the boundaries between problems and solutions. For example, the climate crisis and population malnutrition are both related to challenges with agriculture and food production and distribution. Understanding how the GSCs and their various issues and technologies are related is critical for conducting TA that is effective in addressing GSCs.

Behavior: A major way through which technology contributes to or helps address the GSCs is through its influence on the behavior of people. For example, The availability of certain technologies, such as packaging technologies, enables a wide range of human behaviors that increase convenience, such as the ability to preserve and transport food. However, they also constrain many other behaviors by, for example, contributing to environmental damages. In addition, addressing the GSCs is often understood as requiring significant changes to human behavior, such as changes in consumption and movement patterns. Therefore, TA in this cocntext needs to build on a deeper understanding of the complex ways through which technology becomes entangled with human behavior.

Depth: One of the main challenges of conducting TA for addressing GSCs is that the effects of technology on society manifest across multiple levels [2]. The *first-order effects* of technology are the most immediate and visible ones, such as supporting human activities and improving conditions through efficiency and ease. However, technology is often part of changes that go beyond the immediate and the visible. These *second-order effects* involve the transformation of human activities and conditions in ways that are unintended and unexpected. In addition, technology can have *third-order effects*, which involve the transformation of the institutions that shape human activities. These deeper effects emerge from new sociotechnical configurations of social life. The challenge for TA is that the first-order surface effects are more amenable to quantification and more readily available to participants' cognition during processes of deliberation. However, TA that engages with GSCs needs mechanisms that ensure that deeper effects are considered regardless of the adopted TA approach or methods.

Reflexivity: Given the rapid changes in the boundary conditions of the GSCs and in the technology landscape, TA processes need to be highly reflexive. The assessments need to include the various conceptual and methodological tools we use to collectively make sense of our technological futures, including the TA processes themselves. Schneider et al. (2023), in this special issue, argue for the need to enact such reflexivity toward the *visions* through which we anticipate future societal transformations from the diffusion of emerging technologies, such as 3-D printing, nanotechnology, and AI. As such, reflexivity is important for the sustainability of TA as a field.

IV. Contributions to this Special Issue

This special issue contains four papers covering a wide spectrum of issues on TA processes for addressing GSCs. All accepted papers passed a thorough peer-review process consisting of multiple rounds of review. The first two papers of this special issue address the complexities of developing appropriate frameworks and processes of TA in the context of GSCs. The third and fourth papers are both in the critical domain of agriculture. They take unique approaches to TA for addressing GSCs and provide context-dependent and customized methods for the task at hand.

The first paper, "*Transformative vision assessment and 3-D printing futures: a new approach of Technology Assessment to address Grand Societal Challenges*" is authored by C. Schneider, M. Roßmann, A. Lösch, and A. Grunwald. Technological innovation is often seen as a solution to GSC, however, such development often fails to deal with societal complexity. Furthermore, technology is shaped by society. Therefore, the authors' plea for embedding reflexivity in the technology development process. For this, they introduce the new TA approach named "transformative vision assessment." This TA approach aims to enhance actors' anticipatory competencies, reflexivity, and responsibility while addressing GSC by modulating the visions that influence technological developments. Transformative vision assessment was demonstrated by a case study of 3-D printing. The case showed that transformative vision assessment can be used to analyse technological visions and modulate visionary discourse by adding socio-technical complexity and fostering dialogue between science and society. In this way, the societal and technological elements are balanced.

The digitalization of our society introduces new GSCs, such as fake news, internet addiction, and cyberbullying, resulting in new sources of inequality and discrimination that threaten the stability of society and the lives of individuals. E. H. Diniz, T. R. Santos, and M. A. Cunha authored the paper "*Measuring the Grand Challenge of the Digital Transformation of Society: Practices for Operationalizing Robust Action Strategies.*" They investigated the TA practices and mechanisms, actions and strategies to improve digital society. The authors analyze the processes of *information society assessment* (ISA), which are aimed at measuring the digital transformation of society. For this, the authors investigated a Brazilian ISA organization (Cetic.br) to derive strategies for responding to the grand challenges of digital transformation. The strategies to respond to GSC include: participatory architecture; multivocal inscription; distributed experimenting; and flexible, autonomous management. They highlight the need for local and global stakeholders to be involved for effective ISA processes. They also suggest that all stakeholders should be listened to and their opinions considered, regardless of how divergent their positions and views are. The environment should be sensed, and the research portfolio adapted.

The third paper named "*Technology Assessment Using Satellite Big Data Analytics for India's Agri-Insurance Sector*" by N. P. Nagendra, G. Narayanamurthy, R. Moser, E. Hartmann, and T. Sengupta addresses the GSC of uncertainty in the performance of farms due to weather fluctuations. Data is often disputed and interpreted differently, making it challenging to capture what is going on. The TA using satellite big data-based analytics provides an independent data source that can contribute to a better understanding of the impact. Furthermore, the case shows that satellite data can help arrive at independent assessments and create trust in data, which helps arrive at a situation where solutions to GSC can be better discussed. The case shows that satellite big data analytics helps the settlement of claims by having verifiable data.

D. Liang, W. Tang, and Y. Fu present the TA in the agriculture field in the fourth paper named "*Sustainable modern agricultural technology assessment by a multi-stakeholder transdisciplinary approach.*" The adoption of modern agricultural technologies not only increases productivity and food security, but also enhances agricultural development while reducing poverty. Yet many of these new technologies might affect sustainability in a negative way. In this article, a holistic multi-stakeholder transdisciplinary approach supporting sustainable modern agricultural technology assessment is presented. The approach is demonstrated using a modern agricultural project in Xichang city in China to demonstrate the effectiveness and rationality of the proposed method.

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I. Introduction

THE rapid acceleration of technological developments and the widening scope of technological transformations are challenging our ability to assess existing and emerging technologies' social, economic, and environmental consequences. Public and academic discourses increasingly recognize the need to better understand and evaluate the role of technology in major societal challenges facing humanity in the twenty-first century [10]. Addressing these "*grand societal challenges"* (GSCs) requires the creation of shared visions of the desired futures that can be embodied in organizational strategies, innovation programs, and policy frameworks [28]. Technological innovations can be part of the causes underlying the GSCs by perpetuating historical patterns of social inequality and environmental degradation, but can also be integral to solutions for addressing the GSCs in the article. This paradoxical effect of technology as both an enabler and a constraint to the achievement of a more sustainable human future highlights the need for effective approaches to technology assessment (TA) that can support the evaluation of both the risks and the opportunities embodied in new and emerging technologies [27]. Yet, despite the critical need for appropriate TA frameworks to address the GSCs, little research attention has been paid to the forms that TA needs to take in relation to the imperative of addressing GSCs [8], [25], [26].

The origins of TA have been linked to the formation of the US Office for TA in the 1970s as a means of assessing the impacts of technology on society [25]. However, this expert-based approach has been challenged by alternative perspectives that challenged its assumptions of technocracy and emphasized the emergence of technology's societal impacts from intertwining technological and societal factors [22], [24]. Subsequent approaches to TA have responded to these challenges by advocating the inclusion of a wider group of stakeholders in the TA process, resulting in what has been dubbed participatory TA [9], [25]. Such deliberative processes [28], align with new forms of innovation governance commonly referred to as responsible innovation [21]. These forms of "inverted TA" move away from a limited reliance on expert assessment of potential impacts towards an assessment that is built around the public response to new technologies [6, p. 108]. In addition, TA has been moving from a preventative to a prospective stance, from passive responsibility based on duties or liability to active responsiveness based on quality.

The recent developments in TA are particularly important to analyze in relation to their suitability for addressing GSCs. GSCs reflect multiple complexities and multilevel, multidimensional problems that require concerted efforts by various actors— public, private, and nonprofit. In addition, the boundaries of GSCs are often hard to define as the challenges are interrelated and difficult to isolate. Thus, addressing GSCs requires coordinated and collaborative efforts [10] in which multiple perspectives and approaches are integrated, including those of the poorest and disenfranchised. Typical examples of GSCs include scarcity of materials, climate change, aging societies, poverty, pandemics, and digital inequality. Often GSCs contain a number of interrelated issues which might evolve in different ways and require diverse forms of response. Multiple public values need to be considered when addressing GSCs, and there are often tensions between values, which need to be resolved to enable collective action in the face of GSCs [7].

Yet, despite the significant developments in TA, assessment of technology in relation to GSCs remains problematic. This is particularly true for emerging technologies, such as those commonly subsumed under the term "fourth industrial revolution" [e.g., artificial intelligence (AI), distributed ledger technology, blockchain]. TA is complex in these cases because of the high levels of uncertainty associated with the evolution of such technologies, including their entanglement with the GSCs through rapidly changing cultural norms and socioeconomic relations (Lin, 2011). Thus, while many look to emerging technologies for addressing GSCs [27], the processes through which we can collectively engage with both their positive and negative consequences require further conceptualization and analysis.

Digital Object Identifier 10.1109/TEM.2022.3233460

II. Streams of TA Research and Practice

The TA literature presents three different streams that define the field's evolution over the past few decades: TA as a policy instrument, a deliberation process, and an issue field. Initially, TA was based on input from experts to inform the development and implementation of technology-related policy. However, new approaches that require broader participation from multiple stakeholders emerged as complementary or alternatives to the expert-based approach. More recently, the focus in many TA circles has shifted toward interorganizational and multidisciplinary processes that crate shared imaginaries of the future.

A. TA as a Policy Instrument

The first stream emerged with the practices and discourses that gave rise to the early forms of TA institutionalization. This approach uses TA to describe the deployment of different processes and tools to determine the potential impacts of emerging technologies. It draws heavily on expert knowledge from science and engineering for delivering advisory and precautionary recommendations to organizations and society. This approach continues to develop and remains an integral part of public policy apparatus, such as the design and implementation of early warning systems. It builds on the premise that technology's impact can be quantified and projected.

As a public policy instrument, TA seeks to draw on expert knowledge from science and technology-based disciplines. It is expected to bridge science/technology and politics through the exchange of technical knowledge. However, adopters of this approach to TA need to grapple with the paradox of expert independence [13]. On the one hand, experts are supposed to provide impartial and objective knowledge; on the other hand, their expert advice is supposed to be relevant and responsive to political needs. This makes it difficult for TA to claim its neutrality or impartiality, particularly when policy making institutions fund TA to provide policy makers with an evidence base for their policies. In addition, expert-based TA faces the challenge of the inherent biases in using existing science/technology to deliver oversight over emerging science/technology.

The exclusive reliance on experts' assessment can have two unintended consequences. First, it bolsters the legitimacy of the technologists as the vanguards in shaping the future of our technology-infused societies [29]. In effect, it redistributes power to members of an unelected group and moves our institutional environment towards conditions in which technological risks are detached from the institutional processes that created them [3]. Second, technologists are likely to adopt an instrumental perspective of responsibility, seeking to avoid any legal sanctions and financial penalties, rather than adopt a more normative approach that would widen consultation to include a broader spectrum of stakeholders in co-shaping the role of technology in society.

B. TA as a Deliberation Process

A second approach to TA emerged in the 1980s when questions were raised regarding the role of experts in the process and the importance of public participation in shaping the socio-technical systems that constituted the infrastructure of modern societies. However, several tensions arose when seeking to align lay contributions with expert knowledge. While the objective of this approach was to enhance inclusivity and to create more integrative views of technological questions, it tended to underemphasize the political dimension of TA processes [8]. A stream of practices and studies that have advanced this approach, particularly in Europe, is the responsible research and innovation (RRI) framework and its accompanying literature. This approach tackles GSCs by addressing the procedural aspects of technological change [4], [17].

This approach appeals to the capacity of the organizations involved in technological innovation to achieve socially-valued impact. However, the processes for determining what impact is socially valued can be contentious. The TA literature points to various principles that these processes need to uphold, such as anticipation, reflexivity, inclusion, and responsiveness. However, making deliberation processes more inclusive remains a challenge for multiple reasons, such as the fact that it often requires sharing proprietary knowledge and information, which business organizations tend to resist. In addition, most technological fields reflect high levels of power differentials and information asymmetries, making it difficult to envisage broader applications of deliberative processes beyond the remits of basic research programs and publicly funded universities [23].

C. TA as an Issue Field

The issue field approach organizes TA processes around issues, such as one of the many issues that constitute the GSCs. An issue concerns members of multiple sectors who borrow elements from their respective institutional infrastructures and logics as they shape the issue field (Zietsma et al. 2016). Issue fields are often fragmented, particularly in their emergent stage when field identity is ambiguous and open for contestation. GSCs, consisting of several issues, are often not recognized by all actors or not found to be problematic.

TA as an issue field draws upon contributions from a transdisciplinary set of actors who interact and draw on each other's perspectives to build a shared vision of desired technological futures. Each field actor engages with their own means to conduct TA around aspects of the issue that matter to their distinctive motives (Grodal & O'Mahoney, 2019). The boundaries of the issues are contested, and the practices are regularly challenged based on commitments to diverse institutional arrangements [14].

In this approach, the functions of TA are tempered by the types of imaginaries that become dominant within a field comprising multisectoral actors [15]. In contrast to the first two approaches, there is less emphasis on reducing risks. Instead, proponents of this approach extrapolate from the present to construct imaginaries of the future that are afforded by emerging technologies [18]. In some cases, such as in geoengineering (the use of technology to control the Earth's climate through manipulation of its processes), the assessment involves hypothetical technologies that do not yet have concrete applications but are

TABLE I
OVERVIEW OF TA APPROACHES

Stream	Public Policy Instrument	Deliberation	Issue Field
Main Objectives	Bridging science and politics (anticipatory and precautionary functions)	Enabling the co-evolution of society and technology (innovation policy and programmes)	Creating shared visions of technological futures (mobilizing issue field actors)
Main Principles	Neutrality of expert knowledge	Inclusion, RRI	Multisectoral coordination, normativity, resource mobilization
Type of Technology	Existing technologies	New and emerging technologies	Emerging and potential technologies
Boundaries of TA practices	Boundaries are defined by science and engineering	Boundaries are permeable	Boundaries are contested, leading to shifting practices based on the scope of the issue
Level of analysis	Policy level	Policy and organizational levels	Field level
Sources of authority	Expert knowledge grounded in science and engineering; political authority	Participation in public deliberations	Centrality in the issue field
Main Contentions	Transparency and accountability Neutrality/politicisation of TA	Re-distribution of responsibility	Competing meanings and future imaginaries

TABLE II
OVERVIEW OF PRINCIPLES

Principle	Brief description
Openness	Broaden our imagination of multiple futures and involvement of diverse stakeholders
Neutrality	Organizational and financial independence of TA institutions and the pursuit of objectivity in the assessment processes
Duality	Technology as a source of the GSC and solutions for addressing them
Interrelatedness	Address the dependencies among various technologies and solutions
Behavior	The behavior of people can be a source of the GSC, and addressing GSC might need a change in people's behavior
Depth	Take first, second and third-order effects into account
Reflexivity	Anticipate actions to avert undesired and unintended consequences

being explored for future implementation. TA in this stream is not limited to the analysis of present trends; it focuses as much on potentialities as it does on probabilities [1]. Instead of simply forecasting the future from current conditions, it is equally based on *backcasting*, which involves "working backwards from a particular desired future end-point or set of goals to the present" [20: 842]. As such, this approach to TA is intentionally normative and, therefore, openly political. The different actors in the issue field can be open about their policy motives and do not need to claim impartiality as a condition for contributing to TA.

III. PRINCIPLES AND CHALLENGES OF TA FOR ADDRESSING GSCS

GSCs represent a set of wicked problems that defy simple definitions and are not amenable to single solutions [5]. Wicked problems are characterized by: a lack of definitive formulation, no immediate and ultimate test of a solution and by being unique [19]. Wicked problems cannot be solved by only considering a part of the problem, but require an integral and transdisciplinary approach. Therefore, TA processes that are aimed at addressing GSCs need to follow principles that reflect the nature and complexity of these challenges. The TA literature across the three streams suggests various principles that TA processes need to uphold in order to be effective in having a positive influence on the role of technology in society. We discuss here some of the main principles for TA in the context of GSCs and summarize them in Table II. This list of principles is not meant to be comprehensive but seeks to push the discussion on TA for addressing GSCs.

Openness: Given the nature of GSCs as wicked problems, TA, in this context, needs to avoid premature closures that freeze the process in outcomes that limit the adaptability of the field. In this article, TA needs to aim to broaden our imagination of multiple futures instead of seeking to identify the one future that will deterministically result from current technological conditions or a single ideal future that we need to pursue based on those conditions. It needs to avoid "closing down the future space of options without sufficient evidence and thereby becoming blind to alternatives or spaces for shaping future developments in other directions" [12, p. 98]. This also requires the involvement of people having diverse view.

Neutrality: Neutrality is expected to limit the effect of TA participants' self-interests on the development and outcome of TA processes. Neutrality in TA has both an organizational and an epistemological dimension. From an organizational perspective, the principle of neutrality calls for the organizational and financial independence of TA institutions. From an epistemological lens, neutrality involves the pursuit of objectivity in the assessment processes. However, some TA researchers have questioned the attainability, and even the desirability, of neutrality as a guarantee of objectivity [8]. TA processes are understood as inherently political, so assuming or aspiring for a demarcation between their technical and political dimensions often conceals the power dynamics that shape their evolution. In addition, accepting the political nature of TA process enables TA actors to adopt normative stances that are more conducive to the realization of transformative agendas.

Duality: The paradoxical nature of technology as both a source of many societal problems underlying the GSCs and an element of major approaches to addressing the GSCs makes its assessment complex. For example, taking this dual nature of technology when conducting GSC-oriented TA calls for evaluating or imagining the impact of applying technology, but also that of not applying it. For example, if technology is expected to save lives (as is claimed by the proponents of various medical technologies or self-driving cars) or to enhance inclusion (as is claimed for example by the proponents of digital identification systems), the duality principle would call for consideration of the costs of delaying adoption and implementation along with the risks of premature implementation.

Interrelatedness: GSCs are often related to each other and to multiple technologies. This makes it hard to establish clear boundaries for the set of factors that need to be considered in a TA process. The wickedness and complexity blurs the boundaries between problems and solutions. For example, the climate crisis and population malnutrition are both related to challenges with agriculture and food production and distribution. Understanding how the GSCs and their various issues and technologies are related is critical for conducting TA that is effective in addressing GSCs.

Behavior: A major way through which technology contributes to or helps address the GSCs is through its influence on the behavior of people. For example, The availability of certain technologies, such as packaging technologies, enables a wide range of human behaviors that increase convenience, such as the ability to preserve and transport food. However, they also constrain many other behaviors by, for example, contributing to environmental damages. In addition, addressing the GSCs is often understood as requiring significant changes to human behavior, such as changes in consumption and movement patterns. Therefore, TA in this cocntext needs to build on a deeper understanding of the complex ways through which technology becomes entangled with human behavior.

Depth: One of the main challenges of conducting TA for addressing GSCs is that the effects of technology on society manifest across multiple levels [2]. The *first-order effects* of technology are the most immediate and visible ones, such as supporting human activities and improving conditions through efficiency and ease. However, technology is often part of changes that go beyond the immediate and the visible. These *second-order effects* involve the transformation of human activities and conditions in ways that are unintended and unexpected. In addition, technology can have *third-order effects*, which involve the transformation of the institutions that shape human activities. These deeper effects emerge from new sociotechnical configurations of social life. The challenge for TA is that the first-order surface effects are more amenable to quantification and more readily available to participants' cognition during processes of deliberation. However, TA that engages with GSCs needs mechanisms that ensure that deeper effects are considered regardless of the adopted TA approach or methods.

Reflexivity: Given the rapid changes in the boundary conditions of the GSCs and in the technology landscape, TA processes need to be highly reflexive. The assessments need to include the various conceptual and methodological tools we use to collectively make sense of our technological futures, including the TA processes themselves. Schneider et al. (2023), in this special issue, argue for the need to enact such reflexivity toward the *visions* through which we anticipate future societal transformations from the diffusion of emerging technologies, such as 3-D printing, nanotechnology, and AI. As such, reflexivity is important for the sustainability of TA as a field.

IV. Contributions to this Special Issue

This special issue contains four papers covering a wide spectrum of issues on TA processes for addressing GSCs. All accepted papers passed a thorough peer-review process consisting of multiple rounds of review. The first two papers of this special issue address the complexities of developing appropriate frameworks and processes of TA in the context of GSCs. The third and fourth papers are both in the critical domain of agriculture. They take unique approaches to TA for addressing GSCs and provide context-dependent and customized methods for the task at hand.

The first paper, "*Transformative vision assessment and 3-D printing futures: a new approach of Technology Assessment to address Grand Societal Challenges*" is authored by C. Schneider, M. Roßmann, A. Lösch, and A. Grunwald. Technological innovation is often seen as a solution to GSC, however, such development often fails to deal with societal complexity. Furthermore, technology is shaped by society. Therefore, the authors' plea for embedding reflexivity in the technology development process. For this, they introduce the new TA approach named "transformative vision assessment." This TA approach aims to enhance actors' anticipatory competencies, reflexivity, and responsibility while addressing GSC by modulating the visions that influence technological developments. Transformative vision assessment was demonstrated by a case study of 3-D printing. The case showed that transformative vision assessment can be used to analyse technological visions and modulate visionary discourse by adding socio-technical complexity and fostering dialogue between science and society. In this way, the societal and technological elements are balanced.

The digitalization of our society introduces new GSCs, such as fake news, internet addiction, and cyberbullying, resulting in new sources of inequality and discrimination that threaten the stability of society and the lives of individuals. E. H. Diniz, T. R. Santos, and M. A. Cunha authored the paper "*Measuring the Grand Challenge of the Digital Transformation of Society: Practices for Operationalizing Robust Action Strategies.*" They investigated the TA practices and mechanisms, actions and strategies to improve digital society. The authors analyze the processes of *information society assessment* (ISA), which are aimed at measuring the digital transformation of society. For this, the authors investigated a Brazilian ISA organization (Cetic.br) to derive strategies for responding to the grand challenges of digital transformation. The strategies to respond to GSC include: participatory architecture; multivocal inscription; distributed experimenting; and flexible, autonomous management. They highlight the need for local and global stakeholders to be involved for effective ISA processes. They also suggest that all stakeholders should be listened to and their opinions considered, regardless of how divergent their positions and views are. The environment should be sensed, and the research portfolio adapted.

The third paper named "*Technology Assessment Using Satellite Big Data Analytics for India's Agri-Insurance Sector*" by N. P. Nagendra, G. Narayanamurthy, R. Moser, E. Hartmann, and T. Sengupta addresses the GSC of uncertainty in the performance of farms due to weather fluctuations. Data is often disputed and interpreted differently, making it challenging to capture what is going on. The TA using satellite big data-based analytics provides an independent data source that can contribute to a better understanding of the impact. Furthermore, the case shows that satellite data can help arrive at independent assessments and create trust in data, which helps arrive at a situation where solutions to GSC can be better discussed. The case shows that satellite big data analytics helps the settlement of claims by having verifiable data.

D. Liang, W. Tang, and Y. Fu present the TA in the agriculture field in the fourth paper named "*Sustainable modern agricultural technology assessment by a multi-stakeholder transdisciplinary approach.*" The adoption of modern agricultural technologies not only increases productivity and food security, but also enhances agricultural development while reducing poverty. Yet many of these new technologies might affect sustainability in a negative way. In this article, a holistic multi-stakeholder transdisciplinary approach supporting sustainable modern agricultural technology assessment is presented. The approach is demonstrated using a modern agricultural project in Xichang city in China to demonstrate the effectiveness and rationality of the proposed method.

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