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SOFTWARE TOOL ARTICLE

A web-based interactive simulation environment for the FeliX Integrated Assessment Model

[version 1; peer review: 1 approved, 1 approved with reservations]

Nikolaos Dimitrios Tantaroudas[1], R.Y.W. Tan[2], Ilias Karachalios[3], Philippos Marntiriosian[3], Tina Katika[1], Angelos Amditis[1], Sibel Eker[2], Christos Makropoulos[3]

[1]Iroon Polytechneiou, Institute of Communications and Computer Systems (ICCS), Athens, Attica, 15773, Greece
[2]International Institute for Applied Systems Analysis, Laxenburg, Lower Austria, 2361, Austria
[3]National Technical University of Athens, Zografou, Attica, 15772, Greece

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Abstract

Background

Integrated Assessment Models (IAMs) are essential tools for exploring the interconnections between climate, food, land use, biodiversity, and socioeconomic systems. However, their inherent complexity and dependence on proprietary modelling software have historically restricted their use to specialised research institutions. There is a critical need for accessible tools that mainstream complex IAM results through intuitive interfaces enabling policymakers, educators, and the general public to explore IAM-based scenarios without technical expertise or local software installations.

Methods

This study presents the design, implementation, and validation of a browser-based Interactive Simulation Environment (ISE) for the FeliX (Full of Economic-Environment Linkages and Integration dX/dt) Integrated Assessment Model. The Vensim system dynamics model is compiled to WebAssembly via an SDEverywhere transpilation toolchain, enabling real-time client-side execution. The architecture employs Web Workers for non-blocking computation, a configuration-driven interface using interoperable open-data formats to fully decouple the model from the UI layer, and interactive visualisations built with Chart.js. A three-level validation framework verified numerical fidelity across the transpilation pipeline, and transferability

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1. **Page Kyle**, Pacific Northwest National Laboratory, Richland, USA

2. **Umamahesh V Nanduri**, National Institute of Technology, Warangal, India

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was assessed through a proof-of-concept SIR epidemiological model deployment.

Results

The transpiled WebAssembly model reproduces original Vensim outputs to floating-point precision across all nine thematic output domains (food systems, nutrition, land use, greenhouse gas emissions, fertiliser use, biodiversity, and water resources). The configuration-driven architecture enables deployment with alternative Vensim models without code modifications. The platform supports multi-scenario comparison, scenario import/export, progressive disclosure interfaces, and contextual documentation, all running client-side in standard web browsers.

Conclusions

The FeliX ISE demonstrates the feasibility of compiling complex system dynamics IAMs to WebAssembly for fully browser-based interactive scenario exploration. The modular, configuration-driven architecture ensures transferability to other Vensim-based models. The interface design lowers the expertise threshold for meaningful engagement with integrated assessment science, broadening participation in climate and food system policy analysis.

Plain Language summary

Climate change, food production, biodiversity loss, and water scarcity are deeply interconnected challenges. Scientists use complex computer models called Integrated Assessment Models (IAMs) to understand how these systems interact and to test the effects of different policies. However, these models typically require specialised software and expert knowledge to operate, making them inaccessible to the people who most need their insights, and in particular, policymakers, educators, and citizens.

This paper describes a free, open-source web tool that runs one of these complex models (called FeliX) directly in any standard web browser, with no installation or special software required. The FeliX model simulates how changes in what people eat, how much food is wasted, and what technologies are adopted ripple through climate, land use, biodiversity, and water systems over time. The tool compiles the entire scientific model into a format (WebAssembly) that runs efficiently inside the browser itself, meaning all computation happens on the user's own device, and no data is sent to any server.

Users interact with the model through intuitive sliders, switches, and buttons to build "what-if" scenarios, such as for example, asking "What happens to greenhouse gas emissions if the world shifts toward a healthier diet?" or "How does reducing food waste affect biodiversity?" The results are displayed instantly as interactive charts. Users can also

compare two different scenarios side by side to see the trade-offs between different policy choices or global behavioural change scenarios. Rigorous validation testing confirms that the web tool produces results identical to the original scientific model, ensuring that the accessibility of the interface does not compromise the accuracy of the underlying system dynamics. By making this powerful scientific tool freely available and easy to use, this study aims to support more informed decision-making about the food and climate challenges that affect everyone.

Keywords
integrated assessment models, interactive simulation environment, system dynamics, WebAssembly, climate-food-biodiversity nexus, behaviour change, open-source, scenario exploration, FeliX model, web application

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Corresponding author: Nikolaos Dimitrios Tantaroudas (nikolaos.tantaroudas@iccs.gr)

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Introduction

Background and motivation

The interconnected challenges of climate change, food system transformation, biodiversity loss, and resource depletion demand analytical tools that can capture the complex feedback loops governing Earth system dynamics.[1,2] Integrated Assessment Models (IAMs) have emerged as central instruments for exploring these interdependencies, linking multiple sectors, such as for example, climate, energy, food, land use, economy, and society, within unified analytical frameworks that enable researchers and policymakers to evaluate the long-term consequences of human actions on the Earth system.[3,4] The Intergovernmental Panel on Climate Change (IPCC) has relied extensively on IAMs for its assessment reports, underscoring their role in shaping global climate policy.[5]

Despite their analytical power, IAMs suffer from a persistent accessibility gap. The majority of operational IAMs require proprietary modelling software, specialised technical expertise, and substantial computational resources, effectively restricting their use to well-resourced research institutions and limiting the diversity of perspectives that inform model-derived insights.[6,7] This exclusivity is particularly problematic given that climate change and food system transformation are challenges affecting all sectors of society, requiring tools that are comprehensible and actionable by diverse stakeholders.[8] The IPCC's Sixth Assessment Report identified a critical knowledge gap concerning the potential of demand-side mitigation, specifically how widespread behaviour and lifestyle changes occur through the dynamic interaction of individual, social, economic, and environmental factors.[5] Addressing this gap requires not only models capable of representing these interactions but also interfaces that make such models accessible to non-expert users.

Interactive Simulation Environments (ISEs) offer a promising pathway to bridge this accessibility gap by providing user-friendly, web-based interfaces that translate complex model parameters into intuitive controls and present outputs through clear, interactive visualisations.[9,10] Significant and notable efforts towards this direction include the En-ROADS climate solutions simulator, developed by Climate Interactive, MIT Sloan, and Ventana Systems, which compiles a system dynamics model to WebAssembly for real-time browser-based policy exploration.[11] The En-ROADS simulator has demonstrated the transformative potential of making climate models accessible to broad audiences, having been used by national government leaders, business executives, and educators worldwide.[11] Similarly, the C-ROADS simulator enables users to test and visualise the long-term impacts of climate strategies across regional groups.[11]

However, existing web-based IAM tools primarily focus on energy and emissions systems and do not adequately capture the food-land-biodiversity nexus or the behavioural dynamics that drive sustainability transitions. The FeliX (Full of Economic-Environment Linkages and Integration dX/dt) model, developed at the International Institute for Applied Systems Analysis (IIASA), is a system dynamics-based IAM that uniquely incorporates human behaviour as an endogenous driver of global environmental change.[12,13,14] FeliX captures the complex interconnections between climate, food, land use, biodiversity, water, fertiliser, and population systems, with a distinguishing focus on how individual beliefs, social norms, and collective action shape sustainability outcomes.[13] The integration of behavioural parameters, self-efficacy, social norms, perceived risks, and response efficacy, separates FeliX apart from conventional IAMs that treat human behaviour as an exogenous input rather than a dynamic, modelled component.[13,14]

Previous work by the authors explored the intersection of technology and food system awareness through mixed reality eye-tracking investigations of food consumption habits,[15,16] establishing a foundation for understanding how interactive technologies can influence dietary choices and sustainability awareness. Building upon this earlier research and extending our preliminary work,[17] the present paper provides a comprehensive description of the FeliX ISE, an open-source, browser-based Interactive Simulation Environment that makes the full FeliX model accessible to non-expert users through standard web browsers.

Contributions

The contributions of this paper can be summarised as follows:

- (a) The design and implementation of a fully client-side web application that compiles a complex system dynamics IAM (over 1,300 model elements including 91 stocks) from Vensim to WebAssembly using the SDEverywhere toolchain, enabling real-time in-browser model execution without server-side computation.
- (b) A configuration-driven architecture that decouples the model from the user interface through open data formats configuration files, making the approach directly transferable to any Vensim-based system dynamics model.
- (c) A user-centred interface design that mainstreams complex IAM modelling results through simplified input controls, contextual tooltips, informative hover descriptions, and a structured two-panel layout that makes visually explicit which inputs affect which outputs and how the modelled systems are interconnected, significantly lowering the expertise barrier compared to existing IAM tools.
- (d) An interactive scenario exploration interface featuring multi-scenario comparison, progressive disclosure mechanisms, and comprehensive contextual documentation that supports users ranging from expert modellers to non-specialist policymakers and citizens.
- (e) A three-level validation framework encompassing model conversion numerical comparison, and full input-space automated QA testing, demonstrating high precision fidelity across the transpilation pipeline.
- (f) A preliminary demonstration of the tool's transferability by loading an SIR epidemiological model through the same interface without code modifications.
- (g) The release of the complete source code and deployed application as open-source resources, supporting reproducibility and community-driven extension.

Paper structure

The remainder of this paper is organised as follows. Section 2 reviews related work on IAM accessibility, web-based simulation tools, and system dynamics model deployment. Section 3 describes the methodology, encompassing the FeliX model, the software architecture, the design approach, and the user interface. Section 4 presents the results, including scenario demonstrations and a transferability evaluation. Section 5 discusses the implications, limitations, and future directions. Section 6 concludes the paper.

Related work

Integrated assessment models and their accessibility

Integrated Assessment Models have been developed to understand the complex interactions between human and natural systems across multiple temporal and spatial scales.[3,4] Prominent IAMs include IMAGE, MESSAGE, REMIND, and GCAM, which have been instrumental in generating the scenarios underpinning IPCC assessment reports.[5,18] These models typically operate within specialised modelling environments, such as GAMS, Vensim, or custom Fortran/C++ implementations, and require significant computational resources and expert knowledge to configure, run, and interpret.[6]

The system dynamics modelling example presented in the work of Forrester[19] and subsequently applied to global challenges by Meadows et al.,[20] offers a distinct approach to integrated assessment. Unlike computable general equilibrium (CGE) models that assume systems tend toward equilibrium states, system dynamics models explicitly represent feedback loops, delays, and non-linear interactions that generate emergent system behaviour.[21,22] This example is particularly suited to capturing the path dependencies, tipping points, and behavioural dynamics that characterise sustainability transitions.[13] Notable system dynamics-based IAMs include the World3 model,[20] the iSDG model developed by the Millennium Institute,[23] and the Earth4All model,[24] all of which share a commitment to representing systemic feedback mechanisms.

Several initiatives have sought to improve IAM accessibility. The IIASA Scenario Explorer provides a web-based database for querying and visualising IAM scenario outputs, though it does not support interactive model execution.[25] The Global Calculator, developed by the UK Department of Energy and Climate Change, offered a simplified web-based tool for exploring energy and land use pathways but has since been decommissioned.[26] The iSDG model has been

deployed through interactive web interfaces in specific country contexts.[23] More recently, the Earth4All initiative has released scenario tools that communicate model results to broader audiences.[24] However, none of these efforts combine full in-browser model execution with the thematic breadth of a comprehensive IAM covering climate, food, biodiversity, and behavioural dynamics.

Web-based system dynamics model deployment

The deployment of system dynamics models as web applications has been enabled by advances in web technologies, particularly WebAssembly (Wasm), a binary instruction format designed as a portable compilation target that enables high-performance execution in web browsers.[27] WebAssembly provides near-native execution speed while running within the browser's security sandbox, making it an ideal target for computationally intensive scientific models.[27]

The SDEverywhere toolchain, developed by Climate Interactive, is an open-source collection of libraries and command-line tools that transpile Vensim system dynamics models into C code, which can then be compiled to JavaScript or WebAssembly.[28] SDEverywhere has been in production use since 2019, powering the En-ROADS and C-ROADS climate policy simulators that collectively have been used in engagements with over 100 national government leaders worldwide.[11,12,28] The toolchain provides a plugin-based architecture supporting configuration management, WebAssembly compilation, Web Worker integration for non-blocking computation, and Vite-based build processes for modern web development workflows.[28]

Web Workers, a standard browser API, enable multi-threaded computation in web applications by running scripts in background threads separate from the main user interface thread.[29] This capability is essential for interactive scientific simulations, where computational operations must not block user interface responsiveness. The combination of WebAssembly for high-performance model execution and Web Workers for non-blocking computation provides the technical foundation for responsive, browser-based simulation environments.

Complementary tools in the system dynamics ecosystem include PySD, which translates Vensim and XMILE models to Python,[30] and Simlin, a browser-based model editor that imports Vensim and XMILE formats.[31] However, these tools primarily target model developers rather than end users seeking to explore scenarios through intuitive interfaces.

The FeliX integrated assessment model

The FeliX model has undergone continuous refinement through multiple research programmes.[12,13,14,33] The model consists of nine integrated modules, population, education, economy, energy, water, land, food, carbon cycle/climate, and biodiversity, connected through extensive feedback mechanisms that capture the complex dynamic behaviour characterising the Anthropocene.[14]

A distinguishing feature of FeliX is its endogenous representation of human behaviour in the food and dietary domain. Eker et al.[13] extended the model with a behavioural diet shift module based on key theories from environmental psychology, capturing the role of psychological and social factors, including climate risk perception, self-efficacy, and social norms, alongside traditional socioeconomic drivers such as income and education level. This work demonstrated that social norm effects and self-efficacy are the principal drivers of global diet change, with implications that extend beyond food systems to affect land use, greenhouse gas emissions, and biodiversity.[13] The FeliX 2.0 version, described by Ye et al.,[14] refined the model's population dynamics, food and land use systems, and socioeconomic settings, with robust calibration against historical data since 1950 and projections fully aligned with IPCC assessment scenarios.

FeliX has also been applied to a wide range of sustainability challenges, including emission pathways analysis,[32] poverty alleviation strategies,[34] sustainable development goal interactions,[35] and the assessment of demand-side mitigation potential.[13] The model's baseline scenario maps to benchmark Representative Concentration Pathway (RCP) and Shared Socioeconomic Pathway (SSP) outcomes, enabling robust conclusions regarding the relative impact of various policies and technologies.[14] As of 2025, a regional version (FeliX-R5) has been developed based on five United Nations regional classifications, facilitating fine-scale analysis of socioeconomic-environmental dynamics that account for geographic, socioeconomic, and cultural differences.[14]

Behaviour change and food system modelling

The role of human behaviour in driving sustainability transitions has received increasing attention in the integrated assessment community.[13,36,37] Traditional IAMs often treat dietary shifts and lifestyle changes as exogenous assumptions, essentially external scenarios imposed on the model rather than emergent outcomes of modelled behavioural

dynamics.[6,13] This limitation has been recognised as a critical gap, particularly for assessing demand-side mitigation potential in food systems.[5]

Research on the drivers of dietary change has identified multiple interacting factors, including health awareness, environmental concern, cultural norms, economic constraints, and food availability.[13,38,39] The protection motivation theory and social identity theory provide theoretical foundations for understanding how perceived risks, self-efficacy beliefs, and social norms interact to drive behaviour change.[13,40] FeliX utilises these theoretical constructs within a system dynamics framework, allowing the exploration of how policy interventions targeting different behavioural levers propagate through interconnected food, land, climate, and biodiversity systems.[13,14]

Food loss and waste reduction represents another critical demand-side intervention, with the United Nations estimating that approximately one-third of food produced for human consumption is lost or wasted globally.[41] The FeliX ISE enables users to explore distinct producer-side (loss) and consumer-side (waste) reduction strategies and observe their differential impacts on food system sustainability, land use, and environmental outcomes.

Methods

The model is implemented in Vensim DSS and consists of over 1,300 elements including 91 stocks, with its outcomes determined by interacting reinforcing and balancing feedback loops.[14] The behavioural diet shift module[13] incorporates self-efficacy, social norms, perceived risks, and response efficacy as endogenous drivers of dietary change. The model's temporal scope spans from 1950 to 2100, with historical calibration ensuring coherence with observed data and future projections aligned with established IPCC scenario frameworks.[14] The baseline scenario maps to the SSP2 ("Middle of the Road") pathway and RCP benchmark outcomes.[14]

Software architecture

Technology stack

The FeliX ISE is a static web application built using HTML5, CSS3, JavaScript, and TypeScript. The underlying FeliX model has been transpiled from its native Vensim format to C code and subsequently compiled to WebAssembly (Wasm) using the SDEverywhere (SDE) toolchain.[28] This compilation pipeline enables the full system dynamics model to execute directly in the user's browser without requiring any server-side computation, ensuring privacy, offline capability, and reduced latency.

TypeScript was adopted extensively for code development, providing static type checking for early error detection, improved code readability, and enhanced maintainability. Data visualisation is implemented through Chart.js,[42] a free and open-source JavaScript library supporting line graphs and stacked area charts essential for displaying temporal dynamics of complex system indicators. Figure 1 illustrates the overall software architecture, showing the compilation pipeline from Vensim through SDEverywhere to WebAssembly.

SDEverywhere build pipeline

The SDEverywhere toolchain provides the core build pipeline for translating the Vensim model into a web-executable format.[28] Table 1 lists the key packages used in the FeliX ISE and their roles. The @sdeverywhere/plugin-config package was significantly extended with additional columns beyond default capabilities to support the rich configuration schema required by the FeliX ISE. These extensions include category groupings, secondary input types, hover descriptions,

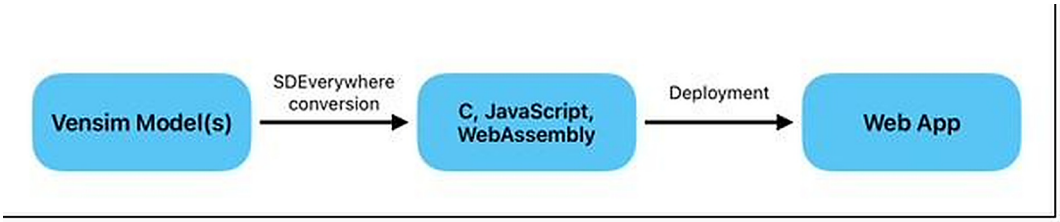


Figure 1. High-level software architecture of the FeliX ISE, showing the compilation pipeline from the vensim model (.mdl) through the SDEverywhere toolchain to webAssembly, and the runtime architecture with Web Workers for non-blocking computation.

Table 1. SDEverywhere packages used in the FeliX ISE build pipeline.

Package	Version	Role
@sdeverywhere/build	0.3.4	Core build and plugin API enabling extensible model processing pipelines
@sdeverywhere/check-core	0.1.2	Model checking and comparison functionality ensuring model validity
@sdeverywhere/cli	0.7.23	Command-line interface facilitating automated build and CI workflows
@sdeverywhere/plugin-check	0.3.5	Model check and comparison test runner for quality assurance
@sdeverywhere/plugin-config	0.2.4	CSV-based configuration reader enabling the configuration-driven architecture
@sdeverywhere/plugin-vite	0.1.8	Vite integration for asset bundling and hot module replacement
@sdeverywhere/plugin-wasm	0.2.3	WebAssembly module builder for high-performance browser execution
@sdeverywhere/plugin-worker	0.2.3	Web Worker generator for asynchronous model computation
@sdeverywhere/plugin-worker	0.2.3	Web Worker generator for asynchronous model computation

segmented button rendering, Material UI icons, markdown description references, range definitions, and enabled/disabled value specifications.

Real-Time computation via Web Workers

The FeliX ISE ensures real-time responsiveness by running the core system dynamics model within a dedicated worker thread using the @sdeverywhere/plugin-worker package. This plugin generates a worker.js file that executes the model asynchronously in a Web Worker,[29] preventing heavy computational tasks from blocking the main UI thread. When a user modifies an input parameter, an event is dispatched to the worker where the model recalculates all outputs. Once computation is complete, the updated results are transmitted back to the main thread and reflected in the output visualisations. This architecture guarantees that the interactive experience remains smooth and immediate regardless of model complexity. Figure 2 illustrates the separation between the main UI thread and the worker thread, with event-based communication for input dispatch and result retrieval.

Configuration-Driven Interface Design

A key architectural innovation of the FeliX ISE is its configuration-driven approach to interface design. Rather than hard-coding interface elements, the system utilises two configuration files based on open data formats, one for model inputs

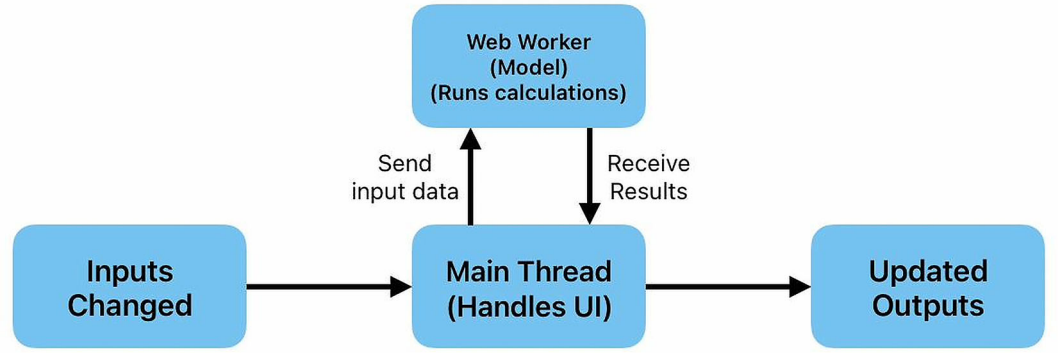


Figure 2. Web workers architecture diagram showing the separation between the main UI thread and the worker thread, with event-based communication for input dispatch and result retrieval.

and another one for model outputs (i.e. graphs.csv), that specify input parameters, output variables, visualisation formats, and interface organisation. The application code is entirely decoupled from these configuration files. Each modification to these files triggers a new build process that regenerates the interface components without altering the application codebase. This design enables efficient collaboration between IAM modellers and software developers, as modellers can modify interface configurations without programming expertise. The input configuration file employs a rich schema supporting diverse input types and configurations. Table 2 summarises the key input characteristics.

The graph configuration file defines output visualisations with comparable granularity, including graph classification, scenario assignment, chart type (line, stacked-area), axis ranges and labels, plot variables, styles, labels, colours, and reference line specifications. Fields introduced as extensions to the default @sdeverywhere/plugin-config capabilities are marked, significantly expanding the visualisation options beyond standard SDEverywhere templates. Figure 3 shows an example of the input file schema structure, while Figure 4 presents the corresponding graph configuration file format.

Deployment

The FeliX ISE is deployed as a static site via GitHub Pages, accessible at https://climatechoice.github.io/felix/. Since no server-side computation is required, the entire application, including the compiled WebAssembly model, is served as static assets. The Vite build process handles bundling, asset optimisation, and the conversion of markdown documentation files into static assets that are loaded on demand. The source code for the FeliX ISE dashboard is available under an open-source licence at https://github.com/climatechoice/felix,[43] and the underlying FeliX model is available at https://github.com/iiasa/Felix-Model.[44]

User interface design

Design principle

The user interface design was guided by the challenging objective of mainstreaming complex IAM modelling results for non-expert audiences without sacrificing scientific depth. This was achieved through principles of progressive disclosure, whereby information is revealed incrementally to avoid overwhelming users with complexity. This approach is particularly important for IAM interfaces, where the depth and breadth of available parameters and outputs can be intimidating to non-expert users.

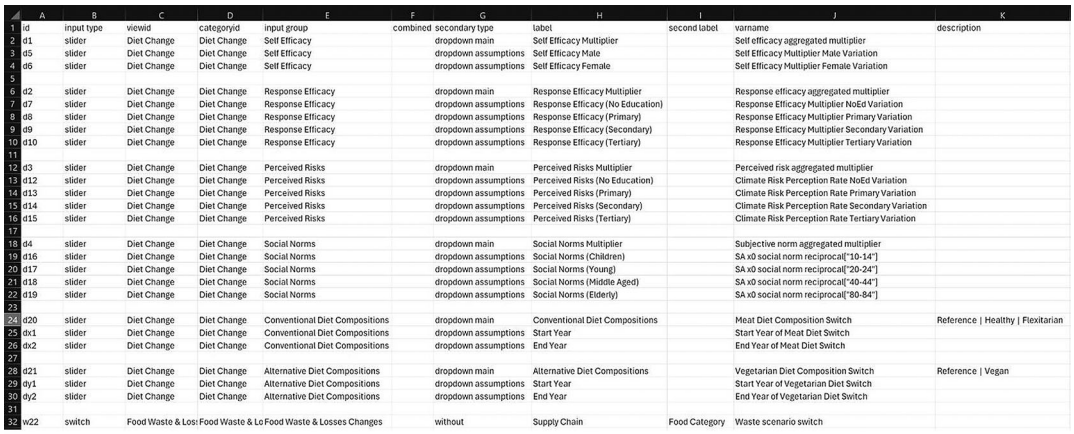
The design adopts a two-panel layout that maps the analytical workflow of adjusting input parameters (left panel) and observing output results (right panel), providing a clear spatial metaphor for the cause-and-effect relationship between scenarios and outcomes. The FeliX ISE translates complex model variables into intuitive, human-readable input controls, sliders, segmented buttons, and switches, accompanied by contextual tooltips and expandable markdown descriptions that explain, in plain language, what each parameter represents and how it connects to broader system dynamics. This design philosophy ensures that the interface communicates not only the values of inputs and outputs but also the systemic interconnections between them, enabling users to build an intuitive understanding of how food, climate, biodiversity, and behavioural systems interact.

Input section

Input variables are organised around behaviour change scenarios structured into three main tabs: Actions, Uncertainties, and External Drivers. Table 3 provides a summary of the scenario input categories.

Table 2. Key input configuration parameters defined in the input file schema.

Parameter	Description
id	Unique identifier for each input enabling programmatic reference
Input type	Interaction modality (slider, switch, segmented button)
categoryid	Category classification enabling logical grouping
input group	Hierarchical section organisation supporting progressive disclosure
secondary type	Nested grouping for dropdown main/assumption separation
slider min/max/step	Range and granularity definitions for continuous inputs
hover description	Contextual information displayed on hover
md description	Reference to detailed markdown documentation



	A	B	C	D	E	F	G	H	I	J	K
1	id	input type	viewid	categoryid	input group	combined	secondary type	label	second label	varname	description
2	d1	slider	Diet Change	Diet Change	Self Efficacy		dropdown main	Self Efficacy Multiplier		Self efficacy aggregated multiplier	
3	d5	slider	Diet Change	Diet Change	Self Efficacy		dropdown assumptions	Self Efficacy Male		Self Efficacy Multiplier Male Variation	
4	d6	slider	Diet Change	Diet Change	Self Efficacy		dropdown assumptions	Self Efficacy Female		Self Efficacy Multiplier Female Variation	
5											
6	d2	slider	Diet Change	Diet Change	Response Efficacy		dropdown main	Response Efficacy Multiplier		Response efficacy aggregated multiplier	
7	d7	slider	Diet Change	Diet Change	Response Efficacy		dropdown assumptions	Response Efficacy (No Education)		Response Efficacy Multiplier NoEd Variation	
8	d8	slider	Diet Change	Diet Change	Response Efficacy		dropdown assumptions	Response Efficacy (Primary)		Response Efficacy Multiplier Primary Variation	
9	d9	slider	Diet Change	Diet Change	Response Efficacy		dropdown assumptions	Response Efficacy (Secondary)		Response Efficacy Multiplier Secondary Variation	
10	d10	slider	Diet Change	Diet Change	Response Efficacy		dropdown assumptions	Response Efficacy (Tertiary)		Response Efficacy Multiplier Tertiary Variation	
11											
12	d3	slider	Diet Change	Diet Change	Perceived Risks		dropdown main	Perceived Risks Multiplier		Perceived risk aggregated multiplier	
13	d12	slider	Diet Change	Diet Change	Perceived Risks		dropdown assumptions	Perceived Risks (No Education)		Climate Risk Perception Rate NoEd Variation	
14	d13	slider	Diet Change	Diet Change	Perceived Risks		dropdown assumptions	Perceived Risks (Primary)		Climate Risk Perception Rate Primary Variation	
15	d14	slider	Diet Change	Diet Change	Perceived Risks		dropdown assumptions	Perceived Risks (Secondary)		Climate Risk Perception Rate Secondary Variation	
16	d15	slider	Diet Change	Diet Change	Perceived Risks		dropdown assumptions	Perceived Risks (Tertiary)		Climate Risk Perception Rate Tertiary Variation	
17											
18	d4	slider	Diet Change	Diet Change	Social Norms		dropdown main	Social Norms Multiplier		Subjective norm aggregated multiplier	
19	d16	slider	Diet Change	Diet Change	Social Norms		dropdown assumptions	Social Norms (Children)		SA x0 social norm reciprocal["10-14"]	
20	d17	slider	Diet Change	Diet Change	Social Norms		dropdown assumptions	Social Norms (Young)		SA x0 social norm reciprocal["20-24"]	
21	d18	slider	Diet Change	Diet Change	Social Norms		dropdown assumptions	Social Norms (Middle Aged)		SA x0 social norm reciprocal["40-44"]	
22	d19	slider	Diet Change	Diet Change	Social Norms		dropdown assumptions	Social Norms (Elderly)		SA x0 social norm reciprocal["80-84"]	
23											
24	d20	slider	Diet Change	Diet Change	Conventional Diet Compositions		dropdown main	Conventional Diet Compositions		Meat Diet Composition Switch	Reference | Healthy | Flexitarian
25	dx1	slider	Diet Change	Diet Change	Conventional Diet Compositions		dropdown assumptions	Start Year		Start Year of Meat Diet Switch	
26	dx2	slider	Diet Change	Diet Change	Conventional Diet Compositions		dropdown assumptions	End Year		End Year of Meat Diet Switch	
27											
28	d21	slider	Diet Change	Diet Change	Alternative Diet Compositions		dropdown main	Alternative Diet Compositions		Vegetarian Diet Composition Switch	Reference | Vegan
29	dy1	slider	Diet Change	Diet Change	Alternative Diet Compositions		dropdown assumptions	Start Year		Start Year of Vegetarian Diet Switch	
30	dy2	slider	Diet Change	Diet Change	Alternative Diet Compositions		dropdown assumptions	End Year		End Year of Vegetarian Diet Switch	
31											
32	w22	switch	Food Waste & Los	Food Waste & Lo	Food Waste & Losses Changes		without	Supply Chain	Food Category	Waste scenario switch	

Figure 3. Example structure of the input configuration file, showing the schema used to define input parameters, their types, ranges, and interface groupings.

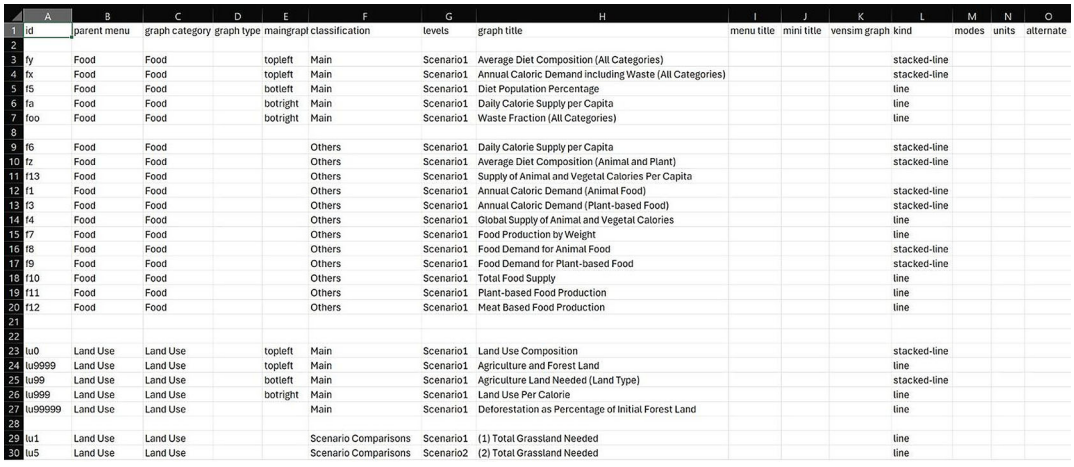
Users interact with the model through four input widget types: continuous sliders for parameters with defined ranges, switches for binary options, segmented buttons for discrete category selection (e.g., diet type), and combined sliders for coupled parameters (e.g., scenario shift start year and duration). Each input modification triggers instant model recalculation via the Web Worker architecture. Figure 5 presents an overview of the complete FeliX ISE interface with its four main sections. Figure 6 shows the tabbed organisation of input categories, Figure 7 demonstrates the progressive disclosure mechanism through collapsible input groups, and Figure 8 illustrates the segmented button widget used for discrete variable selection such as diet composition.

Output section

The output section displays model results across nine thematic graph categories, each containing multiple visualisation panels (Figure 9). Two graph types are supported: line charts displaying temporal dynamics of multiple variables (Figure 10), and stacked area charts showing accumulated quantities with contributing components (Figure 11). Graph selectors within each category enable dynamic chart selection via dropdown menus with informational tooltips providing context for each visualisation.

Navigation and scenario management

The navigation bar (Figure 12) provides access to scenario management functions organised into three sections. The first section contains reset buttons (restoring all inputs to default values) and a summary button that displays all modified



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	id	parent menu	graph category	graph type	maingrapl	classification	levels	graph title	menu title	mini title	vensim graph	kind	modes	units	alternate
2															
3	fy	Food	Food		topleft	Main	Scenario1	Average Diet Composition (All Categories)				stacked-line			
4	fx	Food	Food		topleft	Main	Scenario1	Annual Caloric Demand including Waste (All Categories)				stacked-line			
5	f5	Food	Food		botleft	Main	Scenario1	Diet Population Percentage				line			
6	fa	Food	Food		botright	Main	Scenario1	Daily Calorie Supply per Capita				line			
7	foo	Food	Food		botright	Main	Scenario1	Waste Fraction (All Categories)				line			
8															
9	f6	Food	Food			Others	Scenario1	Daily Calorie Supply per Capita				stacked-line			
10	fz	Food	Food			Others	Scenario1	Average Diet Composition (Animal and Plant)				stacked-line			
11	f13	Food	Food			Others	Scenario1	Supply of Animal and Vegetal Calories Per Capita							
12	f1	Food	Food			Others	Scenario1	Annual Caloric Demand (Animal Food)				stacked-line			
13	f3	Food	Food			Others	Scenario1	Annual Caloric Demand (Plant-based Food)				stacked-line			
14	f4	Food	Food			Others	Scenario1	Global Supply of Animal and Vegetal Calories				line			
15	f7	Food	Food			Others	Scenario1	Food Production by Weight				line			
16	f8	Food	Food			Others	Scenario1	Food Demand for Animal Food				stacked-line			
17	f9	Food	Food			Others	Scenario1	Food Demand for Plant-based Food				stacked-line			
18	f10	Food	Food			Others	Scenario1	Total Food Supply				line			
19	f11	Food	Food			Others	Scenario1	Plant-based Food Production				line			
20	f12	Food	Food			Others	Scenario1	Meat Based Food Production				line			
21															
22															
23	lu0	Land Use	Land Use		topleft	Main	Scenario1	Land Use Composition				stacked-line			
24	lu9999	Land Use	Land Use		topleft	Main	Scenario1	Agriculture and Forest Land				line			
25	lu99	Land Use	Land Use		botleft	Main	Scenario1	Agriculture Land Needed (Land Type)				stacked-line			
26	lu999	Land Use	Land Use		botright	Main	Scenario1	Land Use Per Calorie				line			
27	lu99999	Land Use	Land Use			Main	Scenario1	Deforestation as Percentage of Initial Forest Land				line			
28															
29	lu1	Land Use	Land Use			Scenario Comparisons	Scenario1	(1) Total Grassland Needed				line			
30	lu5	Land Use	Land Use			Scenario Comparisons	Scenario2	(2) Total Grassland Needed				line			

Figure 4. Example structure of the graph configuration file, demonstrating the configuration-driven approach to output visualisation specification.

Table 3. Summary of FeliX ISE scenario input categories and their descriptions.

Input Tab	Variable Type	Description
Actions	Diet Change	Exploration of global dietary transition impacts across four compositions: Reference, Healthy, Mediterranean, and Flexitarian
	Food Loss and Waste	Producer-side loss reduction and consumer-side waste reduction strategies
	Alternative Proteins	Technological replacement trajectories for pasture meat, crop meat, dairy, and eggs
Uncertainties	Population Dynamics of Diet Change	Behavioural drivers including self-efficacy, response efficacy, perceived risks, and social norms
	Food Access and Inequalities	Distribution parameters affecting food equity
	Responses to Food Loss and Waste	Producer and consumer response mechanisms
	Technologies of Alternative Protein	Commodity-specific replacement parameters
	By Food Category	Per-category adjustments across eight food groups
External Drivers	Periods of Change	Transition timing and duration for each scenario dimension
	Socio-Economic Drivers	RCP emission trajectories and SSP socioeconomic pathways

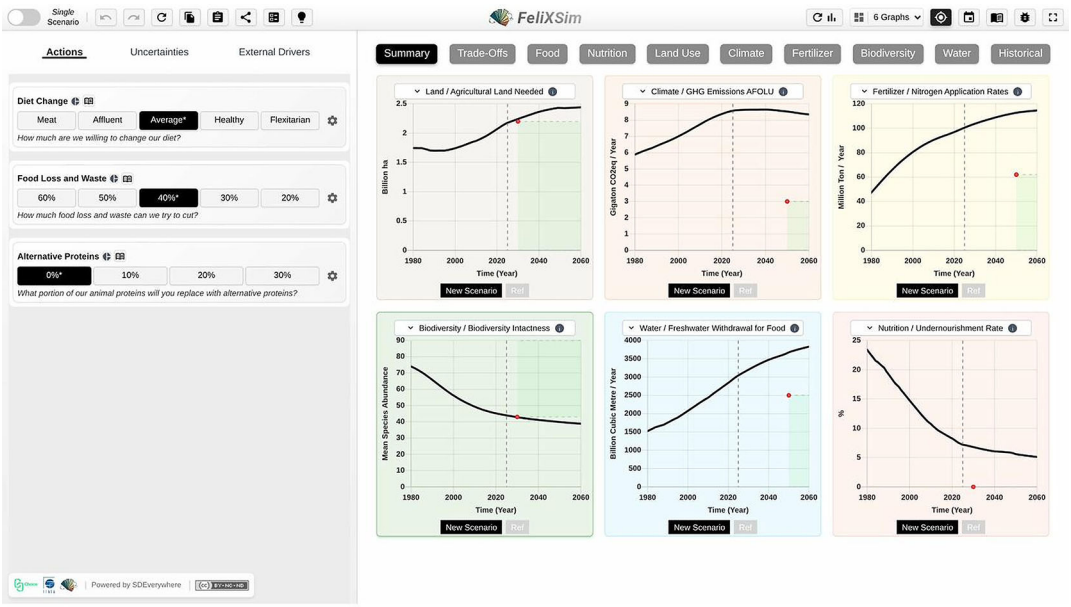


Figure 5. The FeliX ISE online tool showing the four main user interface sections.

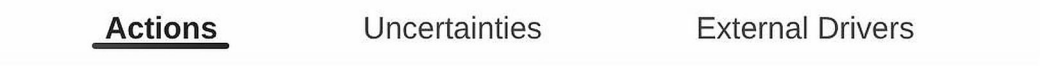


Figure 6. Input categories displayed at the top of the input section, showing the tabbed organisation of actions, uncertainties, and external drivers.

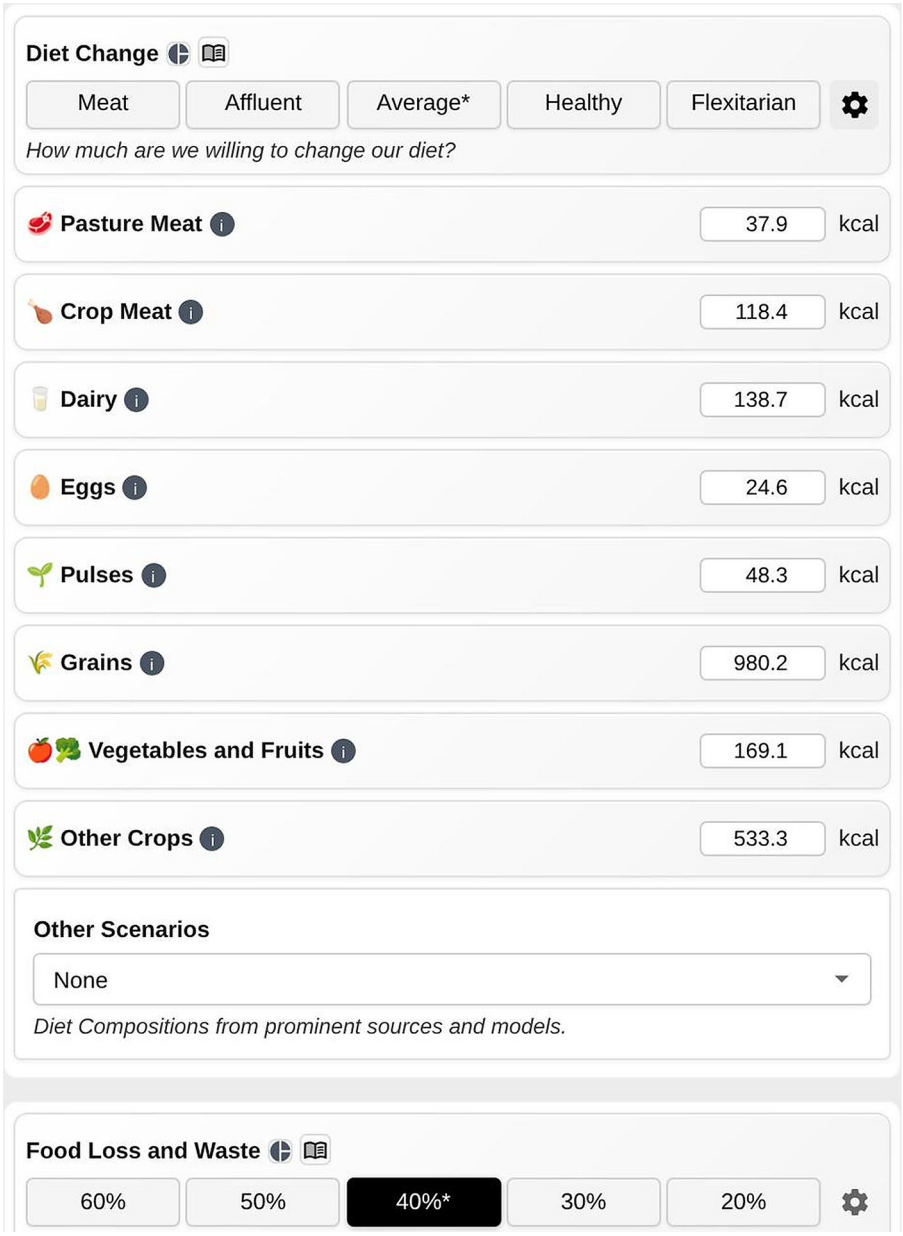


Figure 7. Collapsed (top) and expanded (bottom) input dropdowns showing the progressive disclosure of main and assumption-level sliders within each input group.

parameters in a tabular format (Figure 13). The second section provides layout controls, access to comprehensive documentation (compiled from markdown sources during the build process), a bug reporting link, and a fullscreen toggle.

The sidebar supports multi-scenario comparison mode. When activated via the scenario toggle, the interface expands to display a second set of input controls, colour-coded to distinguish between the two scenarios (Figure 14). Both scenarios maintain independent input variables and are computed simultaneously via separate Web Worker instances. Output graphs render both scenarios overlaid or side-by-side depending on the graph type and user preference, enabling direct visual comparison of policy impacts across all output domains (Figure 15).

Scenario configurations can be exported as JSON files for interoperability, sharing and reproducibility, and imported to reconstruct previously configured scenarios. The import mechanism is order-agnostic, enabling robust interoperability



Figure 8. Segmented button input widget for discrete variable selection, showing the diet composition selector with reference, healthy, mediterranean, and flexitarian options.



Figure 9. Output graph categories at the top of the graph section, showing the nine thematic domains for result visualisation.

across different tool versions. Full documentation of the import/export functionality is maintained on the project's GitHub wiki.[43]

Results

Validation

A critical requirement for the FeliX ISE is ensuring that the transpilation of the original Vensim model through the SDEverywhere toolchain to WebAssembly preserves numerical fidelity. Since the ISE is intended for scientific exploration and policy-relevant analysis, any discrepancies introduced during the conversion pipeline would undermine the tool's credibility. A three-level validation framework was therefore demonstrated, comprising: (1) a verification check between the original and the ISE-adapted Vensim model versions; (2) a direct numerical comparison between Vensim model outputs and those generated by the ISE; and (3) a systematic behavioural assessment across the full input configuration space of the ISE.[17]

Verification of vensim model updates

The development of the FeliX ISE required modifications to the original Vensim model to ensure compatibility with the SDEverywhere transpiler. These modifications included renaming variables to conform to SDEverywhere naming conventions, replacing incompatible built-in Vensim functions (such as Vensim's in-built random functions, which SDEverywhere cannot process), and normalising units across the model. Since these changes do not alter the core system relationships and formulas, the simulated outputs from the modified model should match the outputs from the stable version of FeliX under business-as-usual (BAU) conditions.

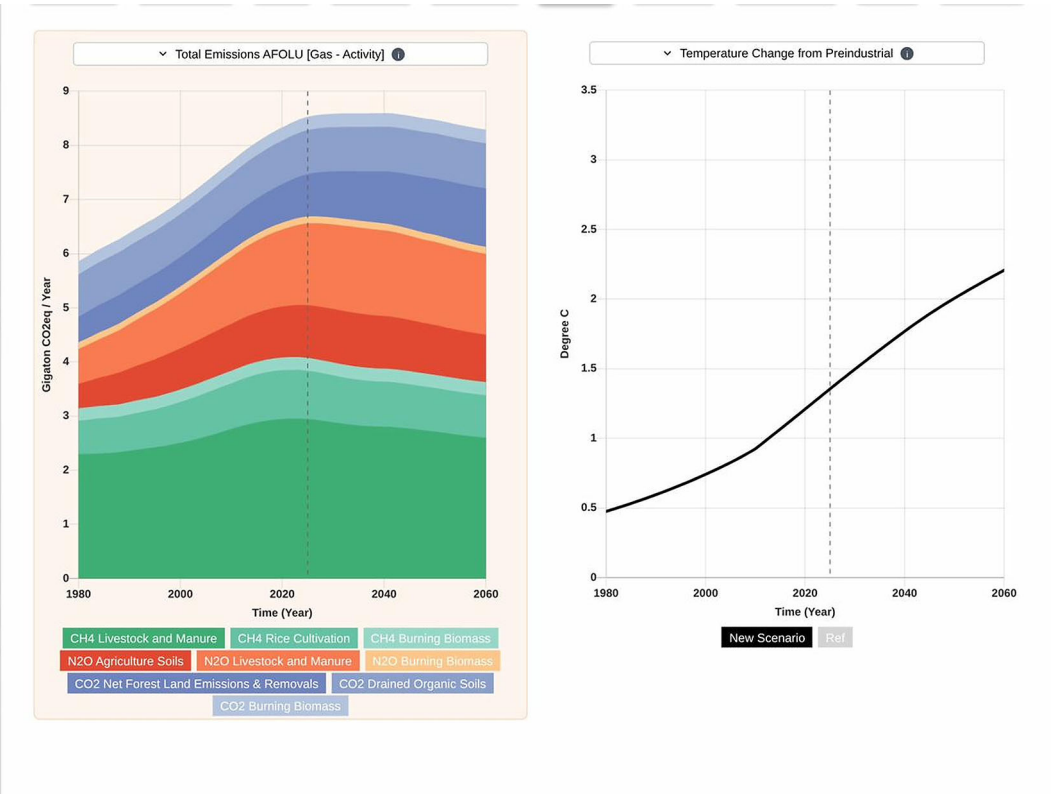


Figure 10. **Example of a line chart showing temporal dynamics of system indicators, with interactive tooltips displaying precise values at specific time points.**

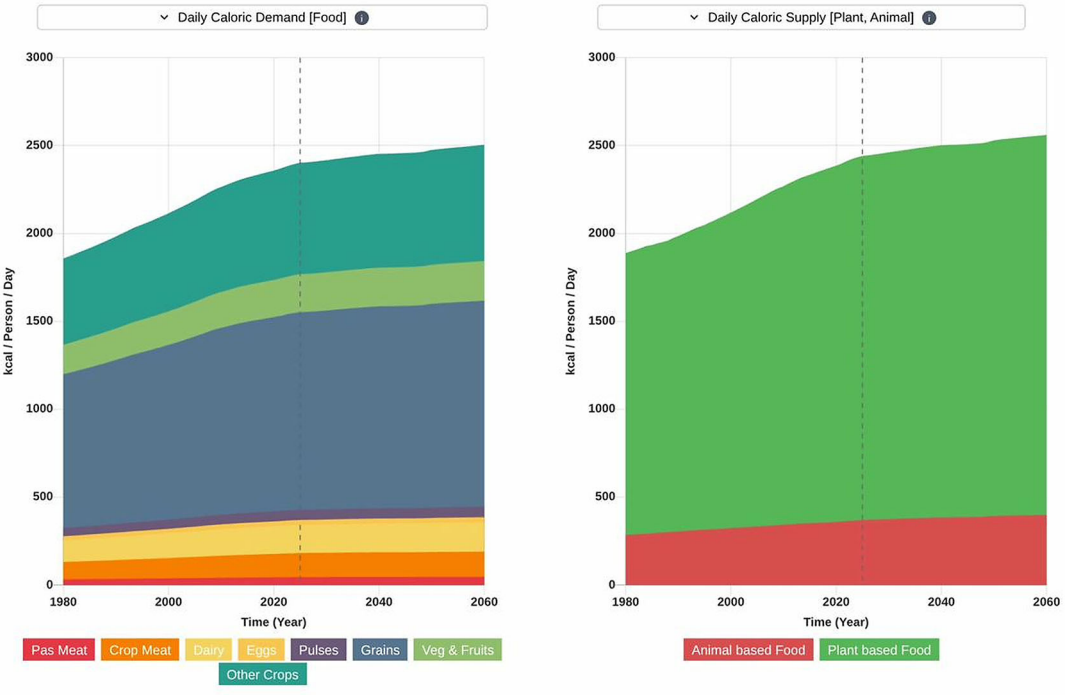


Figure 11. **Example of a stacked area chart showing caloric demand by food category over time, illustrating the compositional visualisation approach.**



Figure 12. Navigation bar showing reset buttons, summary display, scenario toggle, layout controls, and utility buttons.

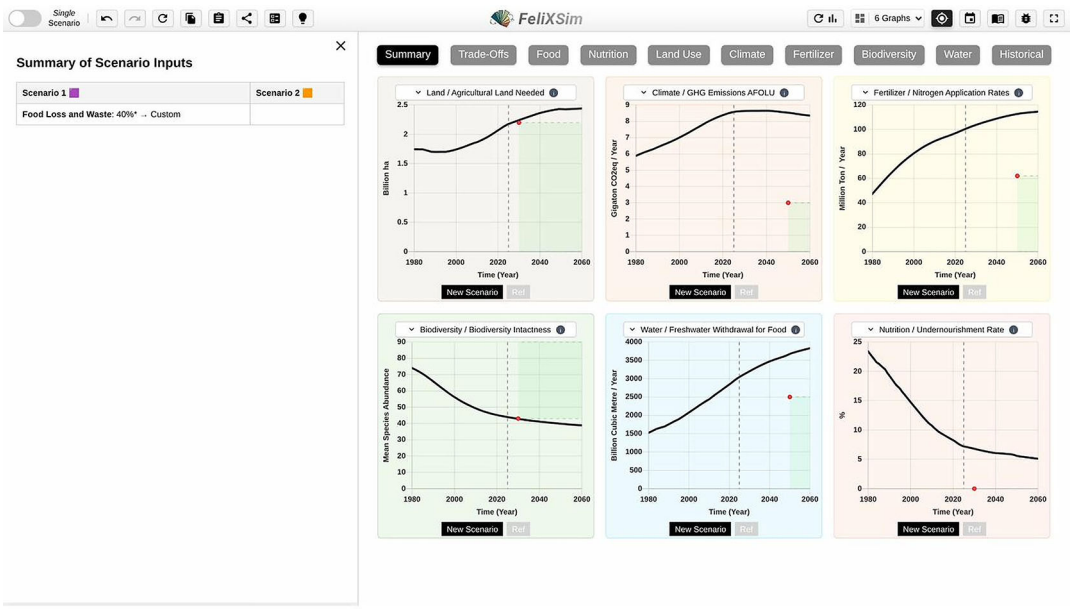


Figure 13. Summary view showing all modified scenario inputs displayed as a table, providing a transparent record of the current scenario configuration.

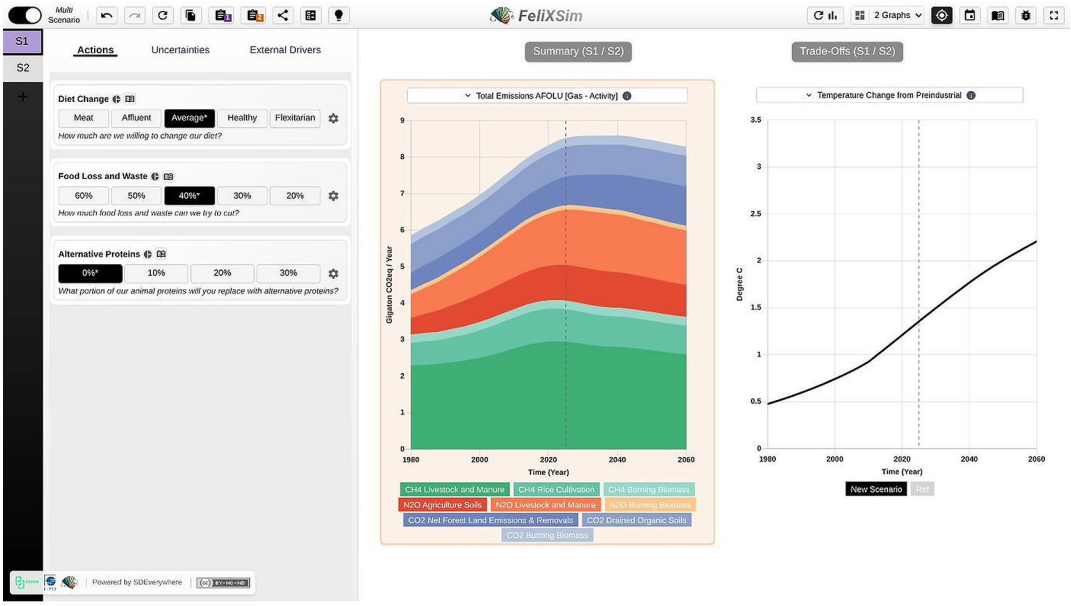


Figure 14. Single-scenario mode (left) and multi-scenario mode (right) with colour-coded inputs, illustrating the dual-scenario comparison interface.

To validate this, the BAU scenario outputs from a baseline version of FeliX were compared with the outputs from an updated version modified for the ISE. The comparison focused on four key output variables selected for their indirect relationship to input parameters, thereby testing a greater number of causal chain interactions: Total CO_2 Emissions from AFOLU, Food and Agriculture Nitrogen Balance, Mean Species Abundance, and Agricultural Water Demand Per Billion

Cubic Metres. As shown in Figure 16, the outputs of the two model versions are in close agreement, with only marginal deviations attributable to the equation-level adaptations necessitated by SDEverywhere compatibility requirements, including the substitution of normal distributions for Poisson distributions and the explicit formulation of delay functions in place of Vensim built-in equivalents.

Validation between vensim and ISE outputs

The most critical validation step verifies that the SDEverywhere conversion pipeline, from Vensim (.mdl) to C to WebAssembly, preserves numerical accuracy. This was assessed by comparing the outputs generated by the Vensim simulation engine with those produced by the ISE's WebAssembly model under identical BAU conditions. Using the year 2020 as a reference datapoint, the Vensim-generated and ISE-generated values were compared for all key output variables. As shown in Figure 17, the comparison reveals exact numerical agreement across all tested output variables. For example, Agricultural Water Demand Per Billion Cubic Metres and Mean Species Abundance produce identical values to 12 significant decimal places in both the Vensim simulation engine and the ISE WebAssembly outputs. This level of precision confirms that the SDEverywhere transpilation and WebAssembly compilation introduce no meaningful numerical error, and that the ISE faithfully reproduces the behaviour of the original Vensim model.

Validation across ISE configuration space

Since the ISE configuration files define continuous input ranges for each parameter rather than discrete presets, the model must behave reasonably across the full n-dimensional scenario space defined by all input variables. The SDEverywhere toolchain includes integrated quality assurance (QA) tools aligned with formal standards of structure and behaviour validity[46] that run locally during the development process.

Three complementary QA mechanisms were employed. The Checks function verifies that output variables remain within predefined bounds (−1000 to 1000 in the normalised scale), serving both as a scale-consistency check and as an extreme condition test to detect whether input variations produce unreasonably high or low outputs. The Comparisons by Scenario function organises custom scenarios using multivariate input combinations and generates output results for each,

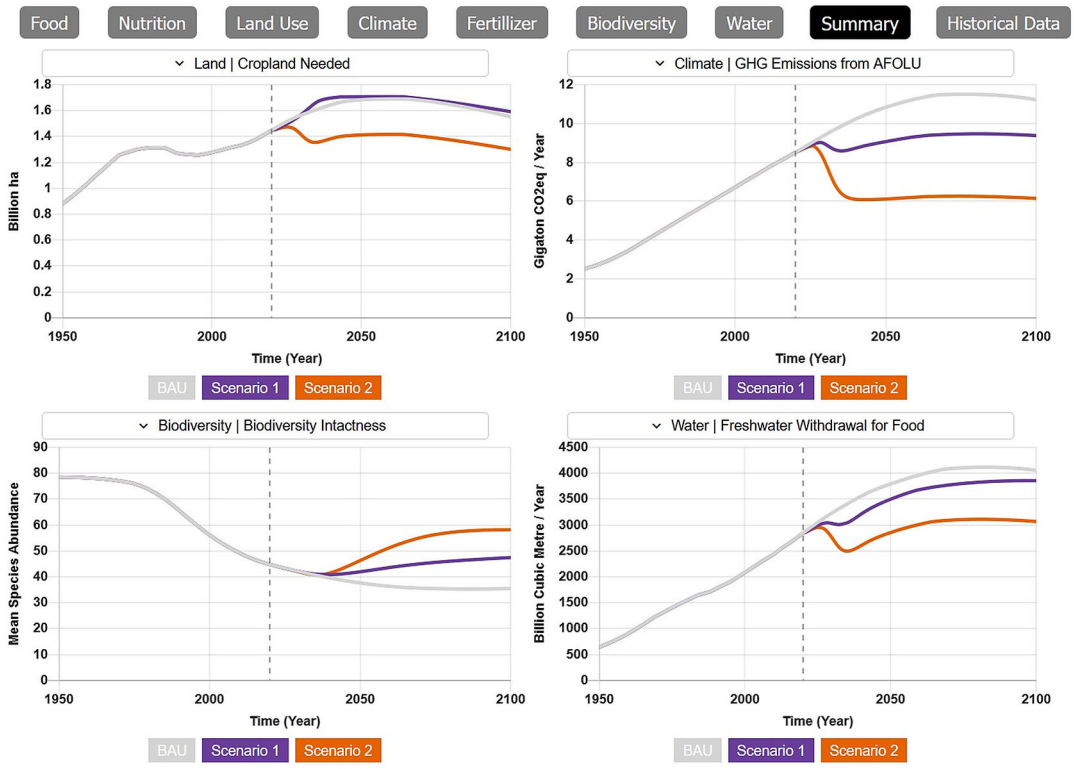


Figure 15. Scenario comparison on the summary graph category showing parallel outputs for two scenarios, enabling direct visual comparison of policy impacts.

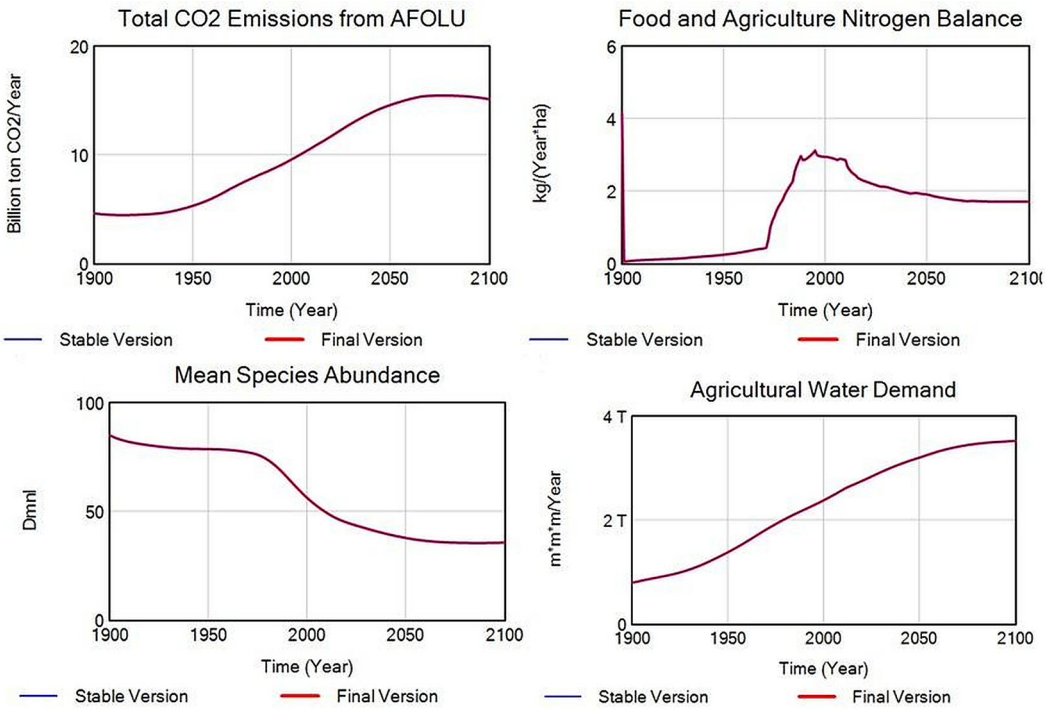


Figure 16. Validation level 1: Comparison of four key output variables between the stable version of FeliX and the final version modified for the ISE.

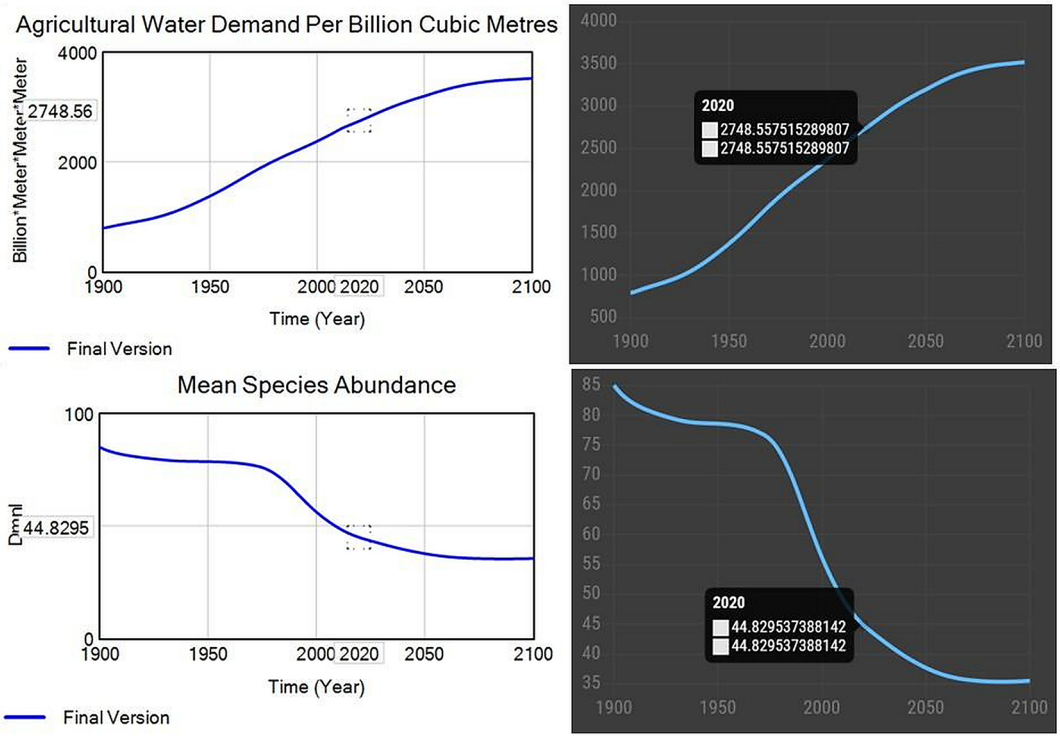


Figure 17. Validation level 2: Side-by-side comparison of vensim outputs (left) and ISE webAssembly outputs (right).

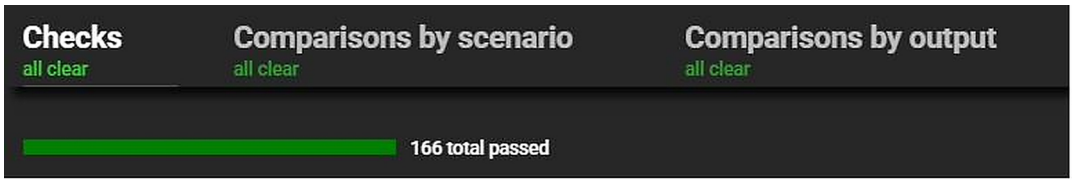


Figure 18. SDEverywhere development environment showing all QA tests results.

enabling systematic sensitivity assessment. The Comparisons by Output function sorts results by outputs, revealing which input variations drive specific output changes. All 166 automated were completed without failures, as shown in Figure 18.[17]

To further verify behavioural plausibility under non-default conditions, custom scenarios combining multiple input modifications were tested. For example, a scenario with Self-efficacy aggregated multiplier = 180%, Subjective norm aggregated multiplier = 180%, Waste Fraction Scenarios by Food Category [Pasture Meat] = 10%, and Waste Fraction Scenarios by Food Category [Pulses] = 10% was evaluated across all four key output variables. The outputs confirmed that all four indicators responded in physically plausible directions under the following combination of inputs Total CO_2 Emissions from AFOLU decreased, Food and Agriculture Nitrogen Balance improved, Mean Species Abundance increased, and Agricultural Water Demand declined. No anomalous behaviours or numerical discontinuities were observed (Figure 19).[17]

Performance characteristics

The FeliX ISE achieves sub-second response times for parameter adjustments, with the full model recalculation completing within the Web Worker and results rendering in the Chart.js visualisation layer before users perceive any delay. The compiled WebAssembly model, combined with all application assets, is served as static files totalling a few

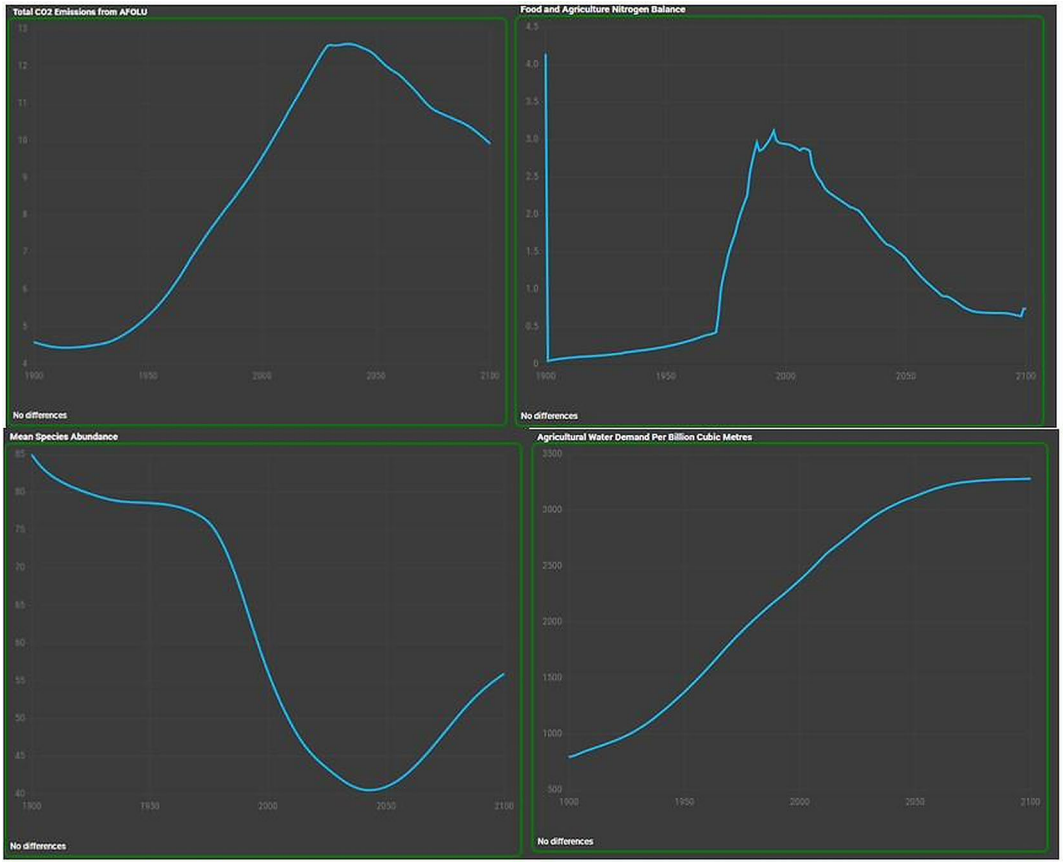


Figure 19. Validation level 3: Key output variables under a custom multi-parameter scenario.

megabytes, enabling fast initial load times even on modest network connections. Once loaded, the application functions entirely offline, as all computation occurs locally in the browser.

The client-side architecture eliminates concerns about server capacity, concurrent user limits, or ongoing hosting costs beyond static file serving. GitHub Pages provides reliable, free hosting with global content delivery network (CDN) distribution, ensuring low-latency access from diverse geographic locations.

Transferability verification

The FeliX ISE architecture was designed in order to be transferable to other Vensim-based system dynamics models. To preliminarily demonstrate this capability, the configuration-driven architecture was tested by loading an SIR (Susceptible-Infected-Recovered) epidemiological model, a standard system dynamics model from a fundamentally different domain. The deployment required only the provision of new CSV configuration files (input and graphs output files) corresponding to the SIR model's parameters and outputs, without any modifications to the application codebase.

The successful loading and rendering of the SIR model through the same interface (Figure 20) suggests that the FeliX ISE architecture is model-agnostic and can in principle be applied to any Vensim-based system dynamics model (.mdl format) by supplying appropriate configuration files.

Scenario demonstration

To illustrate the capabilities of the FeliX ISE, we present two representative scenario demonstrations that showcase the tool's ability to communicate complex system dynamics through interactive exploration.

Scenario 1: Global diet shift

This scenario explores the impact of modifying the Global Diet Compositions parameter from "Reference" to "Healthy." Under the Reference diet, GHG Emissions from Agriculture, Forestry and Other Land Use (AFOLU) are projected at approximately 11.23 Gt CO_2-eq/year by 2100. After transitioning to the Healthy diet composition, the model projects a reduction to approximately 9.37 Gt CO_2-eq/year, a decrease of approximately 16.6%, driven by reduced demand for land-intensive animal products and associated reductions in agricultural emissions.[13,14]

This scenario demonstrates the multi-domain propagation of dietary change: the shift affects not only direct agricultural emissions but cascades through land use patterns (reduced pasture and cropland requirements), biodiversity indicators (reduced habitat pressure), water consumption (lower irrigation demand), and nutritional outcomes (altered caloric and

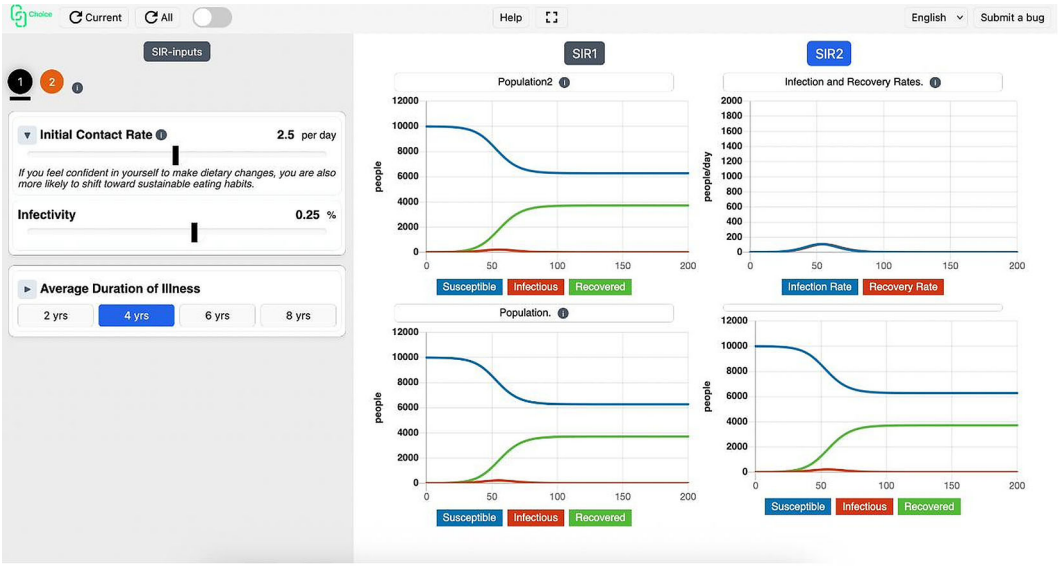


Figure 20. The FeliX ISE interface applied to an SIR epidemiological model, demonstrating the transferability of the configuration-driven architecture to models from different domains.

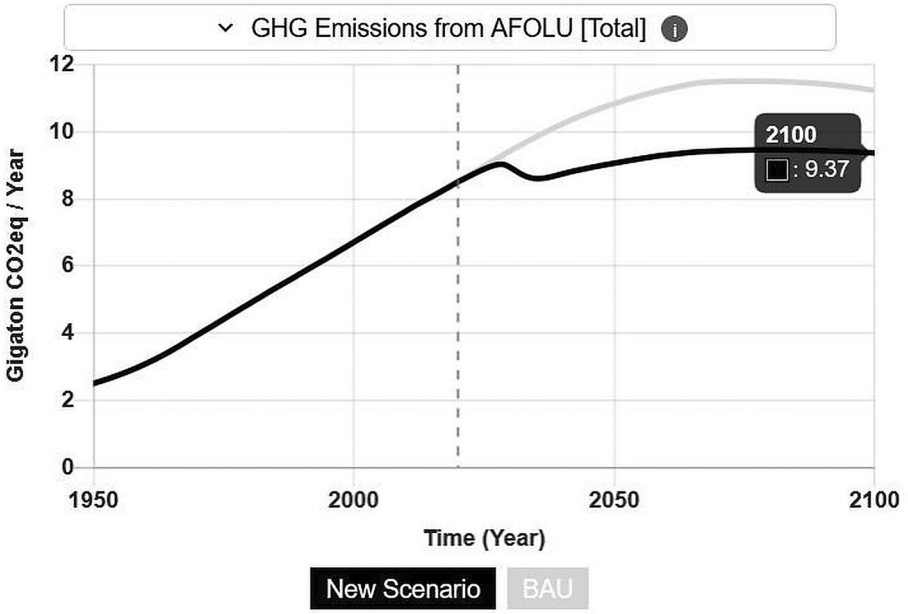


Figure 21. Simulation 1: GHG emissions from afolu under reference versus healthy diet scenarios, showing the projected reduction in agricultural emissions from global dietary transition.

nutrient intake distributions). The ISE enables users to trace these cascading effects across all nine output domains in real time. Figure 21 presents the comparative GHG emission trajectories under the Reference and Healthy diet scenarios.

Scenario 2: Food waste reduction

The second scenario demonstration evaluates the effects of reducing food loss and waste across specific food categories on biodiversity outcomes. This reduction is represented by adjusting the input parameters for Pasture Meat, Crop Meat, and Dairy under the "Food Loss and Waste" category, and under the "by Food Category" option. In the Business As Usual

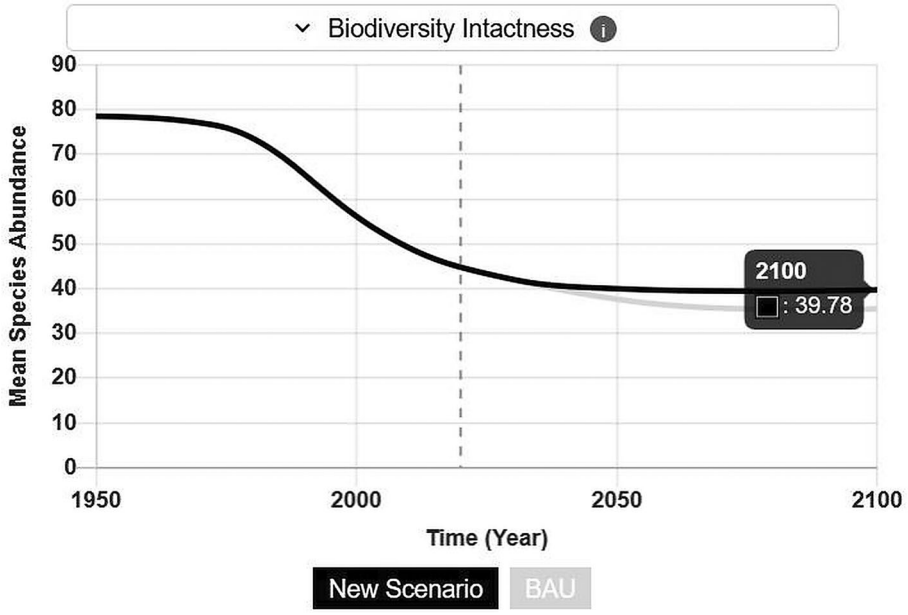


Figure 22. Simulation 2: Biodiversity intactness under baseline versus reduced food waste scenarios, illustrating the positive biodiversity response to demand-side food system interventions.

Table 4. Comparison of the FeliX ISE with existing web-based sustainability simulation tools.

Feature	FeliX ISE	En-ROADS[11]	C-ROADS[11]	iSDG[23]	Earth4All[24]
Thematic focus	Climate-food-biodiversity-behaviour	Energy-climate-economy	Regional emissions	SDG interactions	Socio-economic-environmental
Behaviour modelling	Endogenous (self-efficacy, norms)	Limited	None	Limited	Social dynamics
Architecture	Client-side (Wasm)	Client-side (Wasm)	Client-side (Wasm)	Server-side	Varies
Food system detail	Eight food categories, dietary compositions	Limited	None	Aggregate	Food module, demand changes only through replacement by new technologies
Open-source	Yes	Partial	Partial	No	Partial
Transferability	Any Vensim model	En-ROADS specific	C-ROADS specific	iSDG specific	Earth4All specific
UI/UX mainstreaming	Tooltips, markdown docs, two-panel cause-effect layout, thematic output grouping	two-panel cause-effect layout, thematic output grouping	Sliders with basic labels	Standard web form	Basic sliders

(BAU) scenario, each of the three food categories is set at a loss and waste rate of 20%. In this scenario, we reduce this rate to 10% for each input, representing a 50% reduction in food waste in the three food categories.

The results on the "Biodiversity Intactness" graph - where a value of 100 represents that the ecosystem is undisturbed, 0 represents that the species are completely lost - show that in the year 2100, biodiversity intactness improves from a value of 35.53 to 39.78, and stays relatively steady. This nearly 12% increase signifies that reducing food loss and waste substantially contributes to preserving species populations and maintaining ecosystem integrity. As shown in Figure 22, the Biodiversity Intactness Index shows measurable improvement under the food waste reduction scenario compared to the baseline, reflecting reduced land conversion pressure and lower resource extraction from natural ecosystems.[14]

Discussion

Increase accessibility and understanding of complex integrated assessment outputs

The FeliX ISE represents a concrete step toward increasing accessibility to sophisticated integrated assessment capabilities. By eliminating the traditional barriers of proprietary software, specialised expertise, and computational infrastructure, the tool enables a substantially broader range of stakeholders, including policymakers, educators, students, civil society organisations, and interested citizens, to engage directly with the complex system dynamics underlying climate-food-biodiversity interactions.[7,8]

A central design objective was to mainstream complex IAM outputs through a UI/UX friendly dashboard that conveys information more clearly than the limited available tools. The progressive disclosure interface design addresses the tension between analytical depth and user accessibility. Expert users can access the full breadth of model parameters through the Uncertainties and External Drivers tabs, while non-specialist users can achieve meaningful scenario exploration through the more accessible Actions tab, which provides high-level interventions (diet change, food waste reduction, alternative proteins) without requiring understanding of underlying model mechanics. The structured two-panel layout, contextual tooltips, expandable markdown descriptions, and thematically organised output categories collectively make it transparent which inputs affect which outputs and how the modelled Earth systems are interconnected, a level of interpretive clarity that is currently absent from most existing IAM tools, where users often manipulate parameters without understanding the systemic pathways through which their changes propagate. This layered approach ensures that the tool serves diverse user communities without compromising scientific rigour.

Crucially, the three-level validation framework ensures the tool's credibility for policy-relevant analysis. The demonstration of exact numerical agreement between the original Vensim model and the WebAssembly-compiled ISE,

confirmed to full floating-point precision, addresses a fundamental concern in model transpilation: that the conversion process itself might introduce errors that compromise the scientific integrity of results. By combining automated QA checks (166 tests across the full scenario space), direct numerical comparison at specific datapoints, and behavioural plausibility assessment under custom multi-parameter scenarios, the validation framework aligns with established standards of structure and behaviour validity in system dynamics modelling.[46] This level of validation rigour is essential for ensuring that the accessibility gains achieved through the browser-based interface do not come at the cost of scientific accuracy.

Comparison with existing tools

The FeliX ISE occupies a distinct position in the landscape of web-based sustainability simulation tools. Table 4 provides a comparative overview. The FeliX ISE's distinguishing features include its endogenous behavioural modelling, its detailed food system representation, its demonstrated transferability to arbitrary Vensim models, and its UI/UX design that explicitly communicates system interconnections through contextual documentation, structured input–output mapping, and thematic output organisation. Furthermore, the FeliX ISE provides a richer contextual layer, including per-variable tooltips, expandable markdown descriptions, and thematically grouped outputs, that helps users understand not only what happens when they change a parameter, but why it happens through the interconnected system pathways**.**

Implications for policy and education

The FeliX ISE's accessibility has implications for both policy processes and educational contexts. For policymakers, the tool provides a means to rapidly explore the systemic consequences of food and climate interventions, including trade-offs and co-benefits that may not be apparent from sector-specific analyses.[8] The multi-scenario comparison feature is particularly valuable for policy deliberation, enabling side-by-side evaluation of alternative intervention packages.

For educational contexts, the tool offers a hands-on platform for teaching systems thinking and sustainability science.[45] The immediate feedback loop, adjusting a parameter and observing cascading effects across multiple domains, provides an experiential learning opportunity that complements traditional lecture-based instruction. The tool's coverage of interconnected food, climate, land, biodiversity, and water systems makes it suitable for courses in environmental science, public policy, agricultural economics, and related disciplines.

Limitations and future work

Several limitations of the current implementation should be acknowledged. First, the FeliX model is globally aggregated, meaning it does not capture regional heterogeneity in food systems, climate impacts, or behavioural dynamics. The ongoing development of FeliX-R5, a regionalised version based on five United Nations regional classifications,[14] will enable future ISE versions to support regional analysis.

Second, the current interface supports comparison of at most two scenarios simultaneously. While this covers the most common analytical use case, more complex policy analysis may require comparison across larger scenario ensembles. Third, the reliance on WebAssembly and modern browser APIs means that the tool requires a relatively recent web browser. While this is not a significant barrier for most users, it may limit accessibility in contexts with legacy infrastructure.

Fourth, while the configuration-driven architecture supports transferability to other Vensim models, the current UI patterns (two-panel layout, thematic tabs, slider-based inputs) reflect design decisions optimised for the FeliX model's specific structure. Adaptation to models with fundamentally different input/output structures may require additional interface customisation beyond CSV configuration.

Future development priorities include: (a) integration of the FeliX-R5 regional model to enable sub-global analysis; (b) enhanced export capabilities including report generation and data download in standard formats; (c) guided scenario modes that walk non-expert users through pre-designed analytical workflows; (d) accessibility improvements in compliance with WCAG 2.1 guidelines (the Web Content Accessibility Guidelines, an internationally recognised set of standards for making web content accessible to users with disabilities); and (e) integration of uncertainty quantification and sensitivity analysis capabilities directly within the interactive interface.

Conclusions

This paper has presented the FeliX ISE, a browser-based Interactive Simulation Environment that makes the FeliX Integrated Assessment Model accessible to non-expert users through standard web browsers. By compiling the full system dynamics model to WebAssembly using the SDEverywhere toolchain and employing Web Workers for non-blocking computation, the tool achieves real-time scenario exploration without server-side dependencies. A three-level validation framework, encompassing Vensim model version consistency, direct numerical comparison between Vensim

and WebAssembly outputs, and automated QA testing across the full input configuration space, confirms that the transpilation pipeline preserves exact numerical fidelity, with outputs matching to floating-point precision. The configuration-driven architecture, which decouples the model from the user interface through CSV specification files, is designed for transferability to any Vensim-based system dynamics model, a capability preliminarily demonstrated by loading an SIR epidemiological model through the same interface without code changes.

The FeliX ISE's user interface design represents a systematic effort to mainstream complex IAM modelling results for broader audiences. Through simplified input controls, contextual tooltips, expandable markdown documentation, thematically organised output categories, and a structured two-panel cause-and-effect layout, the dashboard makes it visually explicit which inputs affect which outputs and how the modelled Earth systems are interconnected**.** This UI/UX-driven approach to communicating system complexity significantly lowers the expertise threshold for meaningful engagement with integrated assessment science, distinguishing the FeliX ISE from existing tools that present model parameters without contextual guidance on their systemic significance.

The FeliX ISE enables users to explore how dietary choices, food waste reduction strategies, alternative protein adoption, and behavioural dynamics propagate through interconnected climate, food, land use, biodiversity, water, and socioeconomic systems. The tool's progressive disclosure interface design supports users ranging from expert modellers to non-specialist policymakers and citizens, while maintaining the full analytical depth of the underlying model. Multi-scenario comparison, scenario import/export, and comprehensive contextual documentation further enhance the tool's utility for policy deliberation and educational applications.

By releasing the FeliX ISE as a fully open-source, freely accessible web application, this work contributes to the broader effort of making integrated assessment modelling more accessible and ensuring that the scientific tools needed to address interconnected sustainability challenges are available to all who need them.

Ethics and consent statement

This research did not involve experimentation with human participants. The FeliX ISE processes all user inputs locally within the browser; no personally identifiable information is collected, transmitted, or stored. The system architecture was designed with privacy-by-design principles, as all computation occurs on the client-side without any server communication. No adverse events were reported during the development and testing of the platform. As no human participants were involved in any stage of this research, ethical approval and informed consent were not required.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this manuscript, the authors used generative AI-based tools, specifically large language models such as ChatGPT (OpenAI), solely to assist with language editing and consistency checks in limited sections. All substantive decisions regarding the design of the review, screening, data extraction, analysis and interpretation were made by the authors. The authors carefully reviewed and edited all AI-assisted text and take full responsibility for the integrity and accuracy of the manuscript's content.

Data availability

The FeliX ISE operates on the parameters and equations of the FeliX 2.0 model, which is fully documented in the referenced literature.[15] The tool's functionality was validated through scenario demonstrations using the model's built-in reference data.

Software availability

The software described in this article is available under an open-source licence. The following resources are publicly accessible:

- FeliX ISE Dashboard (source code and live deployment)
  - Software available from: https://github.com/climatechoice/felix
  - Source code available from: https://github.com/climatechoice/felix
  - Archive software available from: https://doi.org/10.5281/zenodo.18876116[43]
  - License: MIT and CC-BY 4.0 License

- FeliX Model (Vensim):
  - Source code available from: https://github.com/iiasa/Felix-Model
  - Archived software available from: https://doi.org/10.5281/zenodo.18876360[44]
  - License: MIT and GPL-3.0 License

Extended data

Zenodo. The FeliX ISE. The following extended data items are available as part of the archived FeliX ISE Dashboard repository (DOI: https://doi.org/10.5281/zenodo.18876116)[43]:

- **Extended Data 1: inputs.csv** — The complete CSV configuration file defining all scenario input parameters, their types, ranges, groupings, and interface metadata used by the FeliX ISE. This file, together with the application codebase, fully specifies the input interface and can be adapted for other Vensim-based models.
- **Extended Data 2: graphs.csv** — The complete CSV configuration file defining all output visualisations, including graph classifications, chart types, axis specifications, variable mappings, and styling parameters for the nine thematic output domains.

Data are available under the terms of the MIT License (source code) and the Creative Commons Attribution 4.0 International licence (CC-BY 4.0) for documentation and configuration files.

Acknowledgements

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✓ **Umamahesh V Nanduri**
National Institute of Technology, Warangal, Telangana, India

This manuscript introduces the development of a fully browser-oriented Interactive Simulation Environment (ISE) for the FeliX Integrated Assessment Model (IAM). The authors compile the Vensim-based FeliX model into WebAssembly using the SDEverywhere toolchain, thereby enabling real-time, client-side model execution without relying on proprietary software.

I appreciate the authors for developing this web-based interactive tool that makes the complex system dynamic models more easily accessible for modelling the climate-food-land-biodiversity interactions. The authors explain the tool well, clearly highlighting its strengths and limitations.

Although the online documentation lists 11 modules, not all are explained in this paper. The Diet Shift module is definitely a major contribution. However, the manuscript focused more on this module, and other modules are not highlighted much.

Is the rationale for developing the new software tool clearly explained?
Yes

Is the description of the software tool technically sound?
Yes

Are sufficient details of the code, methods and analysis (if applicable) provided to allow replication of the software development and its use by others?
Yes

Is sufficient information provided to allow interpretation of the expected output datasets and any results generated using the tool?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Water Resources Systems, Impact of Climate Change on Hydrological Systems, Hydro-climatic Extremes

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Reviewer Report 22 May 2026

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Page Kyle
Pacific Northwest National Laboratory, Richland, Washington, USA

In general, I think it's great that the authors have developed this accessible and online tool for viewing results from a more complex integrated assessment (IA) model. The performance of the model in the online browser is good; results are very quickly plotted when user-specified settings are changed. The authors have done a good job both in this paper and in their online documentation, though the online documentation would benefit from using a single webpage with the entire document, and the chapters implemented as linkable section headings. As it is currently structured, users have to guess which chapter their topic of interest fits under, in order to successfully perform a keyword search, and lots of topics fit logically under multiple subject headings.

As for the model itself, the set of variables that are available to users is small compared to the inputs to IA models, and the online implementation of FeliX seems to be missing entire modules of energy supply and demand, which really are the core of IA models in general. The energy system accounts for significantly more greenhouse gas emissions then agriculture, and generally has wider uncertainty bounds going forward on those emissions. The greenhouse gas emissions in the online browser seem limited to AFOLU, but then the model presumably still tracks global total GHG emissions in order to estimate future temperature change. How this is done should be described.

Temperature change results seem to be driven mostly by energy system dynamics that I assume are baked into the socioeconomic assumptions, but I couldn't find any documentation stating this. Also here I am confused because the pessimistic scenario, SSP3, has pretty similar levels of greenhouse gas emissions and temperature change as SSP2, at least using the official marker scenarios, whereas in these results the emissions are quite different. SSP3 here looks more like the official marker for SSP5. What is the basis for the emissions in SSPs 1, 2, and 3? Is it some published scenario outputs from FeliX?

Agricultural water is known to be a major uncertainty going forward, driven in part by very low present day use of irrigation in Africa, and parts of Latin America and Southeast Asia. The documentation states that the irrigated land shares are a function of wealth, but this appears to be the kind of variable that is exogenous but not user controlled, and no numerical values in the equations are available as far as I can tell. Regardless, there's not a whole lot that can be said about water when modeling at a purely global level. There is an obvious inverse relationship between irrigation water demand and regional water availability; to the extent that water resource scarcity will shape or influence agricultural decisions and outcomes, these dynamics will play out in relatively water-scarce regions.

Both this paper and the online documentation each seem to suggest that there is an energy module, but there does not seem to be one in the actual model, and similarly, this paper doesn't have any figures on energy. Even if this is going to be assessed as only a model of land use and climate, one of the big questions in agriculture to 2050/2100 is the quantity of bioenergy feedstocks that will be produced. There was a section on model limitations towards the end of the manuscript that was helpful, but for some reason there was no mention of the lack of energy supply and demand modules. The documentation indicates that biomass for energy is intended to be part of the model, but no linkages to cropland are provided in the description.

Small note--on p4, please define "self-efficacy" as this isn't a standard term within this field.

Is the rationale for developing the new software tool clearly explained?
Yes

Is the description of the software tool technically sound?
Yes

Are sufficient details of the code, methods and analysis (if applicable) provided to allow replication of the software development and its use by others?
Partly

Is sufficient information provided to allow interpretation of the expected output datasets and any results generated using the tool?
Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Integrated assessment modeling (all aspects)

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.