From modelling problems to socio-ecological awareness

The role of reflective discussions in mathematics education

LISA STEFFENSEN

The focus of this article is on how mathematical modelling problems can facilitate reflective discussions contributing to raising students' awareness of socio-ecological issues. Drawing on theoretical concepts from critical mathematics education, particularly reflective discussions, environmental justice, controversy and uncertainty, two modelling problems, "Artificial turf" and "Wind farms", are analysed. The analysis reveals multiple ways in which these problems can facilitate reflective discussions contributing to raising students' awareness of socio-ecological issues. For instance, choosing a context that is authentic, complex, personalised, has multiple stakeholders, no obvious solutions, involves uncertainty, and is value based and controversial. Additionally, the problems offer opportunities for teachers to initiate conversations on topics such as energy consumption and impacts on the environment, environmental justice, and uncertainty, prompting students to take a stance and engage critically. This research suggests that teachers can engage students in modelling problems involving socio-ecological issues that aim to contribute to raising awareness, and future research can investigate how this could take place in the classroom.

Keywords: Mathematical modelling problems, reflective discussions, socio-ecological issues.

Socio-ecological issues threaten all life, and as a society, we must find sustainable ways to address such issues because the consequences could be severe if we do not. These issues are characterised by an entanglement of environmental challenges, social structures, economic systems and cultural values. Ecological dimensions can involve preserving habitats, economic dimensions can be about financial prosperity for communities, while social dimensions can involve equal opportunities in education. Climate change is one example of a socio-ecological issue in which the

Lisa Steffensen
Western Norway University of Applied Sciences

Steffensen, L. (2025). From modelling problems to socio-ecological awareness: The role of reflective discussions in mathematics education. *Nordic Studies in Mathematics Education*, 30 (4), 141–165.

complex interactions between these dimensions impact both how we understand this issue, and how we respond to the problems. While socio-ecological issues refer to problems typically involving tensions between multiple stakeholders, such as environmental protection versus economic development, sustainability can be a way of thinking how we address these tensions and meeting "the needs of the present without compromising the ability of future generations" (World Commission on Environment and Development, 1987, p. 16).

Sustainability was included as an interdisciplinary topic in the Norwegian curricula and should be embedded in all subjects (Ministry of Education and Research, 2017). The curricula state that students should develop environmental awareness, understand ethical dilemmas, and that mathematical models should help them to make responsible life choices and become aware of how mathematical models lay the foundation for important societal issues. Mathematical modelling has become part of the mathematics curricula worldwide (Cevikbas et al., 2022; Niss & Blum, 2020). In Norway, it was included as a core element of the mathematics curricula in 2019 (Ministry of Education and Research, 2019). In this paper, mathematical modelling is understood as a process for addressing real-world phenomena using mathematical concepts, tools and structures to understand, analyse, predict or make decisions about complex situations.

An inherent part of the modelling process could include *reflective discussions*. Reflective discussions in a modelling context are inspired by Barbosa (2006; 2009; 2013), and in this paper are understood as dialogue in which a critical inquiry is made into a real-world problem itself, and various choices are made in the modelling process (e.g. which assumptions are made, which values are given weight, or the societal implications of the respective mathematical model) In schools, students could be encouraged to critically reflect upon issues such as: What assumptions are being made? Whose interests are represented or excluded? What are the ethical consequences of the modelling? Are there potential harms, and who might be affected? However, such reflective discussions do not happen automatically, and it is challenging for students to identify all the issues that require reflective discussions. In addition, students might consider such discussions "as not being mathematical enough", and perhaps be somewhat reluctant to engage in these types of reflections. Thus, for reflective discussions to take place, teachers can explicit facilitate students' reflective discussions through pedagogical choices and by carefully designed problems.

Mathematics and mathematical modelling play a crucial role in understanding, describing, predicting and communicating about complex socio-ecological issues (Barwell, 2018). These issues are deeply intertwined with quantitative and qualitative data, and the ability to evaluate risks and consequences over time. The 27th ICMI Study (le Roux et al., 2025) highlighted this connection, and involved 67 papers exploring how mathematics education can engage with social, political, ethical and ecological concerns. A significant number of these papers focused on mathematical modelling. For instance, Borromeo Ferri (2025) emphasised that the teaching and learning of mathematical modelling may help students to develop knowledge about sustainability. If students engage in mathematical modelling problems related to socio-ecological issues, they could learn to understand the contributory factors, make projections, and evaluate potential mitigation or adaptation strategies through the lens of mathematics. In this way, mathematical modelling can become more than a technical activity and support critical engagement with urgent socio-ecological issues.

Modelling problems that involve real-world tensions, such as the tensions between local and global pollution, or between economic development and indigenous rights, can raise awareness of socio-ecological issues while highlighting concerns about equity, justice, agency and democratic participation. The choice of context can significantly influence learning and the shaping of students' perceptions of mathematics (Watson & Ohtani, 2015). When carefully chosen, socio-ecological contexts can support students in recognising mathematics as a socially embedded practice that can be used to critically inquire about complex, value-laden challenges. Also, the real-world nature of modelling problems makes them well suited for such inquiry, as relevance and authenticity are key design principles (Galbraith, 2006; Geiger et al., 2022; Wess et al., 2021).

Reflective discussions, when integrated into modelling activities, can further support students in connecting mathematical reasoning with ethical, social and ecological perspectives. Such discussions can encourage students to question assumptions, consider competing interests, and make informed decisions about the issues being modelled. This aligns with the goals of critical mathematics education (Frankenstein, 1983; Gutstein, 2006; Skovsmose, 2023) where mathematics is key to interpreting and acting in a complex world as critical and responsible citizens. Bringing socio-ecological issues into the mathematics classroom is not a straightforward process, as they are often characterised by uncertainty, controversy, complexity and values. However, according to Maass et al. (2023), modelling problems should deliberately include ethical, political and economic dimensions, as well as help students to engage in evidence-based reasoning through dialogue and debate.

Supporting students to become aware of socio-ecological issues could include using mathematics to understand problems related to ecosystems, environments, or production and consumption (Frejd et al., 2024). Previous research has described the incorporation of environmental, social and economic sustainability into mathematical modelling problems (Bulut & Borromeo Ferri, 2025; Li & Tsai, 2022; Vásquez et al., 2023), suggesting that using such problems in mathematics education could be valuable.

Here, I discuss *the ways in which modelling problems facilitate reflective discussions that contribute to raising students' awareness of socio-ecological issues*. I do this by reflecting on two modelling problems, "Artificial turf" and "Wind farms", which I designed as part of a modelling textbook for teachers and pre-service teachers (Steffensen, 2023a).

Socio-ecological issues and modelling

Examples of mathematics education that addresses socio-ecological issues can be found all over the world. In Mexico, Solares-Rojas et al. (2022) examined how teachers and students engaged in a community project on water pollution caused by industrialisation, while in Brazil, Rosa and Orey (2015) discussed student engagement when modelling river pollution from industrial discharge. In Argentina, pre-service teachers designed problems related to water scarcity, waste management and household utility consumption (Villarreal et al., 2015). In South Africa, year 10 students and teachers worked with waste accumulation, the Human Development Index, and the optimal placement of water reservoirs (Julie & Mudaly, 2007). Brazilian 4th year students critically reflected on water usage in food production (de Almeida Luna et al., 2015), while in Norway, 10th year students explored their carbon footprint (Steffensen et al., 2021), and primary school students engaged in discussions about plastic pollution (Steffensen, 2023b; Johnsen-Høines, 2020). In Colombia, pre-service teachers discussed global warming (Zapata-Cardona & Martínez-Castro, 2021) and in Japan, 13–14-year-old students explored the causes of global warming, how to prevent it, and decision-making (Fukuda, 2020).

Combined, the above examples, as well as the contributions from the ICMI study (le Roux et al., 2025) illustrate a growing global interest in connecting modelling with socio-ecological issues. However, few of these examples explicitly integrate reflective discussions about the broader socio-ecological issue in their modelling problems. Thus, the discussions in this paper aim to contribute to addressing this gap by creating space for reflective discussions through modelling problems about, for instance, who is affected, what is valued, and how decisions are justified, thereby potentially supporting critical citizenship.

Berget (2022) found that modelling problems in Norwegian mathematics textbooks were overly structured, simplified and mathematised, limiting students' opportunities to engage in the core modelling process. Similar findings can be found elsewhere, for instance, in Denmark (Wolfsberg, 2015), Sweden (Frejd, 2013), Holland (Zwaneveld et al., 2017), Singapore and Indonesia (Syam et al., 2019) and Australia (Stillman et al., 2013). Such modelling tasks often leaves little room for reflective discussions about assumptions, variables or the implications of the modelling itself. I therefore reflect on how the two modelling problems can create opportunities for students to consider multiple perspectives, explore uncertainty, and critically reflect on the socio-ecological dimensions.

Tesfamicael and Enge (2024) found that sustainability themes appear both explicitly and implicitly in a Norwegian textbook series, covering topics such as water management, food, energy and indigenous issues, indicating the potential for the integration of socio-ecological issues in the teaching and learning of mathematics using a textbook as the starting point. However, while there might be opportunities to include socio-ecological issues in mathematics textbooks, there is little guidance on how such issues might be pedagogically framed, or how modelling problems could engage students in reflective discussion on these socio-ecological issues.

Reflective discussions and socio-ecological issues

Skovsmose (1994, 2023) and Barbosa (2006, 2009, 2013) emphasised that students should develop a critical worldview, recognising that neither mathematics nor mathematical models are neutral. This is sometimes referred to as *socio-critical modelling*, viewing knowledge as dependent, situated and value-laden, and recognising that models are constructed representations shaped by assumptions, interests and aims. The concept of reflective discussions in modelling is inspired by Barbosa (2006, 2009, 2013) and Skovsmose (1994, 2023) and understood as dialogue that critically inquires about both real-world problems and key modelling choices. Ideally, such dialogue would happen throughout the modelling process and would form part of the entire process. This could be classroom dialogue in which students critically examine assumptions, values and implications of the models in society. This dialogue is not limited to mathematical correctness or procedure, but includes ethical, political and social dimensions, supporting students' awareness about the nature and role of mathematical modelling in socio-ecological issues, potentially leading to more equitable and socially responsible modelling practices.

Skovsmose (1994, 2023) and Barbosa (2006, 2009, 2013) differentiated between three types of classroom discussion: mathematical, technological and reflective. While mathematical and technological discussions are often problem-driven and solution-oriented, reflective discussions can be characterised by more epistemological and ethical questioning. These discussions can occur in moments of uncertainty, disagreement or ambiguity, where students examine, negotiate and critique not only how to model, but why certain choices are made and what consequences these choices have for the broader social, political and ethical implications. They can centre on how models represent reality, which criteria are used, whose perspectives they reflect, and their implications. They can challenge the assumption of modelling as a neutral activity mirroring 'reality', highlighting instead the value-laden choices embedded in how real-world problems are framed, mathematised and interpreted. Reflective discussions can therefore provide an opportunity to raising awareness about socio-ecological issues in which students actively can engage, form standpoints, and practice critical citizenship.

Socio-ecological issues can help to provide a context that facilitates a view of mathematics as something that is not value-free and objective, and where mathematical modelling can become a space for negotiating. Reflective discussions could include epistemological questions: how knowledge is constructed and validated in the modelling process, for instance, through simplifications, assumptions and choice of data. They could also involve reflections of a more ethical nature; discussions about what is at stake in each modelling decision, for instance, who is affected, which values are prioritised, and what is considered acceptable. Rather than seeking definitive answers, students could engage in reflective discussions about questions such as what assumptions are embedded in the model? What perspectives or values are prioritised or excluded? How would conclusions be affected by alternative scenarios, and what is the impact on multiple stakeholders? Explicitly inviting students to engage in reflective discussions in all parts of the modelling process could help to make such discussions more visible and potentially encourage the students to question whose interests mathematics serves, what realities it represents, and how modelling choices shape sustainable futures.

Skovsmose (2023) argued that environmental issues involve question of justice, concerning who benefits, who bears the costs of ecological decisions, and whose voices are heard. Skovsmose's concept of *environmental justice* includes the relationships between citizens and the environment, and the interactions among people, and that this generates questions of justice across space, time and social groups. For instance, it concerns ecological decisions about justice across generations, (e.g. future impact of today's actions), geography (e.g. unequal distribution of pollution and climate vulnerability), and social structures (e.g. marginalised communities facing greater environmental risks with limited political influence). Examples include the overexploitation of natural resources, such as fisheries, or the unequal global access to clean air, water or energy. Incorporating environmental justice into classroom discussions could raising students' awareness of such inequalities and support them to make informed opinions about socio-ecological issues, through reflective discussions. Skovsmose (2023) argued that mathematics education is vital in addressing environmental justice because of, for example, the way mathematics is used, not only to describe real-world issues, but also how it can be part of forming society.

Socio-ecological issues can cause controversies among citizens, stakeholders and decision-makers. *Controversy* is understood as prolonged public disagreement, characterised by being authentic and contemporary (Hess, 2009). Hess linked controversies with democracy and argued that students' participation in discussions on tense socio-political issues promotes tolerance. However, mathematics teachers may be ambivalent about using controversial issues as context (Atweh & Brady, 2009; Simic-Muller et al., 2015). They may be reluctant to indoctrinate their students with specific standpoints or receive negative feedback from parents or school leaders (Abtahi et al., 2017; Hess, 2009). Additionally, as Simic-Muller et al. (2015) describe, teachers struggle to provide concrete examples of incorporating controversies into mathematics lessons.

Mathematical modelling of socio-ecological issues involves *uncertainty*, and Hauge and Barwell (2017) argued that discussions should be included regarding uncertainties in situations where facts are uncertain, values are in dispute, the stakes are high, and decisions are urgently needed. They stated that uncertainty is not only to be regarded as a technical issue to be resolved, but a key aspect of complex societal challenges. This includes technical uncertainty (e.g. about statistical measures), methodological uncertainty (e.g. about methodological choices), and epistemic uncertainty (e.g. about incomplete or unknown knowledge). These often overlap, and Hauge and Barwell highlighted the importance of critical reflection on what is known, how it is known, and what remains uncertain. By foregrounding uncertainty as a characteristic of complex real-world problems, rather than a flaw of the modelling process, students' reflective discussions during the modelling process can help them to make informed decisions under conditions of uncertainties.

Methods

In order to reflect on the ways in which modelling problems can facilitate reflective discussions that contribute to raising students' awareness of socio-ecological issues, I have analysed two modelling problems, "Artificial turf" and "Wind farms". These problems were originally developed by Steffensen (2023a) as part of a mathematics-didactic book for teachers. Each problem is accompanied by contextual texts offering suggestions for classroom implementation aiming at supporting teachers in facilitating critical engagement with socio-ecological issues. For instance, in the "Wind farm" problem, it is suggested that students could investigate who benefits from the wind farm, who is affected, and what consequences this will have for them, and links are provided to articles discussing the total environmental impact of wind farms.

During the design phase, the modelling problems were reviewed by mathematics educators and researchers with experience of both school-based teaching and problem design. They were inspired by the design principles described by Galbraith (2006), Maaß (2010), Wess et al. (2021) and Geiger et al. (2022). For instance, to ensure a genuine link with the real world, the context of the modelling problems involves two issues that are both real, relevant and need to be urgently addressed. Elaborations on the design principles are not included in this paper due to word limitations, but an overview of the most important guiding principles is shown in table 1 and are also described in the mathematics book by Steffensen (2023a).

Table 1. *In designing the modelling task, I used the six principles of design by Galbraith (2006), the classification scheme by Maaß (2010), criteria for modelling tasks by Wess et al. (2021), and the design and implementation framework by Geiger et al. (2022)*

Geiger et al. design and implementation framework (2022)	Maaß classification scheme (2010)	Wess et al. criteria (2021)	Galbraith's six principles (2006)
• Nature of problem • Relevance and motivation • Accessibility • Feasibility of approaches • Feasibility of outcome • Didactical flexibility • Pre-engagement • Modelling process review • Initial problem presentation • Body of lesson • Conclusion (presentation, report)	• Focus of modelling activity • Data • Nature of relationship to reality • Situation • Type of model used • Openness of task • Type of representation • Cognitive demand • Mathematical content	• Reality relation • Relevance • Authenticity • Openness • Promoting sub-competencies	• Genuine link with real world • Identifying mathematically tractable questions • Feasibility of solution process • Solution of the mathematics for the problem is possible for students • Evaluation procedure • Didactical principle (e.g. sequential of problems)

While these design principles guide aspects such as real-world relevance, accessibility, feasibility and cognitive demand, they provide limited guidance of how modelling problems can explicitly facilitate reflective discussions that contribute to raising awareness of socio-ecological issues. This gap motivated both the design and the analysis of the modelling problems.

The analysis was guided by theoretical perspectives from the critical mathematics outlined above, in particular: reflective discussions, environmental justice, controversy, and uncertainty. These theoretical perspectives were part of the design and were also used to support the interpretation of the modelling problem. The two problems were chosen because they address urgent socio-ecological issues relevant to a Norwegian context, hold conflicting interests, are controversial, have no obvious or ”correct solutions”, and need to be addressed. For each of the modelling problems, particular focus was given to the real-world context and how this could facilitate reflective discussions on aspects of environmental justice, controversy or uncertainty. This approach can allow for a theoretically grounded examination of how modelling problems can embed complex social and ecological concerns in mathematics education. Although individual analysis of modelling problems developed by oneself introduce bias, it can also allow for a closer examination of the aim of the design and how specific features were designed to invite reflective engagement. Acknowledging this limitation, the analysis does not aim to evaluate the modelling problems or present them as exemplary. Rather, it is about exploring opportunities for reflective discussions in order to raising awareness of socio-ecological issues within a theorised framework. For instance, I discuss how modelling problems can facilitate reflective discussions around issues such as environmental degradation and economic aspects.

Examples of reflective discussions

Artificial turf

The first problem, ”Artificial turf” (figure 1), involves plastic pollution, an issue that devastates human health, animals and nature.

Artificial turf

Plastic in nature is a major challenge for animals and people. But how big is the problem? How much plastic is there in nature? And why is it problematic? How will it develop? Why is it difficult to reduce the amount of plastic? What can be done? An artificial 11-lane football turf typically contains around 100 tonnes of rubber granules and is replenished annually with 4–7 tonnes. Your sports team needs help controlling how much is disappearing from their facility. Create a mathematical model that helps them map how many granules are disappearing from the turf and propose concrete measures stopping granules from getting into nature. Also comment on uncertainties in the model.

Figure 1. *Artificial turf – amongst the largest microplastic polluters in Norway (picture made with AI).*

Although awareness of plastic pollution has increased (Walker & Fequet, 2023), students may not be aware of how this issue relates to artificial turf. However, in Norway, Denmark and Sweden, rubber granules from turf are the second largest source of microplastic emissions (OSPAR, 2024), and from 2031, there will be a ban from selling such granules (Norwegian Environment Agency, 2023). There are more than 2000[1] artificial turf pitches in Norway that support physical activity, and replacing them will be challenging, mainly because there are currently no good alternatives. Also, the UN has initiated an internationally legally binding agreement by 2024 to end plastic pollution (UNEP, 2022). Thus, it could be argued that this problem is an urgent socio-ecological challenge with limited time to solve.

This socio-ecological issue is situated in the students' immediate surroundings (e.g. in schools and sports arenas), which could support initial interest and provide a promising starting point for students' reflective discussions. However, contextual familiarity alone does not guarantee meaningful engagement. Relevance will only emerge when the students can perceive the problem as personally or socially significant. While students and their families may be familiar with granules clinging to their clothing and shoes and impacting their daily lives, they may not be aware of the full extent of the problem, such as runoff into ditches and streams, deposits left on the ground and in the water, and the need to replenish about 4–7 tonnes nationally on an annual basis[2]. Thus, one way that a modelling problem can raise socio-ecological awareness through students' reflective discussions is to focus on local issues in the students' immediate environment; issues such as artificial turf, and pointing to the broader environmental or political concerns.

The modelling text (figure 2) presents some information but the problem is relatively open and underdetermined, requiring students to gather information, make assumptions, select variables, and justify their modelling choices on their own. It does not explicitly ask them to discuss, reflect, create argumentation, etc. The students' reflective discussions will most likely not happen by themselves; they must somehow be initiated and facilitated. Thus, as teachers, it is relevant to reflect on how reflective discussions could be facilitated.

Another way the modelling problem facilitated reflective discussions that can contribute to raising awareness was through the text accompanying the modelling problem in the book (Steffensen, 2023a). This text suggested to the teachers that students could start by making hypotheses about where the granules disappear, that they work in groups, discuss, reflect and have inquiry-based dialogues in the classroom, as well as with the people responsible for the turf. The text also suggested facilitating students' reflections on what would happen when the granules were banned – and how this would impact their ability to engage in sport. However, it could be imagined that the modelling problem explicitly asked students to engage in reflective discussions about who should bear the cost of replacing the turf. They could inquire about how the financial burden is distributed and suggest models that they consider fair. They could explore how infrastructure decisions are tied to broader questions about public spending and resource allocation. Also, it could have included prompts to reflect and discuss how access to sports facilities is affected by socio-economic inequality, and how this might impact inclusion and participation in community life.

In Norway, such discussions are already taking place. Discussions about who should bear the cost of replacing artificial turf typically involve four options: the individual pitch owner could cover these costs; they could be shared by the owners of football facilities; they could be shared by everyone in Norwegian sports; or shared by Norwegian society via the state budget (Gran et al., 2024). These options have serious implications for the affected parties. If individual sports teams end up with the cost of replacing the turf, they may have to increase their payment models to members to cover their expenses, meaning that some young people may not be able to engage in sports activities. In Norway, access to organised sports and recreational activities is characterised by socio-economic inequality (Jacobsen et al., 2021). Children and youth from lower-income families and minority backgrounds (particularly girls) are significantly underrepresented in sports, especially when they involve high costs. In modelling problems that address issues like artificial turf or access to public facilities, such disparities can be more explicitly visible, prompting students to reflect on questions of equity, inclusion and whose needs are prioritised. The problem can encourage students to consider how environmental policies or infrastructure decisions affect different social groups, especially vulnerable populations in alignment with the environmental justice, as described by Skovsmose (2023).

One way the modelling problem could facilitate reflective discussions that contributes to raising awareness of socio-ecological issues is when students in the modelling problem are explicitly asked to comment on uncertainty in their models. This could pave the way for reflective discussions such as: What data are missing? Is it reasonable to assume that runoffs are evenly distributed throughout the year? How could weather patterns or geography affect runoff? This is not only a mathematical process, but also an epistemological one: students must reflect on the nature and limits of the knowledge they produce. It could provide a starting point for students to engage with assumptions and uncertainty in real-world contexts. However, students might be unfamiliar with formulating such questions and reflecting and discussing the uncertainty in their data. Thus, teachers need to carefully consider how to facilitate these discussions on uncertainty.

A key challenge in the modelling problem is estimating how many rubber granules are lost annually from a specific turf, and data sources often give varying estimates[3]. Using their local turf could personalise the problem, in line with what Geiger et al. (2022) described, and the decisions made could be relevant to them and their community. However, most likely the local sports team have no data on run off. For example, students could use estimates regarding the problem for an 11-lane football turf and adjust to their own sports arena, or, if their sports teams have installed brush stations or catch basins for runoffs, these could be used. Students must decide whether to use high, medium or low estimates, or potentially every kind of estimate. Students could encounter technical and methodological uncertainty, as described by Hauge and Barwell (2017), as they must choose from different data sources and estimation methods and assumptions. They also face epistemic uncertainty, because not all relevant factors are known, measurable or even recognised, especially regarding long-term environmental impacts or social consequences.

Raising awareness of socio-ecological issues can lead to a sense of hopelessness when students realise the extent of the problem (see e.g. Ojala, 2023). In the problem, students are asked to suggest concrete measures. This could be another way of raising awareness, and they could contact their local sports teams and recommend new approaches because of new insights into this issue. Such involvement could support students in taking action, thereby empowering them through mathematics education (see e.g. Valero, 2009; Wright, 2021).

Wind farms

The second modelling problem, "Wind farms", involves renewable energy, and asks students to make a report where they consider whether a wind farm should be developed in their municipality (figure 2). In the following, I examine how reflective discussions can take place through two examples: controversies and economic aspects.

Wind farms

A typical wind turbine can produce 14 GWh, corresponding to the consumption of about 700 households. Make a report to your municipality where you assess whether or not a wind farm should be developed. You can include approximately how many wind turbines are needed to cover the electricity consumption where you live. You can estimate land use, costs, income, CO_2 budget and energy needs in Norway. You can say something about the location and how many turbines you would recommend. Identify possible conflict areas and consider how different conflicts of interest can be handled.

Figure 2. *Wind farms and renewable energy (image made using AI).*

One way this modelling problem could facilitate reflective discussions is by explicitly including a controversial issue. Globally, the shift to reduce CO2 emissions has driven up the demand for renewable energy and in Norway, increased wind farm development has caused controversies due to conflicting interests. For instance, local municipalities may experience negative impacts (e.g. major interventions in nature or noise pollution), while the country benefits from achieving its climate goals and ensuring a sufficient energy supply. This raises questions about procedural and distributive environmental justice: Who gets to decide what wind farms are installed, and where? Whose voices are heard in the planning processes? And who bears the costs of achieving the national goals? These tensions are seen in current debates about wind farm development in Norway, where local communities often resist installations that they perceive as being intrusive or unfair, despite the potential financial benefits or alignment with the climate targets. Thus, the modelling problem involves a highly controversial socio-ecological issue with multiple stakeholders and with no obvious solutions.

It explicitly addresses the controversies of the socio-ecological issue by asking students to identify areas of conflict and consider how various interests can be addressed, rather than merely focusing on modelling the energy needed or the estimated number of wind turbines. It could therefore be argued that the modelling problem can raising awareness of the controversies of socio-ecological issues. However, to facilitate reflective discussions on these controversies, the modelling problem (or the teacher) can more explicitly state that students should engage in reflective discussions on the controversies. These issues are not straightforward, and students could benefit from reflecting on various perspectives. This could take place in groups – or in plenary discussions, where students weigh their concerns, including perspectives such as culture and values, not only those that are more easily measured, like financial perspectives.

In Norway, the controversies around wind farms intensified when the Supreme Court ruled that two wind farms at Fosen, part of Europe's largest onshore wind farm, violated the human rights of the Sámi people, who rely on this land for reindeer herding, and which is part of their culture and traditional way of life (Supreme Court of Norway, 2021). Thus, the context of the modelling problem has to do with environmental justice, involving conflicts about indigenous rights, land use and renewable energy development. Although in this case the ruling favoured indigenous rights and it could be argued that environmental justice was served to some extent, this might often not be the case elsewhere, and conflicting interests between indigenous rights and environmental concerns are a global concern. In Australia, mining in sacred Aboriginal sites and drawing water from sacred rivers are in breach of indigenous rights (Huntley & Wallis, 2024; Moggridge & Thompson, 2021). In New Zealand, fracking in the Taranaki region impacts the history and culture of the M?ori (Bettini, 2022). In the United States and Canada, the pipeline projects on tribal treaty lands and the fracking industry affect land and native cultural traditions, and create environmental injustice for the indigenous population, as well as potentially influencing democratic participation (Bratman et al., 2022; Hurlbert & Datta, 2022).

Another way the modelling problem could facilitate reflective discussions contributing to raising awareness of socio-ecological issues involves economic dimensions. Students could be engaged in reflective discussions about how natural resources like wind power should be managed – and who it should benefit. Around 70% of wind farms in Norway are foreign owned, with less transparency on income management and beneficiaries (Idsø, 2021). Such economic management is in contrast with other renewable energy sources in Norway such as hydropower, where

90%[4] is publicly owned. The ownership (e.g. state-governed or privately/foreign owned) could influence how the profits from natural resources are used, and the willingness to develop wind farms. For example, while state-owned companies typically benefit citizens, this may not be the case in private sector companies.

Students' reflective discussions could address questions such as: What economic models are in place? Do they benefit the municipality or the state? Citizens? If so, to what extent, and at what cost? Should the state be subsidising privately owned wind farms? Who owns the wind – and who should benefit from it – if anyone? These questions concern ownership, resource management and the distribution of profits. The students could also engage in economic aspects directly involving citizens, such as energy prices. In Norway, there are stark examples of price variations. For instance, as shown in figure 3, there was a price span of NOK 0.15 in the north[5] to NOK 13.15 in the east in December 2024. The difference in price is a combination of several factors, but one important factor is that while the southern part of Norway is connected to the European energy market by cable, the northern part is not. These price differences have sparked public controversy as they cause inequality in living costs for both individuals and companies. Also, because Norway exports electricity to European countries, there are arguments for cutting the cables to possibly reduce energy prices, at the expense of risking increased prices for other European countries. So, within both the national borders and outside of them, there are energy concerns about fairness. Energy prices profoundly impact citizens' finances and lives, and raise broader concerns about environmental justice within the social and economic dimensions.

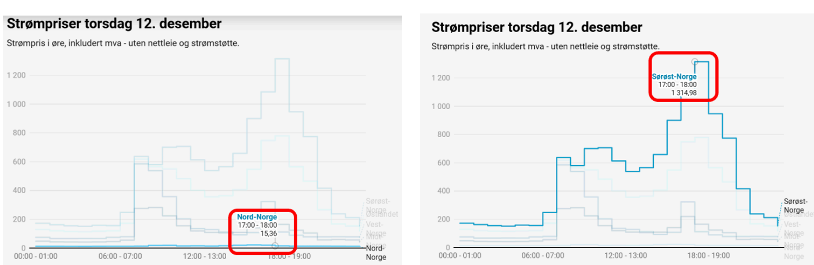

Figure 3. *Two snapshots from 12 December 2024 showing the price span in Norway, varying from NOK 0.12 per kWh including VAT in the north (left) to around NOK 13 in the south (right). Graph from Andersen (2024).*

These two factors are not exhaustive, and students could have reflective discussions on related or other issues such as land use or the impact on wildlife. However, one aspect of the problem is worth highlighting: students are explicitly asked to take a standpoint – not only to consider how various conflict areas could be handled. They are asked to evaluate whether or not wind farms should be developed. The aspects of decision-making and well-founded decisions are key to critical citizenship (Maass et al, 2023). While it may not traditionally be seen as the mathematics teacher's role to raising awareness of issues beyond school mathematics, modelling problems that encourage students to relate mathematics to socio-ecological issues provide opportunities for them to be empowered as informed and reflective citizens.

Concluding comment

In this paper I have discussed the ways in which mathematical modelling problems can facilitate reflective discussions contributing to raising students' awareness of socio-ecological issues. Theoretical perspectives from critical mathematics education (Skovsmose, 2023), particularly the concepts of reflective discussions, environmental justice, controversy and uncertainty, were used to analyse two modelling problems, ”Artificial turf” and ”Wind farms”.

Contributions of this research include reflections about ways to combine mathematical modelling with socio-ecological issues. One way identified as relevant is *the choice of contex*t. The modelling problems present urgent, socio-ecological issues about plastic pollution and renewable energy, relevant to both local and global context. They are authentic and complex, have multiple stakeholders, no obvious solutions, involve uncertainty, value-based dilemmas, will impact unevenly, and are controversial.

Another way identified is to *explicitly ask students to identify conflicting interests – and to take a stand*, rather than just asking them to model the problem (e.g. estimate the energy needed). Controversies were suggested by Hess (2009) as a fruitful way of facilitating democratic practices through discussions, and where students can experience competing values (e.g. cultural versus economic) and fairness (e.g. energy prices). Taking a stand and decision-making was also highlighted as essential by Maas (2023) in order to achieve critical citizenship. This taps into the third way: *students' reflective discussions can include the notion of environmental justice* as described by Skovsmose (2023). Socio-ecological issues raise questions about environmental justice: who bears the costs, whose voices count, and which interests dominate? Taking this into account, students may reflect about intergenerational aspects (e.g. discuss who is responsible for protecting future generations), geographical aspects (e.g. reflect on whether rural or peripheral areas are disproportionately affected), and social aspects (e.g. consider if marginalised communities have equal influence).

A fourth way is to *explicitly ask for reflections on uncertainty*. Students could ask questions such as: What do we know? How reliable is our knowledge? What do we not know, and why does it matter? and acknowledge that uncertainty is not simply a technical problem to be minimised but an aspect of the situation to be understood and discussed. As Hauge and Barwell (2017) argued, such questions are essential in contexts where the stakes are high, and the values are in conflict. A fifth way is to *explicitly ask the students to include concrete measures*. This could encourage the students not to lose hope (Ojala, 2023) in severe issues, and empower them through mathematics (Valero, 2009).

The limitations of the study include the fact that there is no comparison with other modelling problems, the problems may be specific to a Norwegian context, the analysis focuses on specific theoretical perspectives, it does not include classroom examples, nor does it specifically focus on the role of teachers or students when facilitating reflective discussions in the classroom. Finally, while analysing self-designed modelling problems allows for a closer examination of the design intentions, it also introduces potential bias.

To facilitate students' reflective discussions contributing to raising awareness of socio-ecological issues, modelling problems could leave space for ambiguity, complexity and open-ended inquiry. Rather than pushing towards a correct answer, the modelling activities could explicitly facilitate the negotiation of standpoints through reflective discussions. However, the inclusion of socio-ecological issues in mathematics education is not straightforward, and schools and teachers struggle to implement this in their mathematics classroom (Li & Tsai, 2022; Vásquez et al., 2023; Vásquez et al., 2020). Challenges include lack of teacher training, limited knowledge, resistant attitudes, lack of best practice examples, and the complexity of connecting authentic sustainability contexts with mathematical content. Although to some extent this paper discusses how teachers can become aware of how to facilitate reflective discussions, for instance, that *modelling problems can explicitly include text asking students to engage in reflective discussions on specific issues*, or *modelling problems could be accompanied by text with suggestions*, this aspect needs more research. Integrating socio-ecological issues into mathematics education remains underdeveloped (Paredes et al., 2020; Tesfamicael & Enge, 2024), with few best-practice examples (Wiegand & Borromeo

Ferri, 2023). Thus, as a next step, it could be relevant to investigate how these two modelling problems are implemented in the classroom, where they facilitate reflective discussions contributing to raising students' awareness of socio-ecological issues.

References

Abtahi, Y., Gøtze, P., Steffensen, L., Hauge, K. H., & Barwell, R. (2017). Teaching climate change in mathematics classroom: An ethical responsibility. *Philosophy of Mathematics Education Journal*, *32*, 1–18.

Andersen, I. (2024, 11. December). Strømprisen når nye høyder i Sørvest-Norge – over 13 kroner kilowattimen [Energy prices reach new highs in Southwest Norway – over 13 kroner per kilowatt hour]. Teknisk ukeblad. https://www.tu.no/artikler/stromprisen-hopper-opp-til-over-13-kroner-timen-inkludert-moms-i-sorvest-norge-torsdag/553823

Atweh, B., & Brady, K. (2009). Socially response-able mathematics education: Implications of an ethical approach. *EURASIA Journal of Mathematics, Science & Technology Education*, *5*(3), 267–276. https://doi.org/10.12973/ejmste/75278

Barbosa, J. C. (2006). Mathematical modelling in classroom: A socio-critical and discursive perspective. *ZDM – Mathematics Education*, *38*(3), 293–301. https://doi.org/10.1007/BF02652812

Barbosa, J. C. (2009). Mathematical modelling, the socio-critical perspective and the reflexive discussions. In M. Blomhøj & S. P. Carreira (Eds.), *Proceedings from Topic Study Group 21 at the 11th International Congress on Mathematical Education in Monterrey, Mexico* (pp. 133–143). Roskilde Universitet

Barbosa, J. C. (2013). The students' discussions in the modeling environment. In R. Lesh, P. Galbraith, C. Haines, & A. Hurford (Eds.), *Modeling Students' Mathematical Modeling Competencies. International Perspectives on the Teaching and Learning of Mathematical Modelling* (pp. 365–372). Springer. https://doi.org/10.1007/978-94-007-6271-8_31

Barwell, R. (2018). Some thoughts on a mathematics education for environmental sustainability. In P. Ernest (Ed.), *The Philosophy of Mathematics Education Today* (pp. 145–160). Springer. https://doi.org/10.1007/978-3-319-77760-3_9

Berget, I. K. L. (2022). Mathematical modelling in textbook tasks and national examination in Norwegian upper secondary school. *Nordic Studies in Mathematics Education*, *27*(1), 51–70. https://doi.org/10.7146/nomad.v27i1.149184

Bettini, A. (2022). *Voices from a fractured landscape: Fracking, senses of place, and risks in Taranaki, Aotearoa New Zealand* [Doctoral thesis]. University of Alberta. https://doi.org/10.7939/r3-jjha-7y67

Borromeo Ferri, R. (2025). Mathematical, modelling as a key practice for promoting learners' competencies targeting the transformation of global, sustainability. In K. le Roux, A. Coles, A. Solares-Rojas, A. Bose, C. P. Vistro-Yu, P. Valero, N. Sinclair, M. Makramalla, R. Gutiérrez, V. Geiger, & M. Borba, (Eds.), *Mathematics education and the socio-ecological* (pp. 284–291). MATHTED and ICMI.

Bratman, E., Auch, T., & Stinchfield, B. (2022). The fracking frontier in the United States: A case study of foreign investment, civil liberties and land ethics in the shale industry. *Development and Change*, *53*(3), 469–494. https://doi.org/10.1111/dech.12707

Bulut, N., & Borromeo Ferri, R. (2025). Bridging mathematical modelling and education for sustainable development in pre-service primary teacher education. *Education Sciences*, *15*(2), 248. https://doi.org/10.3390/educsci15020248

Cevikbas, M., Kaiser, G., & Schukajlow, S. (2022). A systematic literature review of the current discussion on mathematical modelling competencies: State-of-the-art developments in conceptualizing, measuring, and fostering. *Educational Studies in Mathematics*, *109*, 205–236. https://doi.org/10.1007/s10649-021-10104-6

de Almeida Luna, A. V., Souza, E. G., & de Souza Lima, L. B. (2015). Mathematical texts in a mathematical modelling learning environment in primary school. In G. A. Stillman, W. Blum, & M. Salett Biembengut (Eds.), *Mathematical Modelling in Education Research and Practice: Cultural, Social and Cognitive Influences* (pp. 535–543). Springer. https://doi.org/10.1007/978-3-319-18272-8_45

Frankenstein, M. (1983). Critical mathematics education: An application of Paulo Freire's epistemology. *The Journal of Education*, *165*(4), 315–339. https://doi.org/10.1177/002205748316500403

Frejd, P. (2013). An analysis of mathematical modelling in Swedish textbooks in upper secondary school. *Nordic Studies in Mathematics Education*, *18*(3), 59–95. https://doi.org/10.7146/nomad.v18i3.148516

Frejd, P., Ärlebäck, J. B., & Vos, P. (2024). Fostering student's mathematical literacy through mathematical modelling tasks. In O. H. Bolstad, S. Goodchild, & M. Goos (Eds.), *International perspectives on teaching and learning for mathematical literacy* (pp. 178–203). Brill. https://doi.org/10.1163/9789004710962_008

Fukuda, H. (2020). *Research towards a Principle for the Statistics Curriculum in Japan from the Perspective of Context* [Doctoral thesis]. Hiroshima University.

Galbraith, P. (2006). Real world problems: Developing principles of design. *Identities, cultures and learning spaces*, *1*, 229–236.

Geiger, V., Galbraith, P., Niss, M., & Delzoppo, C. (2022). Developing a task design and implementation framework for fostering mathematical modelling competencies. *Educational Studies in Mathematics*, *109*, 313–336 https://doi.org/10.1007/s10649-021-10039-y

Gutstein, E. (2006). *Reading and writing the world with mathematics: Toward a pedagogy for social justice*. Routledge.

Gran, B., & Bjøru, E. C. (2024). *Konsekvenser av forbudet mot plastholdig fyllmateriale i kunstgressbaner.* Rapport nr. 27-2024 fra Samfunnsøkonomisk analyse. SØA. https://www.fotball.no/globalassets/klubb-og-leder/anlegg/rapport-konsekvenser-av-forbud-mot-gummigranulat.pdf

Hauge, K. H., & Barwell, R. (2017). Post-normal science and mathematics education in uncertain times: Educating future citizens for extended peer communities. *Futures*, *91*, 25–34. https://doi.org/10.1016/j.futures.2016.11.013

Hess, D. E. (2009). *Controversy in the classroom: The democratic power of discussion*. Routledge. https://doi.org/10.4324/9780203878880

Huntley, J., & Wallis, L. A. (2024). Case study: The destruction of Australian Aboriginal heritage and its implications for Indigenous peoples globally. In J. A. G. Zarandona, E. Cunliffe, & M. Saldin (Eds.), *The Routledge Handbook of Heritage Destruction* (pp. 384–394). Routledge. https://doi.org/10.4324/9781003131069-34

Hurlbert, M. A., & Datta, R. (2022). When the environment is destroyed, you're destroyed: Achieving Indigenous led pipeline justice. *Energy Research & Social Science*, *91*, Article 102711. https://doi.org/10.1016/j.erss.2022.102711

Idsø, J. (2021). Growth and economic performance of the Norwegian wind power industry and some aspects of the Nordic electricity market. *Energies*, *14*(9), Article 2701. https://doi.org/10.3390/en14092701

Johnsen-Høines, M. (2020). *Begynneropplæringen. Matematikkdidaktikk - barnetrinnet.* Caspar Forlag.

Julie, C., & Mudaly, V. (2007). Mathematical modelling of social issues in school mathematics in South Africa. In W. Blum, P. L. Galbraith, H. Henn, & M. Niss (Eds.), *Modelling and applications in mathematics education* (pp. 503–510). Springer. https://doi.org/10.1007/978-0-387-29822-1_58

le Roux, K., Coles, A., Solares-Rojas, A., Bose, A., Vistro-Yu, C. P., Valero, P., Sinclair, N., Makramalla, M., Gutiérrez, R., Geiger, V., & Borba, M. (2025). . MATHTED and ICMI.

Li, H. C., & Tsai, T. L. (2022). Education for sustainable development in mathematics education: what could it look like? *International Journal of Mathematical Education in Science and Technology*, *53*(9), 2532–2542. https://doi.org/10.1080/0020739X.2021.1941361

Miljødirektoratet. (10 november 2023). *Plastholdig fyllmateriale på kunstgressbaner.* https://www.miljodirektoratet.no/ansvarsomrader/avfall/avfallstyper/gummigranulat-fra-kunstgressbaner/
Ministry of Education and Research. (2017). *Verdier og prinsipper for grunnopplæringen - overordnet del av læreplanverket* [Values and principles for primary and lower secondary education]. https://www.udir.no/lk20/overordnet-del
Ministry of Education and Research. (2019). *Læreplan i matematikk 1.–10. trinn* [Curriculum for Mathematics year 1–10]. https://www.udir.no/lk20/MAT01-05
Moggridge, B. J., & Thompson, R. M. (2021). Cultural value of water and western water management: An Australian Indigenous perspective. *Australasian Journal of Water Resources*, *25*(1), 4–14. https://doi.org/10.1080/13241583.2021.1897926
Maaß, K. (2010). Classification scheme for modelling tasks. *Journal für Mathematik-Didaktik*, *31*(2), 285–311. https://doi.org/10.1007/s13138-010-0010-2
Maass, K., Zehetmeier, S., Weihberger, A., & Flößer, K. (2023). Analysing mathematical modelling tasks in light of citizenship education using the COVID-19 pandemic as a case study. *ZDM – Mathematics Education*, *55*(1), 133–145. https://doi.org/10.1007/s11858-022-01440-9
Niss, M., & Blum, W. (2020). *The learning and teaching of mathematical modelling*. Routledge.
Ojala, M. (2023). Hope and climate-change engagement from a psychological perspective. *Current Opinion in Psychology*, *49*, Article 101514. https://doi.org/10.1016/j.copsyc.2022.101514
OSPAR. (2024). *Background Document on reducing microplastic contamination from performance infill in artificial grass pitches.* OSPAR Commission
Paredes, S., Cáceres, M. J., Diego-Mantecón, J.-M., Blanco, T. F., & Chamoso, J. M. (2020). Creating realistic mathematics tasks involving authenticity, cognitive domains, and openness characteristics: A study with pre-service teachers. *Sustainability*, *12*(22), Article 9656. https://doi.org/10.3390/su12229656
Rosa, M., & Orey, D. C. (2015). Social-critical dimension of mathematical modelling. In G. A. Stillman, W. Blum, & M. S. Biembengut (Eds.), *Mathematical Modelling in Education Research and Practice* (pp. 385–395). Springer. https://doi.org/10.1007/978-3-319-18272-8_32
Simic-Muller, K., Fernandes, A., & Felton-Koestler, M. D. (2015). "I just wouldn't want to get as deep into it": Preservice teachers' beliefs about the role of controversial topics in mathematics education. *Journal of Urban Mathematics Education*, *8*(2), 53–86. https://doi.org/10.21423/jume-v8i2a259

Skovsmose , O. (1994). *Towards a philosophy of critical mathematics education*. Springer.
Skovsmose, O. (2023). *Critical mathematics education*. Springer. https://doi.org/10.1007/978-3-031-26242-5
Solares-Rojas , A., Arellano-Aguilar, O., García González, M. M., López-Vargas, M. d. R., Coles, A., & Méndez Serrano, A. (2022). Mathematics education and social-environmental crises: An interdisciplinary proposal for didactic innovation with rural communities in Mexico. *Research in Mathematics Education*, *24*(2), 202–223. https://doi.org/10.1080/14794802.2022.2062781
Steffensen, L. (2023a). *Modellering: matematikk for skole og samfunn*. [Modelling: mathematics for school and society]. Caspar forlag.
Steffensen, L. (2023b). Sustainability and mathematical modelling in 5th grade. *Prometeica 27*(10/2023), 241–251. https://doi.org/10.34024/prometeica.2023.27.15290
Steffensen, L., & Kacerja, S. (2021). Carbon footprints calculators and climate change. In F. K. S. Leung, G. A. Stillman, G. Kaiser, & K. L. Wong (Eds.), *Mathematical Modelling Education in East and West* (pp. 513–523). Springer. https://doi.org/10.1007/978-3-030-66996-6_43
Stillman, G. A., Brown, J. P., Faragher, R., Geiger, V., & Galbraith, P. (2013). The role of textbooks in developing a socio-critical perspective on mathematical modelling in secondary classrooms. In G. A. Stillman, G. Kaiser, W. Blum, & J. P. Brown (Eds.), *Teaching mathematical modelling: Connecting to research and practice* (pp. 361–371). Springer. https://doi.org/10.1007/978-94-007-6540-5_30
Supreme Court of Norway. (11 october, 2021). *Licences for wind power development on Fosen ruled invalid as the construction violates Sámi reindeer herders' right to enjoy their own culture*. https://www.domstol.no/en/supremecourt/rulings/2021/supreme-court-civil-cases/hr-2021-1975-s/
Syam, S., Wijaya, A., & Retnawati, H. (2019). Comparison of modelling tasks in Indonesian and Singaporean mathematics textbooks. *Journal of Physics: Conference Series*, 1320, Article 012057. https://doi.org/10.1088/1742-6596/1320/1/012057
Tesfamicael, S. A., & Enge, O. (2024). Revitalizing sustainability in mathematics education: The case of the new Norwegian curriculum. *Education Sciences*, *14*(2), Article 174. https://doi.org/10.3390/educsci14020174
UNEP. (2 march, 2022) Historic day in the campaign to beat plastic pollution: Nations commit to develop a legally binding agreement. https://www.unep.org/news-and-stories/press-release/historic-day-campaign-beat-plastic-pollution-nations-commit-develop

Valero, P. (2009). What has power got to do with mathematics education. In P. Ernest, B. Greer, & B. Sriraman (Eds.), *Critical issues in mathematics education* (pp. 237–254). Information Age Publishing.

Vásquez, C., Alsina, Á., Seckel, M. J., & García-Alonso, I. (2023). Integrating sustainability in mathematics education and statistics education: A systematic review. *Eurasia Journal of Mathematics, Science and Technology Education*, *19*(11), em2357. https://doi.org/10.29333/ejmste/13809

Vásquez, C., Seckel, M. J., & Alsina, Á. (2020). Belief system of future teachers on Education for Sustainable Development in math classes. *Uniciencia*, *34*(2), 1–15. http://dx.doi.org/10.15359/ru.34-2.1

Villarreal, M. E., Esteley, C. B., & Smith, S. (2015). Pre-service mathematics teachers' experiences in modelling projects from a socio-critical modelling perspective. In G. Stillman, W. Blum, & M. Salett Biembengut (Eds.), *Mathematical Modelling in Education Research and Practice* (pp. 567–578). Springer. https://doi.org/10.1007/978-3-319-18272-8_48

Walker, T. R., & Fequet, L. (2023). Current trends of unsustainable plastic production and micro(nano)plastic pollution. *TrAC Trends in Analytical Chemistry*, *160*, Article 116984. https://doi.org/10.1016/j.trac.2023.116984

Watson, A., & Ohtani, M. (2015). Themes and issues in mathematics education concerning task design: Editorial introduction. In A. Watson & M. Ohtani (Eds.), *Task design in mathematics education: An ICMI study 22* (pp. 3–15). Springer. https://doi.org/10.1007/978-3-319-09629-2_1

Wess, R., Klock, H., Siller, H.-S., & Greefrath, G. (2021). Mathematical modelling. In R. Wess, H. Klock, H.-S. Siller, & G. Greefrath (Eds.), *Measuring Professional Competence for the Teaching of Mathematical Modelling: A Test Instrument* (pp. 3–20). Springer. https://doi.org/10.1007/978-3-030-78071-5_1

Wiegand, S., & Borromeo Ferri, R. (2023). Promoting pre-service teachers' professionalism in steam education and education for sustainable development through mathematical modelling activities. *ZDM – Mathematics Education*, *55*(7), 1269–1282. https://doi.org/10.1007/s11858-023-01500-8

Wolfsberg, A. (2015). 'Literature' on mathematical modelling from a teacher perspective: A textbook's portrayal. In K. Krainer & N. Vondrová (Eds.), *Proceedings of the Ninth Congress of the European Society for Research in Mathematics Education* (CERME9, 4–8 February 2015) (pp. 951–957). Charles University in Prague, Faculty of Education and ERME.

World Commission on Environment and Development. (1987). *Report of the world commission on environment and development: Our common future*. United Nations.

Wright, P. (2021). Transforming mathematics classroom practice through participatory action research. *Journal of Mathematics Teacher Education*, *24*(2), 155–177. https://doi.org/10.1007/s10857-019-09452-1

Zapata-Cardona, L., & Martínez-Castro, C. A. (2021). Statistical modeling in teacher education. *Mathematical Thinking and Learning*, *25*(1), 64–78. https://doi.org/10.1080/10986065.2021.1922859

Zwaneveld, B., Perrenet, J., van Overveld, K., & Borghuis, T. (2017). Mathematical modelling in Dutch textbooks: Is it genuine mathematical modelling? In G. A. Stillman, W. Blum, & G. Kaiser (Eds.), *Mathematical Modelling and Applications: Crossing and Researching Boundaries in Mathematics Education* (pp. 503–514). Springer. https://doi.org/10.1007/978-3-319-62968-1_42

Notes

1 Europe has over 51,000 artificial turf pitches and Norway has (March 2020) 2038 artificial turf pitches (OSPAR, 2024).

2 Studies reports various estimates, for instance, Løkkegaard, et al. (2019) report an average varying from 580–4000 kg per annum, from a full-size field. The estimate of a 4–7 tonne replacement per facility is based on the report from Norwegian facilities, and where descriptions on methods and uncertainties are elaborated (Rambøll, 2018).

3 Studies report various estimates, for instance, Løkkegaard, et al. (2019) report an average varying from 580–4000 kg per annum, from a full-size field. The estimate of a 4–7 tonne replacement per facility is based on the report from Norwegian facilities, and where descriptions on methods and uncertainties is elaborated (Rambøll, 2018).

4 The income from publicly owned hydropower plants serves the public interest https://www.nve.no/energi/analyser-og-statistikk/eierskap-i-norsk-vann-og-vindkraft/

5 Prices are included VAT and excluded grid costs and financial support from the Norwegian government https://www.nettavisen.no/okonomi/nye-sjokkpriser-pa-strom-13-kroner-i-sor-norge/s/5-95-2181953

Lisa Steffensen

Lisa Steffensen is an Associate Professor at the Western Norway University of Applied Sciences, where she has worked since 2014. Prior to that, she taught mathematics and natural science at the lower-secondary level. Her research focuses on how mathematics education can support students in engaging as critical citizens with societal challenges like socio-ecological issues. She is particularly interested in mathematical modelling as a tool for describing, predicting, and communicating about complex, value-laden problems. Steffensen is a central board member of LAMIS (Landslaget for matematikk i skolen) and serves on the International Committee of MES (Mathematics Education and Society).

Lisa.Steffensen@hvl.no