Sustainability in mathematical modelling competitions: An analysis of competition tasks

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This study examines how sustainability is represented and made mathematically actionable in secondary-level modelling competition task statements. Using qualitative document analysis, we analysed 48 publicly available tasks (2020-2025) from two contexts: HiMCM (n=12) and SJMMA (n=36). Tasks were coded in three stages for sustainability salience, structural positioning, and dominant mathematical framing. Sustainability was salient in most HiMCM tasks, but in a minority of SJMMA tasks. When salient, sustainability was predominantly positioned as a driver in both competitions, while SJMMA showed a broader spread of non-driver roles. Framing patterns indicate different emphases: prediction-oriented framings occur more frequently in HiMCM, whereas decision/evaluation framings are more prevalent in SJMMA.

Keywords: mathematical modelling; education for sustainable development (ESD); modelling competitions; task analysis

Introduction

Education is often seen as both a prerequisite for and a powerful tool in the pursuit of a sustainable future (Holfelder, 2019; UNESCO, 2017). In mathematics education, growing attention has been paid to engaging students with sustainability in response to global socio-ecological crises (Just et al., 2026). As noted in the *ICMI Study 27 Discussion Document*, mathematics education is implicated in the multiple and intersecting social, political, and ecological issues of climate change, poverty, inequality, health crises, discrimination, and marginalisation. Among these, mathematical modelling is frequently regarded as an important pathway for linking mathematical activity to complex real-world problems and for supporting students' reasoning about socio-ecological systems (Stillman et al., 2013).

Mathematical modelling is not a straightforward translation of real-world situations into mathematics. Instead, it involves moving back and forth between context and mathematical representation, selecting relevant information, making assumptions, interpreting results, and revising ideas (Blum & Leiss, 2007). Because real-world problems are often uncertain and involve constraints and trade-offs, the way a modelling task is designed matters. Competition task statements, therefore, do more than describe a problem: they shape which issues are foregrounded and what kinds of mathematical work students are invited to do.

However, existing work on education for sustainable development (ESD) in mathematics education has predominantly focused on classroom enactment and pedagogical approaches (Just et al., 2026), with comparatively less attention to how sustainability is embedded in the design of modelling tasks, especially in the context of mathematical modelling competitions. This study examines how sustainability is represented and made mathematically actionable in modelling competition tasks. We analyse task statements from two secondary-level mathematical modelling competition contexts situated in different institutional settings: the High School Mathematical Contest in Modelling (HiMCM) and the Shanghai Joint Secondary School Mathematical Modelling Activity (SJMMA).

Guided by qualitative document analysis (Bowen, 2009), we address two research questions: RQ1: How is sustainability positioned within modelling competition tasks? RQ2: Through what mathematical framings is sustainability operationalised in these tasks? By providing an initial cross-case analysis across HiMCM and SJMMA, the study offers an analytic lens for examining sustainability-oriented modelling tasks and identifies task design patterns that may inform future task design.

Data and method

The dataset comprised 48 publicly available secondary-level mathematical modelling competition task statements published between 2020 and 2025: 12 from the High School Mathematical Contest in Modelling (HiMCM), organised by the Consortium for Mathematics and its Applications in the United States, and 36 from the Shanghai Joint Secondary School Mathematical Modelling Activity (SJMMA), a regional inter-school modelling activity in Shanghai. These two competition contexts were selected purposively because they were pedagogically relevant to the author's institutional context and formed part of the modelling opportunities available to students in the school. HiMCM and SJMMA also offered a useful contrast between an international competition context and a regional one, enabling comparison across different task-setting traditions. Besides, task statements from both competitions were consistently accessible over the six-year period, enabling the construction of a manageable yet coherent corpus for analysis.

The task statements were treated as designed texts that translate real-world concerns into assessable modelling work. The analysis proceeded in three stages. First, all tasks were screened for the salience of sustainability and coded as explicit, implicit, or non-salient. A task was coded as *explicit* when sustainability-related concerns were directly named in the prompt, such as through reference to environmental impact, emissions, resources, ecological protection, or related long-term societal goals. A task was coded as *implicit* when sustainability was not directly named, but the problem context clearly involved sustainability-related trade-offs or longer-term environmental, social, or economic consequences. Tasks were coded as *non-salient* when they used real-world settings, but sustainability did not substantively shape the central problem focus.

Second, sustainability-salient tasks were coded for the structural positioning of sustainability within the task. Sustainability was coded as a *driver* when it formed the central modelling objective; as a *criterion* when it appeared as one evaluative dimension among several; as a *constraint* when it operated as a condition, limit, or requirement; and as *background* when it functioned primarily as contextual framing without substantially shaping the core modelling demand. Where tasks displayed overlapping features, coding focused on the dominant positioning.

Third, sustainability-salient tasks were coded for their dominant mathematical framing, that is, how sustainability was made mathematically actionable. *Decision/evaluation* (DEC) refers to tasks that ask participants to compare options, assess trade-offs, or justify recommendations. *Optimisation* (OPT) refers to tasks foregrounding the search for the best solution under stated conditions or criteria. *Prediction/forecasting* (PRED) refers to tasks asking teams to estimate future outcomes, trends, or scenarios. *Dynamic/simulation* modelling (DYN-SIM) refers to tasks that emphasise change over time, interactions among variables, or the simulation of system behaviour.

These categories captured the dominant mathematical activity invited by the task statement, rather than the specific techniques used in teams' eventual solutions. In practice, these framings may be associated with different families of modelling approaches: decision/evaluation tasks often invite multi-criteria comparison or ranking methods; optimisation tasks are commonly linked to constrained maximisation or minimisation models; prediction/forecasting tasks frequently draw on regression or time-series approaches; and dynamic/simulation tasks often involve recurrence, differential, or scenario-based simulation models. These associations are indicative rather than deterministic, since the coding addressed the modelling demand foregrounded by the task statement rather than the solution techniques ultimately adopted by teams.

Stage	Analytical focus	Codes
1	Sustainability salience	explicit; implicit; non-salient
2	Structural positioning	driver; criterion; constraint; background
3	Mathematical framing	DEC; OPT; PRED; DYN-SIM

Table 1. Overview of the analytical procedure

Findings

Sustainability salience across years and competitions

Year	HiMCM (E/I/N; n=2)	SJMMA (E/I/N; n=6)
2020	1/0/1	3/0/3
2021	1/1/0	1/1/4
2022	2/0/0	2/0/4
2023	2/0/0	2/0/4
2024	2/0/0	1/0/5
2025	1/0/1	1/3/2
Total	9/1/2 (n=12)	10/4/22 (n=36)

Table 2. Sustainability salience by year in HiMCM and SJMMA (2020-2025)

Table 2 summarises sustainability salience in task requirements across 2020-2025, distinguishing explicit (E), implicit (I), and non-salient (N) references. Overall, sustainability is salient in most HiMCM tasks (E+I = 10/12), whereas it is salient in a minority of SJMMA tasks (E+I = 14/36). HiMCM shows a relatively consistent pattern over time: from 2022 to 2024, both annual tasks are sustainability-salient (2/0/0), and only two tasks across the six-year corpus are non-salient. By contrast, SJMMA displays a more episodic pattern, with several years dominated by non-salient tasks. Taken together, these results indicate that sustainability is a more consistent organising concern in HiMCM task requirements than in SJMMA.

Structural positioning of sustainability within task structure

Role	HiMCM (n=10)	SJMMA (n=14)
Driver	7 (70%)	9 (64%)
Criterion	2 (20%)	4 (29%)
Constraint	0 (0%)	1 (7%)
Background	1 (10%)	0 (0%)

Table 3. Positioning of sustainability within task structure

In both competitions, sustainability is most often positioned as a driver of the modelling objective (HiMCM: 7/10; SJMMA: 9/14; Table 3). However, SJMMA includes a larger share of tasks where sustainability plays a non-driver role, appearing as a criterion or constraint (5/14), compared with HiMCM (2/10). Overall, this suggests that when sustainability is present, it is usually treated as the main modelling focus, but in some tasks it is integrated as part of a broader evaluation or as a constraint on feasible solutions.

Mathematical framing of sustainability

Mathematical framings	HiMCM (n=10)	SJMMA (n=14)
DEC	4 (40%)	8 (57%)
OPT	1 (10%)	2 (14%)
PRED	3 (30%)	1 (7%)
DYN-SIM	2 (20%)	3 (21%)

Table 4. Dominant mathematical framing of sustainability in sustainability-salient tasks

Table 4 reports the dominant mathematical framing assigned to each sustainability-salient task. Across both competitions, decision/evaluation framings (DEC) are the most common (HiMCM: 4/10; SJMMA: 8/14). The distributions also indicate differences in emphasis: prediction-oriented framings occur more frequently in HiMCM (PRED: 3/10) than in SJMMA (1/14), while SJMMA shows a slightly higher share of optimisation framings (OPT: 2/14 vs 1/10). Simulation/dynamic framings (DYN-SIM) appear at broadly similar levels across the two corpora. Given the relatively small number of tasks, these results are interpreted as descriptive patterns that motivate the illustrative cross-case comparison in the following section.

Illustrative cases

Three exemplars briefly illustrate how task statements translate sustainability-related concerns into assessable mathematical work. HiMCM 2022B (CO_2 and Global Warming): sustainability as a driver framed through prediction. In this task, sustainability is foregrounded as the central modelling objective, with students asked to "fit various... mathematical models... and predict future concentration levels of CO_2" and to "predict the CO_2 concentrations... in the year 2100". The requirements further extend the modelling work to future temperature trajectories: teams are asked to "build a model to predict future land-ocean temperature changes" and to determine when warming thresholds may be reached. These directives operationalise sustainability primarily through forecasting future states (PRED), making the mathematics of trend modelling, extrapolation, and model reliability the core work.

SJMMA 2025E (River/Highway excavation and scheduling): sustainability embedded within optimisation. Here, sustainability is not labelled "sustainable development" but is incorporated into the task requirements through performance metrics that include energy use. The optimisation component sets the objective as shorter completion time and lower energy consumption, and the task asks teams to develop high-efficiency, low-energy solutions and to quantify how proposed plans can reduce energy consumption and costs. In this sense, sustainability-related concerns are operationalised through optimisation (OPT): energy consumption becomes a measurable target within a scheduling problem, positioned alongside conventional efficiency goals.

SJMMA 2022D (Effectiveness of charitable resources): social welfare as a sustainability-relevant concern. This task asks teams to define "effectiveness" in charitable resource allocation, develop an evaluative model of charitable effectiveness, and make model-informed decisions about allocating funds across projects and stages to maximise impact. It exemplifies how sustainability in the corpus can extend beyond environmental/resource issues to include social welfare and effectiveness-oriented decision-making (DEC).

Discussion

This study examines sustainability in mathematics education from a task-level perspective by analysing the design of modelling competition task statements. Across the 2020-2025 corpus, sustainability is more consistently salient in HiMCM than in SJMMA. When sustainability is salient, it is most often positioned as a driver of the modelling objective in both competitions, indicating that sustainability is frequently treated as a central modelling concern rather than a peripheral theme. At the same time, the competitions differ in the dominant forms of mathematical work invited: HiMCM includes a higher share of prediction-oriented framings, whereas SJMMA more frequently operationalises sustainability through decision/evaluation and optimisation framings. One plausible explanation for these cross-competition differences concerns task-generation and revision procedures. SJMMA tasks are selected and revised from a large pool of student-proposed ideas, which may produce a more heterogeneous thematic landscape, and sustainability-related considerations may enter the final task as embedded, measurable requirements rather than as an explicitly named organising theme. By contrast, where a competition relies on a smaller set of centrally authored tasks, sustainability may be more consistently foregrounded as the primary modelling objective. While the present dataset does not allow definitive causal attribution, task-generation and revision processes are plausible factors shaping how sustainability becomes mathematised in modelling competition tasks.

From an ESD perspective, these results highlight that modelling competitions do not merely include sustainability themes; they structure the forms of mathematical work through which students are invited to reason about sustainable futures. Making the intended sustainability dimensions and the value trade-offs they entail more explicit in task requirements may support richer socio-ecological reasoning beyond primarily efficiency-oriented framings.

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