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The Future of Ammonia Use in 30 Years: A Deliberative Experimental Study Envisioning the Perspective of a Future Generation

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Abstract

Non-technical summary

Humans are currently grappling with the challenge of nitrogen (N) management, which involves a multidimensional tradeoff between the benefits of N use and the consequences of N pollution. For this study, a deliberative experiment was conducted in which five N scientists, divided into two groups, envisioned the future of NH_3 use in the 2050s, adopting the perspective of an imaginary future generation. Through this experience, the study encourages scientists to adopt the proposed framework and embrace freedom to explore desirable future visions, in addition to their usual task of empirically establishing universal disciplinary knowledge.

Technical summary

Humans are currently grappling with the challenge of nitrogen (N) management, which involves a multidimensional tradeoff between the benefits of N use and the consequences of N pollution. The urgency to address this issue is already pronounced and may escalate further due to the emergence of ammonia (NH_3) as a carbon-free energy resource. For this study, a deliberative experiment was conducted in which five N scientists, divided into two groups, envisioned the future of NH_3 use in the 2050s, adopting the perspective of an imaginary future generation. The study revealed that some scientists encountered what is referred to in this study as the "positivist gap," which involves difficulties forming narratives about unpredictable futures that rely on arbitrary assumptions. From this experience, this study develops and illustrates a framework that incorporates (i) Future Design workshops and (ii) abstracting operation for the workshop outputs. Although conducted in Japan, this study aims to inspire similar research in other countries.

Social Media Summary

A visioning experiment showed how scientists handle nitrogen tradeoffs, imagining NH_3's roles in a complex 2050 world.

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Introduction

Like other life on Earth, humans once had limited access to reactive forms of nitrogen (N), hereafter denoted as Nr. In the mid-19th century, humans discovered fossilized Nr as guano and saltpeter, employing them as fertilizer and gunpowder. However, these are depletable resources. Due to the challenge of acquiring N fertilizer to avoid starvation connected to population growth, an artificial N fixation technology known as the Haber–Bosch process was developed in the early 20th century (Erisman et al., 2008; Galloway et al., 2021). This technology creates NH_3 from dinitrogen (N_2) and hydrogen. Humans today create a huge amount of NH_3 through the Haber–Bosch process – more than 100 Tg N yr^{-1} as of the 2010s (Galloway et al., 2021). Fixed NH_3 has been used for various purposes either directly or through conversion to other Nr forms, such as chemical fertilizers and industrial materials, including explosives, reagents, resins, and ceramics.

Mainly due to intensive anthropogenic activities in agriculture and industry and low N use efficiency (NUE), we are currently facing "the N dilemma," a multidimensional tradeoff between the benefits of N use and massive unintentional N pollution. (UNEP, 2019; Sutton et al., 2021). N pollution has diverse environmental impacts on water, air, greenhouse gas balance, ecosystems, and soil (Sutton et al., 2011), and artificial Nr synthesis (N fixation with the Harber-Bosch process and Nr formation with combustion) has outweighed terrestrial biological N fixation in recent decades (Fowler et al., 2013). Further, assessments conducted between the 2000 and 2020s have shown that the anthropogenic perturbation of the Earth's biochemical N cycles is beyond the planetary boundary (Rockström et al., 2009; Steffen et al., 2015; Richardson et al., 2023). From this, the fundamental reason for N pollution is low NUE (approximately 20% in the entire system), which leads to a significant loss of Nr to the environment from human activities (Sutton et al., 2013).

The urgency to address the challenge of N management may increase. In recent years, the emerging use of NH_3 as hydrogen new energy (i.e., the emerging use of NH_3 as a fuel and hydrogen carrier) has attracted attention in the context of decarbonization. However, the use of NH_3 could worsen the state of N pollution (Lu et al., 2018; Nishina, 2022; Wolfram et al., 2022). When NH_3-derived hydrogen energy is implemented in society, widespread changes could occur to global production and consumption patterns. This could have significant social impacts, as increased Nr use and elevated Nr emissions may lead to nitrogen pollution and conflict could arise among sectors vying for Nr. The future of N use is unforeseen, as are its consequences for humans and the natural world.

Given the facts regarding current N use and its consequences for N pollution, global sustainable N management is essential. This would involve the enhancement of NUE in human society and the recycling of Nr and altering Nr into N_2 before its release (Sutton et al., 2019). In a series of positive moves, the United Nations Environment Programme (UNEP), as the implementation body for the International Nitrogen Management System Project (Sutton et al., 2019; https://www.inms.international/), adopted the Colombo Declaration (United Nations, 2019) and the Resolutions on Sustainable Nitrogen Management at the fourth and fifth United Nations Environment Assemblies (UNEP, 2020; 2022). The UNEP has also facilitated international N management through the UNEP Working Group on Nitrogen (https://www.unep.org/nitrogen-management-WG). Technological development to enhance NUE, particularly in agriculture, and to treat exhaust gas and wastewater has progressed, and these achievements help further effective N management (Kanter & Searchinger, 2018; Sutton et al., 2022). Moving forward, a holistic approach to N management policy will be necessary for resolving conflicts and optimizing the effectiveness of relevant technologies (Kanter et al., 2020a).

For this study, we asked the following question: What role can current N scientists play in developing successful N management? Given that managing N sustainably presents multiple challenges, including technological, political, and behavioral barriers (as identified by Kanter et al., 2020b), collaboration with diverse stakeholders such as governments, industrial sectors, and citizens is essential. This collaboration could effectively enable desirable management systems and reveal pathways for transition, thereby facilitating the surmounting of these barriers. Collaborative creation of transformative narratives (Veland et al., 2018) and transition pathway narratives (Luederitz et al., 2017) is a promising strategy. Despite this, scientists are likely to face significant hurdles when engaging in the construction of transformative narratives. This study refers to this as the "positivist gap" because this may be explained by the positivist stance adopted by most scientists, emphasizing the derivation of the laws of nature to explain phenomena from empirical data (e.g., Park et al., 2020). While positivist scientists can create "world-describing narratives" (Veland et al., 2018, p. 42) using existing and historical data as evidence, they are likely to encounter substantial difficulties in developing narratives about inherently unpredictable futures, where assumptions set in an arbitrary manner must be used. It is noteworthy that in sustainability science literature, scant existing research directly addresses this "positivist gap." Even the advisability of presenting obtained scientific results in story form is contentious among scientists (Krywinski & Cairo, 2013a, 2013b; Katz, 2013). Thus, some scientists reasonably hesitate to tell stories about uncertain futures or the paths that lead there.

This study (i) proposes a framework to bridge the positivist gap and (ii) illustrates the framework's application. For (i), our developed framework has two distinct parts (Figure 1). In the first part, incorporating a Future Design methodology (Saijo, 2020; Nakagawa, 2024), participating scientists are encouraged to roleplay imaginary future people in vision discussions such that discomfort are alleviated while creating detailed future vision narratives based on arbitrary assumptions (output I). In the second part, abstracting operations developed by this study are applied to obtain an abstracted vision narrative (output II) and messages to the present generation (output III). The generation of outputs II and III should be designed so (a) their outputs reflects the discussants' individual desires of for the future and so (b) the outputs do not explicitly refer to arbitrarily set assumptions, even where they were crucial for creating the vision narrative.

In pursuing objective (ii), five N experts (four of the six authors of this paper and another scientist) were divided into two groups (groups A and B) and engaged in discussions to envision a future of N use in the 2050s. The chosen timeframe represents three decades beyond the 2020s when the use of NH_3 cofiring technology for coal-fired boilers was actively implemented by the Japanese government. The remaining two study authors facilitated the discussions (referred to below as "the secretariat"). In 2024, Japan, the first country to conduct experimental NH_3 co-firing in the commercial-scale thermal plant, must take the lead in examining the impacts of nitrogen-related technologies and utilization, including NH_3. Following this belief, this study outlined a vision for nitrogen use in Japan, which may serve as inspiration for countries with no abundant natural resources. It is also expected to provide valuable insights for those overcoming the challenges of scientists engaging in vision formation outside Japan.

> The importance of achieving objectives (i) and (ii) becomes even clearer by referring to theories on anticipation. The key point of Poli's (2010, 2017) anticipation theory is that human decision-making and actions are not solely based on past experiences or current circumstances, but are significantly influenced by anticipations (or expectations) about future outcomes. This theory emphasizes that expectations are dynamic, forming a "feedback loop" in which actions and outcomes shape and adjust future expectations. As a result, expectations continuously evolve and play a crucial role in guiding individual and collective decision-making processes. This theory suggests that explicitly addressing expectations about the future is a critical element of human decision-making processes. The present study explores how natural scientists can engage with this concept. The future is filled with uncertainty, and the range of plausible expected futures varies depending on the perspective of the individual making the judgment. For natural scientists, whose perspectives are grounded in academic viewpoints, their judgments should serve as an important reference point for others in forming their expectations.

Group A obtained all outputs; in Group B, however, outputs II and III were not generated, as the group's opinions did not converge on a single vision in the generation of output I. The framework for objective (i) was constructed through considering how group B could have avoided this difficulty, producing outputs II and III, as in Group A.

(Figure 1 inserted about here)

Results

Workshops were held for Group A on November 14, 2021; April 21, 2022; and December 7, 2022, and Group B had workshops on November 14, 2021, and April 19, 2022. The outcomes are outlined below.

Group A

After concluding the discussion within Group A (K.H. and K.M.), the group and the secretariat (Y.N. and T.S.) engaged in communication and finalized the vision narrative as follows. Overall, Group A successfully achieved a vision for Japanese society.

(Output I: Vision narrative)

[Paragraph A1] Over the past 30 years since 2020s, cities have changed significantly. Specifically, urban planning with a holistic perspective to control the flow of energy, food, and nutrients within local areas has been developed. This includes the use of renewable energy in housing, the establishment of forests as woody biomass energy sources, food production in animal farming facilities, and nutrient management in wastewater, all of which are carried out with an awareness of their interrelationships. This series of changes has had a profound impact on our lifestyle. For instance, industrial food production has led to the emergence of people who value traditional food cultures. In addition, the use of woody biomass has reduced the psychological distance between forests and people. Furthermore, there is a growing momentum to achieve energy self-sufficiency at the local level, rather than relying on the nation. Consequently, there has been an increased emphasis on living in harmony with traditional culture and nature within local communities.

[A2] In such cities, efforts have been made to source as much energy as possible locally, but electricity for manufacturing industries, which cannot be provided locally, is supplied through a regional power grid. One source of such regional energy is NH_3, which is used for various purposes, including as a raw material for fertilizers and industrial products. Specifically, NH_3 serves as an energy source that helps stabilize the time-dependent and seasonal fluctuations of renewable energy. The NH_3 use for energy was triggered by global initiatives to achieve carbon neutrality using NH_3 as a fuel and hydrogen carrier. While initially gray and blue NH_3 derived from fossil fuels were prevalent, there was a shift to green NH_3 sources from renewable energy. This transformation was

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not an easy process, but it was facilitated by international regulatory frameworks that limited the use of blue NH_3 and a growing consciousness in nations rich in fossil fuel resources to conserve these resources.

[A3] With the expansion of NH_3 use for energy, the N flow increased at least temporarily. However, this raised awareness of the importance of sustainable N use. Consequently, technological efforts have been made to improve the recovery of nutrients, including NH_3, nitrogen oxides, and nitrate, from exhaust gasses and wastewater, expanding the concept of the "urban mine" recognized in 2020s and earlier. In agriculture, there was a growing awareness of recycling/reusing agricultural waste and improving the NUE. In households, initiatives to compost food waste and prevent food loss have become more widespread. These efforts were driven not by uniform mass consumption of food but by the consumption of delicious food while preserving unique regional food cultures. The establishment of a school education system that combined food and environmental aspects has also supported this societal transformation. In parallel with these efforts, the total amount of regulation for N use was put in place to control environmental impacts.

[A4] In summary, NH_3 as an energy source influences how people manage nutrients within their communities with their own food culture. In 2050s, Japan will store some of its domestically generated renewable energy in the form of NH_3 and have the option of importing green NH_3 from abroad to satisfy domestic demand as necessary. This energy supply system, through the innovation of NH_3 manufacturing, transportation, storage, utilization, and recovery technologies, has allowed resource-poor Japan to achieve carbon neutrality. This system sets a precedent for countries with similar characteristics of resource scarcity and reliance on imports. By presenting this model, Japan makes a significant contribution to the international community.

This vision narrative includes arbitrary assumptions associated with either societal (i.e., the shift in NH_3 production from fossil fuel-based gray and blue NH_3 to green NH_3 from renewable energy) or technological (e.g., innovation in NH_3 manufacturing, transportation, storage, utilization, and recovery technologies in Japan) uncertainties. While communicating with Group A, the secretariat (Y.N. and T.S.) abstracted the vision narrative to avoid overmuch dependence on the assumptions. This extracted information in four interconnected questions, as detailed in Figure 2 and the Methods section. An abstracted vision narrative is shown below; underlining denotes responses extracted as answers to the referenced questions. Where the response to a question was lacking in the initial iteration of the vision narrative, members of Group A and the secretariat provided one.

(Figure 2 about here.)

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(Output II: Abstracted vision narrative)

In the last three decades leading to the 2050s, Japanese society has established a framework for sustainable N use in (Q1) urban planning, educational, energy, agricultural, household, and urban waste management sectors. These sectors fulfill their roles while fostering intersectoral support. Thanks to (Q4-2) this interconnectedness, (Q4-1) the environmental loss of Nr is also consistently monitored, and measures are in place to prevent Nr flow from exceeding the limits collectively agreed-upon by the society.

While the societal landscape of the 2050s differs significantly from that of the 2020s, (Q3-1) two constants remain. First, there is a steadfast commitment to transferring local food culture to the next generation, even in a significant lifestyle and awareness shifts aimed at curbing Nr loss to the environment. Second, Japan's identity as an island nation not abundantly endowed with mineral and fossil fuel resources has motivated a sustained drive to lead the world in the innovation of technologies related to NH_3.

In this way, Japan in the 2050s will (Q2) successfully balance the richness of daily life by managing N use to prevent adverse environmental impacts. The judicious use of NH_3 as an energy carrier to complement renewable energy contributes in part to maintaining this balance. This balance was also maintained with technologies to recover Nr from drainage and exhaust, (Q3-2) in line with Japan's historical introduction of urban mining in the 1980s, and with the accumulation of world-leading research on NH_3 combustion and NH_3 synthesis in recent decades.

This no longer relies on arbitrary assumptions. Finally, drawing on this abstracted vision narrative, the message Group A sent to the 2020s in their discussions was enriched, as follows.

(Output III: Messages to the present generation)

From the perspective of the 2050s, we hope that people in the 2020s seek to foster an awareness to achieve balance between the benefits of using N and mitigating its environmental impact as a common societal purpose. Consider the exploration of the new application of N, such as its use as an energy carrier, as an opportunity to kickstart initiatives toward this goal. Furthermore, we encourage discussions to commence in the six sectors of urban planning, education, energy, agriculture, household, and urban waste management to explore the roles that each sector can play, to identify how one sector can support others in their roles, including schools to modify household behaviors through children's education.

Group B

Group B developed multiple future visions during their discussion but were unable to consolidate these into one vision (H.S., B.L., and K.N.). The vision narrative for Group B is presented in Supplementary Material 2 (output I). As indicated, uncertainty became a point of discussion regarding whether the world of the 2050s sees the development and dissemination of catalytic technology that enables NH_3 synthesis with low energy or green energy. Given such uncertainty, depicting a scenario for the 2050s was noted as difficult. As a result, the final output of this group was a narrative of multiple scenarios (probable future states) rather than a single vision (desirable future state). Therefore, unlike the case with Group A, the procedure to craft outputs II and III was not followed.

Reflection on the discussions

Five scientists were asked to become imaginary future people in the 2050s and freely envision the shape of that future society. This request necessitated setting arbitrary assumptions that the scientists themselves found plausible. Under such a request, we endeavored to learn what the experience of discussion was like for them. Below are the reflections they expressed after the discussion concluded. In Group A, one member (K.H.) mentioned the following:

Well, you see, I was in a role-playing mood, so I was speaking with a sense of being in that world, where I felt like I was still there, regardless of uncertainties. Looking at it from the present, of course, there are uncertainties about everything, but if I assume I were someone in the future, there is only the world that exists right now. So, I didn't really worry about it that much.

For K.H., the application of the imaginary future people was helpful in seamlessly establishing premises and concretizing a desirable future society. The other member of the group (K.M.) agreed with this statement.

Meanwhile, in Group B, H.S. explicitly cast doubt on the discussion setting defined by the secretariat (Y.N. and T.S.) as follows:

With the current setting, it's like the people in 2051 are supposed to send a message to those in 2021, but what I've been feeling lately is how to enhance the persuasiveness of this Future Designer's (i.e., imaginary future people's) statement. What should be the basis for setting the premises? How realistic should they be? The more we think about such matters, the more challenging the discussion becomes. (Note: This remark was made on the group discussion day in 2021.)

The background to the statement of H.S. seems to be the premise that by the 2050s, technology enabling the cost-effective mass synthesis of NH_3 would have been developed (see paragraph [B2] in Supplementary Material 5; also see Ashida et al., 2019). This premise was introduced to the group by K.N., with the belief that society should undergo technological innovation in the next 30 years. However, H.S. did not perceive this as a probable assumption. Another group member (B.L.) continued this line of discussion, asserting that it is difficult to envision the 2050s unless environmental conditions beyond their control are provided.

Methods

The concept of Future Design

Future Design, an emerging methodology in future studies and sustainability science, has recently begun to attract particular attention as a means of systematizing how citizens and policymakers conceive of policies from the perspective of future generations (e.g., MacAskill, 2022). It aims to design social systems that activate people's inherent desire to care for future generations rather than adhere to presentism (e.g., Saijo, 2020). This methodology relies on the working hypothesis that humans experience increased happiness when they forego current benefits to enrich future generations. Saijo (2019) coined this fundamental tendency of humans as "futurability." In participatory envisioning processes where organizational, regional, or larger-scale visions are created by relevant stakeholders, Future Design can be implemented by letting the participants adopt the perspective of future generations and discussed in groups on a desired future state (e.g., Kamijo et al., 2017). Experimental studies have found that this deliberative setting affects individuals' attitudes sustainably (e.g., Nakagawa et al., 2019a, 2019b) and can stimulate individuals' creativity (Nakagawa, 2020). Through the process of role-play, scientists are expected to transport themselves into the evolving transition narrative they are creating and thus overcome the positivist gap.

Workshop design adopting the thought device of the imaginary future people

For this study, five N research scientists were divided into two groups, Group A (K.H. and K.M.) and Group B (B.L., K.N., and H.S.), to envision a future of the 2050s. The procedure of the workshop was as follows.

Step 1: Ice breaker session (50 minutes). Participants were requested to reflect on the online lecture delivered by Dr. Ken-ichi Aika "The effect of fuel NH_3 on the global environment: From the perspectives of N-intensity and C-intensities." Each member was then requested to provide his or her own opinion regarding the roadmap proposed in the lecture, stating, "use blue NH_3 as an energy carrier first and then replace it with green NH_3 while balancing the reduction of greenhouse gas emissions and domestic energy supply."

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Step 2: Past Design session (60 minutes). In each group, the participants were asked to reflect on their own life experiences one by one and share insights on (a) “what prompted you to become a researcher in your field” and (b) “the societal background in which that motivation arose.” Then, they were requested in groups what messages they would like to send to the society of the time identified by item (b).

Step 3: Future Design session (100 minutes). To preserve the freedom of discussion, no specific theme was provided to these two groups. Instead, they were first asked to imagine themselves time-traveling to the 2050s and becoming part of that society. Next, they were required to freely discuss the world of the 2050s given the historical fact that, in Japan in the 2020s, a roadmap had been proposed, stating, “use blue NH_3 as an energy carrier first and then replace it with green NH_3 while balancing the reduction of greenhouse gas emissions and domestic energy supply.” [This guiding remark is derived from the online lecture by Dr. Ken-ichi Aika (Professor Emeritus, Tokyo Institute of Technology) entitled “The effect of fuel NH_3 on the global environment: From the perspectives of N-intensity and C-intensity,” hosted by the Research Institute of Humanity and Nature (27th April, 2021), which the five scientists who participated in this study attended.] Finally, the groups were asked what messages they would like to send present-day society.

The result of Step 1 is summarized in Supplementary Material 1. The result of Step 2 is omitted because the content is not relevant to Step 3.

One thing should be noted regarding the relationship between Steps 2 and 3. These two steps are analogous to each other, and thus experiencing the former serves as a good practice for the latter step (Nakagawa, 2019a, 2019b), despite the fact that the topic of the former is not directly associated with that of the latter. In fact, each step contains the task of describing the society at a specific point in the timeline and then sending messages from that point to a previous point in the time line. The relationship between the two steps is visualized in Figure 3. In Past Design, actions that were never actually taken are imagined. This leads to a broader imagination of the actions that the present generation should have taken for the future generation in Future Design.

(Figure 3 inserted about here.)

Creation of a vision narrative

After the conclusion of the group discussions, a vision narrative was created by the secretariat (Y.N. and T.S.) to incorporate the discussion outcomes of both groups. They adopted Nakagawa’s (2020) technique to visualize the context of the discussion and convert it into a cohesive narrative. In cases where ambiguity arising from insufficient discussion was present in the narrative, email exchanges or online meetings were conducted between the secretariat and each group. Through these steps, the vision narratives for each group were finalized.

Abstracting operation on the vision narrative

The secretariat applied abstracting operations to abstract the finalized narrative with reference to the list of questions in Figure 2. As noted, the procedure should be designed so that (a) its output reflects the discussants' individual desires for the future and that (b) the output does not explicitly refer to arbitrarily set assumptions, even if these played a crucial role in creating the vision narrative. This study proposes that vision narratives be analyzed in terms of four different types of question: what, who, why, and how, such that the aggregation of the answers to these questions satisfy these criteria. The rationale for elaborating these questions runs as follows.

The question beginning with "What" should investigate what is desirable for the entire society rather than what is desirable according to the individual perspective of the discussant. Wiek and Iwaniec (2013) considered the requirement that a vision should follow sustainability principles, among others. In addition, the desirability of a state sustained over a certain period of time, rather than a singular event, should be investigated. We take into consideration the perspective of Jones (2013), who argued that, in designing social systems, it is crucial to identify an ideal state, which suggests that design efforts are linked with the continuous endeavor to uphold an ideal state. Bearing these two requirements in mind, we set Q1 as follows: "What societal purposes are maintained in the vision?"

This argument forms as a guide for refining a question starting with "Who." In fact, the discussants' desires for a future state should be accompanied by their wish with respect to who could commit to the achievement of societal purposes. This requirement seems to be consistent with Wiek and Iwaniec (2013), who demonstrate that visions should display a critical degree of convergence, agreement, and support among relevant stakeholders. Thus, we set Q2 as follows: "Who commits to the societal purpose?"

The discussants' desires with respect to a future state should be accompanied by their wishes with respect to "How" the state is maintained by the stakeholders, as identified in Q2. To break this "How" question down, it is important to refer to the premise of the systems theory literature that social systems are surrounded by the unpredictable dynamics of their contemporary social, economic, and ecological environments (e.g., Fredig and Ludema, 2005). This premise has two main implications. First, taking into account the unpredictability of environmental changes and their indeterminate nature when a state deviates from its ideal, it is essential to continuously monitor the state to determine where actions are necessary. Second, stakeholders may require the performance of different functions than usual if the system is to be returned to its ideal state once it has deviated unexpectedly from that state, and thus, it would be useful to consider how a whole system enhances its capacity for performing such functions by strengthening ties among stakeholders who are elements of the system. In association with the first point, we set Q3-1 as follows: "How do the actors make functions of monitoring and feedback work to maintain the purposes?" This is consistent with Jones (2014), who demonstrated that a system should include feedback processes—gathering information, applying control signals, and measuring and coordinating for optimal performance to reach a desired state. In association with the second point, we set Q3-2 as follows: "How are the actors interdependent on each other to maintain the purposes?" This is consistent with Lichtenstein's (2000) claim that high levels of interdependence and communication among components of an organization should be secured for an organization to be sustainable.

Finally, the discussants' aspirations for a future state should be accompanied by reasons explaining indicating why they believed the goal belongs to the given stakeholders as identified in Q2 rather than to others. This requirement is consistent with Wiek and Iwaniec (2013), who demonstrated that a vision should be regarded as relevant to those to whom it matters. This study proposes to meet this requirement with two question beginning with "Why": "Why can the societal purposes be the actors' own?" This question was broken down into the following two questions: Q4-1 "What do the actors uphold despite the transition toward a state where their purposes are maintained?" and Q4-2 "What integrates the transition into the actors' broader historical context?" To the best of the authors' knowledge, few earlier vision studies, including that of Wiek and Iwaniec (2013), have ever proposed specific strategies for meeting requirement of relevance. Our question Q4-2 (What integrates the transition into the actors' broader historical context?) was inspired by Lichtenstein's (2000) claim that the newly emerging configuration of a transitioning organization is better connected to the experience and expertise of the organization.

Regarding condition (b), following the extraction of answers to the questions, it was found that they did not rely on arbitrary assumptions associated with societal and technological uncertainty.

After the answers to these questions were extracted, they are aggregated to an abstracted vision narrative in which the associations among the answers are clarified. Messages to the present generation are also composed in relation to this abstracted vision narrative.

General Discussion

This study aimed to (i) propose a framework to alleviate the discomfort of positivistic scientists engaging in the transformative narrative creation process, and (ii) implement it to check whether this framework is applicable and effective indeed. In pursuing (ii), five scientists were divided into two groups and envisioned the future of the 2050s.

In association with objective (i), we developed a framework combining the methodology of Future Design (Saijo, 2020) and the abstracting operation. It produces a vision narrative (I), an abstracted vision narrative (II), and a message from an imaginary future generation to the present generation (III). It was confirmed that this framework was applicable to one of two scientist groups.

Two major findings emerged. The first pertains to variation in the consequences of scientists adopting the thought devices of imaginary future people. In their future uncertainty, scientists in Group B considered it impossible to establish convincing assumptions about it. Consequently, they refrained from depicting a single vision of the future. Group A, by contrast, obtained a perspective of future individuals that provided a sense of certainty within future uncertainties. At the time of the group discussion, the framework to be proposed in (i) was not yet developed, and Group B was not informed that its final goal would be independent of arbitrary assumptions. It is crucial to explore whether providing this information before the envisioning deliberation will alleviate discomfort.

Second, while the goals of the proposed framework (i.e., outputs II and III) were abstract, these outputs were formulated based on output I, which includes specific details embracing arbitrary assumptions associated with future uncertainty. This suggests that the Future Design, taking a detour by boldly establishing arbitrary assumptions related to future uncertainty and depicting specific details of the future landscape was not in vain for Group A. For example, the imagination of a highly advanced industrial food production in Japanese cities in 2050, where the flow of nutrients in the urban environment is completely controlled, led to the derivation of the urban planning sector as playing a crucial role, and regional-specific food cultures are integral to their identity. These ideas seem to possess a relevance that extends to broader contexts

To state the second finding differently, we suggest that valuable insights about the future can arise from seemingly invalid premises. This may challenge positivistic perspectives, but it aligns with transdisciplinary (TD) principles. TD research is criticized for its perceived lack of generalizability from case studies. As a counterargument, Adler (2018) proposes treating knowledge transfer across cases as arguments by analogy, emphasizing the importance of shared aspects. In accordance with this, this study proposes the application of the abstracting operation, which is a useful step for identifying aspects in which the narrative and the future to be realized are analogical.

In his classic textbook of future studies, Bertrand de Jouvenel (1967) sought to reconcile human freedom to guide the future and the creation of foreknowledge concerning the destiny of modern societies (Mahoney, 2012). Following this perspective, this study encourages positivistic scientists to embrace freedom and delve into the desirable future, in addition to being engaged with their usual task of empirically establishing universal laws creating foreknowledge. Crucial tasks remain after this novel study, namely, revealing how nitrogen researchers and more general scientists assess the outputs of this study, in particular, the abstracted vision narrative and message to the present, and how they might make use of this framework in their own contexts.

This study has some important methodological limitations. First, the sample size was small (n=5). Even among these individuals, there was a significant difference in how they accepted the imaginary future people as a thought device. Expanding the sample size would likely reveal further diversity. Second, the sample was composed only of academic researchers. In discussions on scientific themes like those explored in this study, how practitioners and the general public accept this thought device is an important question. Third, while this paper focused on depicting the state of society in 2050 and how that state is maintained, it did not give sufficient attention to the processes through which that state was built. It is necessary to conduct future research that addresses these three limitations.

Lastly, we would like to address another significant challenge that remains for the future. This study argues for the necessity of deeper involvement of scientists in normative activities, specifically in overcoming the positivist gap and articulating desirable futures. Achieving this alone can be a significant challenge for some scientists. However, this will lead to even greater difficulties for them. This is because engaging in the articulation of desirable futures inevitably implies that scientists will become actors involved in the politics of transitions toward the future. Transitions are inherently political processes, in the sense that different individuals and groups will disagree about the desirable directions of transitions, the appropriate ways to steer such processes, and the potential for transitions to lead to winners and losers (Köhler et al., 2019). Many scientists may believe that engaging in this political process will hinder their primary activity—namely, positivistic research. Addressing this second difficulty faced by scientists will be an important future challenge. Nevertheless, this paper can offer a provisional answer to this challenge, as follows: As Nakagawa (2024) argues, one of the most important characteristics of the thought device of the imaginary future generation is that it takes a modest ethical stance. That is, this device refrains from imposing strong demands on individuals to care for future generations by adopting specific values or beliefs. Instead, individuals are only asked to reflect on their actions from the perspective of future generations. By avoiding such impositions, the pathway remains open for individuals with diverse values and beliefs to embody the imaginary future generations. Even individuals with opposing political stances can simultaneously become part of the imaginary future generations while continuing to conflict with each other. Therefore, when scientists use this thought device, it contributes to increasing the diversity of political stances in society by demonstrating that such stances exist within the scientific community itself, and it improves the quality of social decision-making. One strategy to ease the second difficulty faced by scientists would be for society as a whole to recognize that the scientific community can play such a social role.

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Author contributions

T.S. and Y.N. designed the study. K.H., K.M., B.L., and K.N. envisioned the future in the deliberative experiment. Y.N. and T.S. processed the transcribed voices during the experiment. K.H. and Y.N. wrote the Introduction and the rest of the first complete draft of the manuscript, respectively. All authors provided input at various stages during writing.

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Declarations

Competing interests

The authors declare no competing interests.

Ethics

In this study, five scientists took part in the deliberative experiment. They were informed of the purpose of the experiment and agreed to participate on the condition that they would become co-authors of the paper to be written after the experiment concluded. However, subsequently, due to various circumstances, one out of the five individuals decided, of their own volition, not to become a co-author. Nonetheless, he agreed that the paper would still be written by the rest authors and published as planned.

Data availability

The qualitative data generated by this study are in Japanese, comprising over one hundred pages. Each individual sentence within this data contains subtle nuances, making it challenging to provide translations that accurately reflect their intended meanings. Therefore, interpretations conducted in Japanese were summarized, translated, and presented in the main text and Supplementary Material of the paper.

Figure 1

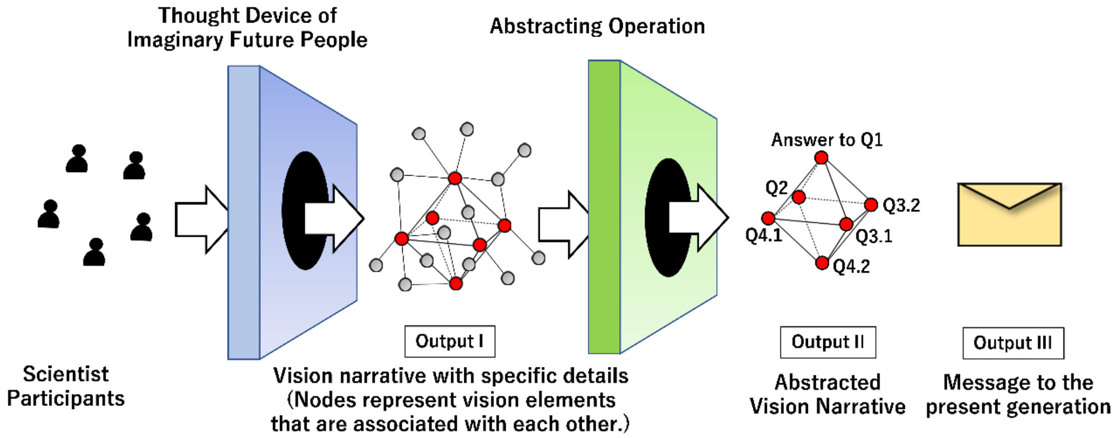

Figure 2

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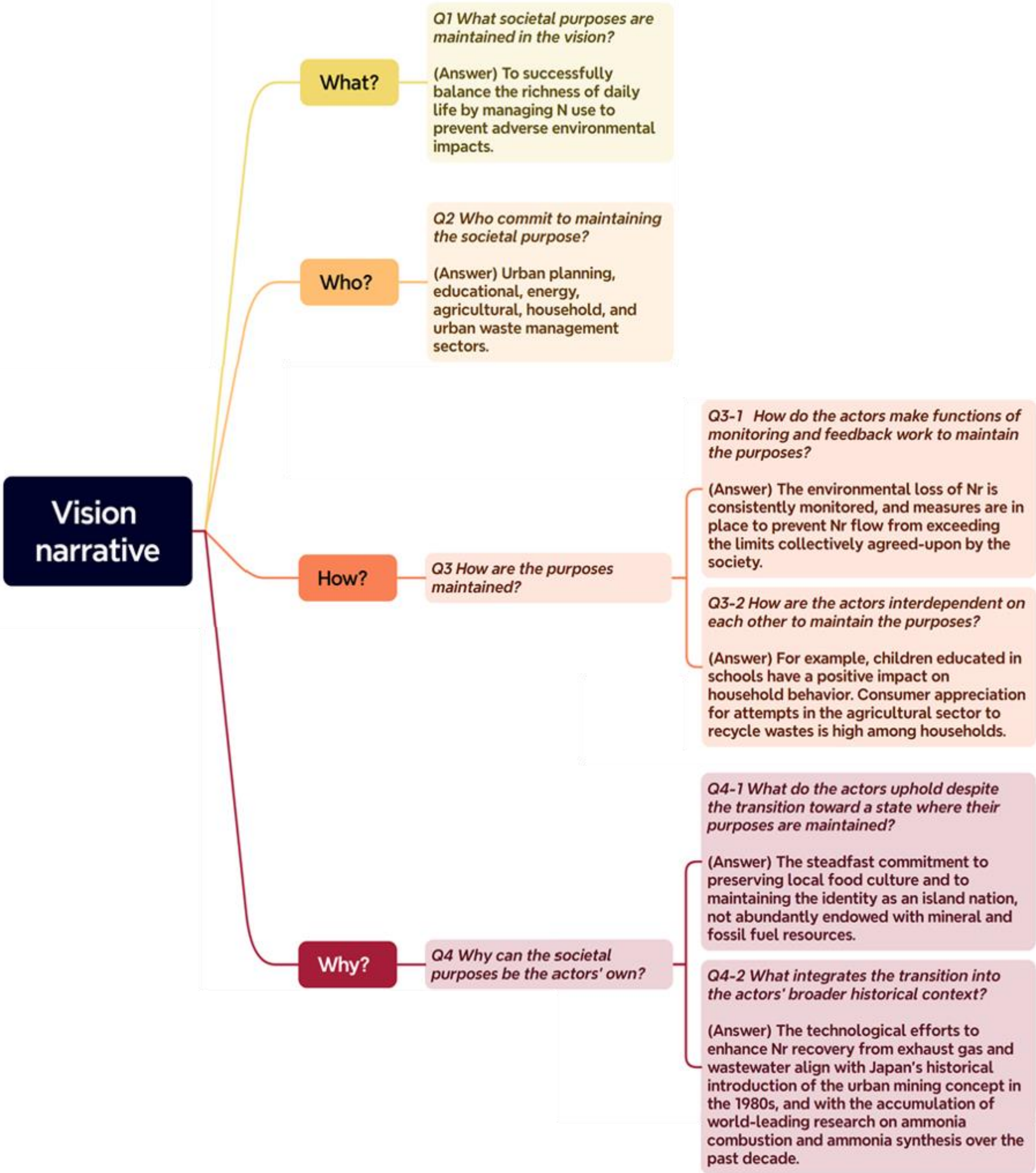
Vision narrative
What?
Q1 What societal purposes are maintained in the vision?
(Answer) To successfully balance the richness of daily life by managing N use to prevent adverse environmental impacts.
Who?
Q2 Who commit to maintaining the societal purpose?
(Answer) Urban planning, educational, energy, agricultural, household, and urban waste management sectors.
How?
Q3 How are the purposes maintained?
Q3-1 How do the actors make functions of monitoring and feedback work to maintain the purposes?
(Answer) The environmental loss of Nr is consistently monitored, and measures are in place to prevent Nr flow from exceeding the limits collectively agreed-upon by the society.
Q3-2 How are the actors interdependent on each other to maintain the purposes?
(Answer) For example, children educated in schools have a positive impact on household behavior. Consumer appreciation for attempts in the agricultural sector to recycle wastes is high among households.
Why?
Q4 Why can the societal purposes be the actors' own?
Q4-1 What do the actors uphold despite the transition toward a state where their purposes are maintained?
(Answer) The steadfast commitment to preserving local food culture and to maintaining the identity as an island nation, not abundantly endowed with mineral and fossil fuel resources.
Q4-2 What integrates the transition into the actors' broader historical context?
(Answer) The technological efforts to enhance Nr recovery from exhaust gas and wastewater align with Japan's historical introduction of the urban mining concept in the 1980s, and with the accumulation of world-leading research on ammonia combustion and ammonia synthesis over the past decade.

Figure 3