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ORIGINAL ARTICLE

Transdisciplinary approaches to local sustainability: aligning local governance and navigating spillovers with global action towards the Sustainable Development Goals

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Abstract
In an evolving world, effectively managing human–natural systems under uncertainty becomes paramount, particularly when targeting the United Nations 2030 Agenda for Sustainable Development Goals (SDGs). The complexity in multi-actor decision-making and multi-sectoral settings, coupled with intricate relationships and potential conflicting management approaches, makes understanding the local implications of progressing towards the global SDGs challenging. We used a transdisciplinary approach for knowledge co-production with local stakeholders to assess the impact of local action to boost sustainability in the Goulburn–Murray region, Victoria, Australia, and its alignment with global action towards the SDGs. Together, we co-developed 11 local actions geared towards achieving four locally important environmental and socioeconomic SDGs, with a particular emphasis on addressing potential 'spillovers'—unintended effects that influence SDGs across scales. Through system dynamics modelling, we evaluated the interplay between these local actions and global scenarios, emphasising their synergies, trade-offs, and the resulting impact on SDG indicators. Key findings indicate a predominant synergy between global and local actions across most SDG indicators. However, certain areas like dairy production, riverine algal blooms, and agricultural profit displayed trade-offs. Local actions significantly impacted indicators, such as crop production, dairy output, agricultural land use, and agricultural profitability. Findings highlighted the need for complementary actions in areas, such as water availability management, skilled workforce, and salinity control. This study underscored the importance of harmonising local initiatives with global sustainability objectives and can inspire local governance to champion resilience policies that harmoniously integrate local actions with global sustainability goals, adapting to evolving uncertainty scenarios.

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Graphical abstract

SDG	Indicator	Global ACTION	Local ACTION	Global ACTION + Local ACTION	Local and Global ACTION Interactions
	Crop production	+	+++	++++	
	Dairy production	- - - -	+++	-	
	Net water availability	+	+	++	
	River water salinity	+	+	++	
	Skilled workforce	0	++	++	
	Agricultural profit	-	++++	+++	
	Agricultural land	+	+++	++++	
	Blue green algal bloom	-	++	++	

Level of effect:

Very Strong Positive Effect: ++++ Strong Positive Effect: +++ Moderate Positive Effect: ++ Mild Positive Effect: +
Neutral Effect: 0
Very Strong Negative Effect: - - - - Strong Negative Effect: - - - Moderate Negative Effect: - - Mild Negative Effect: -

Synergy Trade-off Benign

Keywords Stakeholder engagement · Localising · SDGs · Global goals · Knowledge co-production · System dynamics modelling

Introduction

Successful realisation of the United Nations 2030 Agenda for SDGs hinges on local initiatives (UN 2015). However, complexity exists in understanding the local implications of global SDG achievement (Sachs et al. 2019). Every nation and local region shapes the advancement or impediment of the 2030 Agenda's success through competing development agendas (Messerli et al. 2019). Local scale implementation of the SDGs, championed by local communities, cities, and organisations, provides a tailored approach that aligns with the distinct characteristics of each region (Moallemi et al. 2019). However, progressing on one SDG can generate 'spillovers'—unintended effects that influence the same or other SDGs across scales (Engström et al. 2021; SDG Watch Europe 2019). There is an urgent need for research that effectively governs for spillovers and empowers local regions to consider global implications when implementing local SDG policies (Engström et al. 2021).

Sustainability science uses scenario analysis to address future uncertainties and craft policies for sustainable development (Swart et al. 2004). Several recent studies have undertaken scenario analysis for sustainability at various scales (Hatfield-Dodds et al. 2015; Lamontagne et al. 2019). Moallemi et al. (2022) modelled global socioeconomic and climatic change scenarios and their uncertainty for sustainable development. At the national level, Gao and Bryan (2017) utilised an integrated land system model to evaluate numerous scenarios aiming to assess multiple SDG targets. However, as Moallemi et al. (2020) underscored, diverse local priorities can sometimes clash with overarching policies set at national or global levels. To effectively achieve the aspirations set forth in the SDGs, there must be a harmonious integration of local actions with global sustainability objectives, while fostering coordination among all stakeholders to ensure a sustainable future for all.

Policymakers may encounter challenges in crafting evidence-based sustainability policy, often due to a lack of detailed information about potential uncertainties, requiring careful consideration and analysis (Chappin et al. 2017; Forni et al. 2016). The intricacies and uncertainties of the SDGs can benefit from the application of systems models, commonly known as integrated assessment models (IAMs) (van Beek et al. 2020) to comprehend the interplay of synergies and trade-offs both among and within the SDGs (Neumann et al. 2018) and capturing the joint impacts of global uncertainties and local actions on local priorities. Previous studies have shown systems modelling (Babatunde et al. 2017; Greeven et al. 2016; Sterman et al. 2012; van Beek et al. 2020; Wiedmann 2009) to be effective in modelling intricate feedback interactions, exploring sector interconnections, and grasping non-linearities and radical shifts

(Moallemi et al. 2021b), with wide-ranging applications within the broader sustainability topics (Eker et al. 2019) or those closely tied to the SDGs (Allen 2019; Randers et al. 2019).

However, relying solely on integrated assessment models proves inadequate to guide us through the complexity of the system (Koasidis et al. 2023) within intricate societal, economic, and environmental frameworks characterised by a range of stakeholders with diverse needs, values, and priorities (Messerli et al. 2019). A *transdisciplinary approach* (Game et al. 2018) is required to enable the development of local sustainable pathways while elevating the salience and legitimacy of the information derived from integrated assessment models (Cash et al. 2003). The 2030 Agenda implementation requires engaging all stakeholders (Independent Group of Scientists appointed by the Secretary-General 2019). Engaging both scientists and non-scientific knowledge in transdisciplinary collaboration (Michas et al. 2020), co-design (Moser 2016), and co-production (Norström et al. 2020) represents a transformative strategy for merging science and policy to fulfill humanity's collective aspiration for sustainable development. The aim of these concepts is gravitating towards knowledge co-production as a promising strategy to advance in the intricate challenges arising in the field of sustainability while also exerting a meaningful influence on the decision-making processes of policy-makers (Moallemi et al. 2021a). Norström et al. (2020) highlighted that achieving high-quality knowledge co-production for sustainability requires being "local, pluralistic, goal-oriented, and interactive". A discernible void persists in the realm of local sustainability, pertaining to the realisation of such a transdisciplinary approach of knowledge co-production.

In this study, we pioneered a unique transdisciplinary approach to unravel the spillovers of local sustainability actions within a broader global sustainability framework. Utilising a local IAM based on system dynamics, the Local Environmental and Socioeconomic Model (LESEM) (Bandari et al. 2023), we focused on the Goulburn–Murray region in Victoria, Australia, while, we acknowledge the rich and well-established work conducted in this region. The purpose of this research is to analyse the current dynamics within the Goulburn–Murray system and test proposed resilience actions using a system dynamics model tailored specifically to the intricacies of this region up to 2050. Our approach was distinctive in its rigorous integration of knowledge co-production principles at each step, ensuring that our research was deeply embedded in local sustainability contexts. We co-developed 11 local actions towards achieving four locally relevant environmental and socioeconomic SDGs. Furthermore, we explored the interplay of four combinations of global scenarios, including Shared Socioeconomic Pathways (SSPs) and Representative Concentration Pathways (RCPs) scenarios, global diet, and food waste, with these local actions. Ultimately, our goal is to inspire local governance to embrace both local and global sustainability goals, championing policies that align with the evolving scenarios and consistently support both local and global sustainability objectives.

Methodology

Study area

The Goulburn–Murray region is situated adjacent to the River Murray in northern Victoria, Australia. This region represents the country's largest irrigation district, encompassing six local government areas—Moira, Greater Shepparton, Loddon, Campaspe, Gannawarra, and Swan Hill (Fig. 1). The Goulburn–Murray region has a long history of social–ecological systems analysis and resilience planning, particularly in the Goulburn-Broken catchment (RMCG 2022). This region is recognised as Australia's primary food production hub, characterised by extensive cropping, livestock production, and horticulture (GMIDWL 2018). Nonetheless, the agricultural sector and economy in the Goulburn–Murray region have endured significant impacts from recent economic, policy, and environmental changes, such as climate change, declining commodity prices, water reform policies, fluctuating water prices, droughts, variations in water availability, and unpredictable international agriculture commodity markets (RPG 2020). The region serves as a valuable case study for investigating the complex interplay of diverse future sustainability actions and scenarios at both local and global scale.

Methodological approach

Our transdisciplinary approach to the identification and assessment of local actions under global scenarios followed four key steps, as shown in Fig. 2. In Step 1, we co-designed and employed a local IAM (i.e., LESEM) to analyse sustainable development across local priority SDGs. In Step 2, we co-produced and quantified local actions through a participatory approach with local stakeholders in the Goulburn–Murray region. We defined the assumptions for global scenarios (Step 3). We elaborated our scenario assumptions including both global scenarios and local actions and utilised these assumptions in the model. In Step 4, we utilised LESEM to simulate and capture the interplay of implementing the local actions under the global scenario frameworks across multiple SDGs.

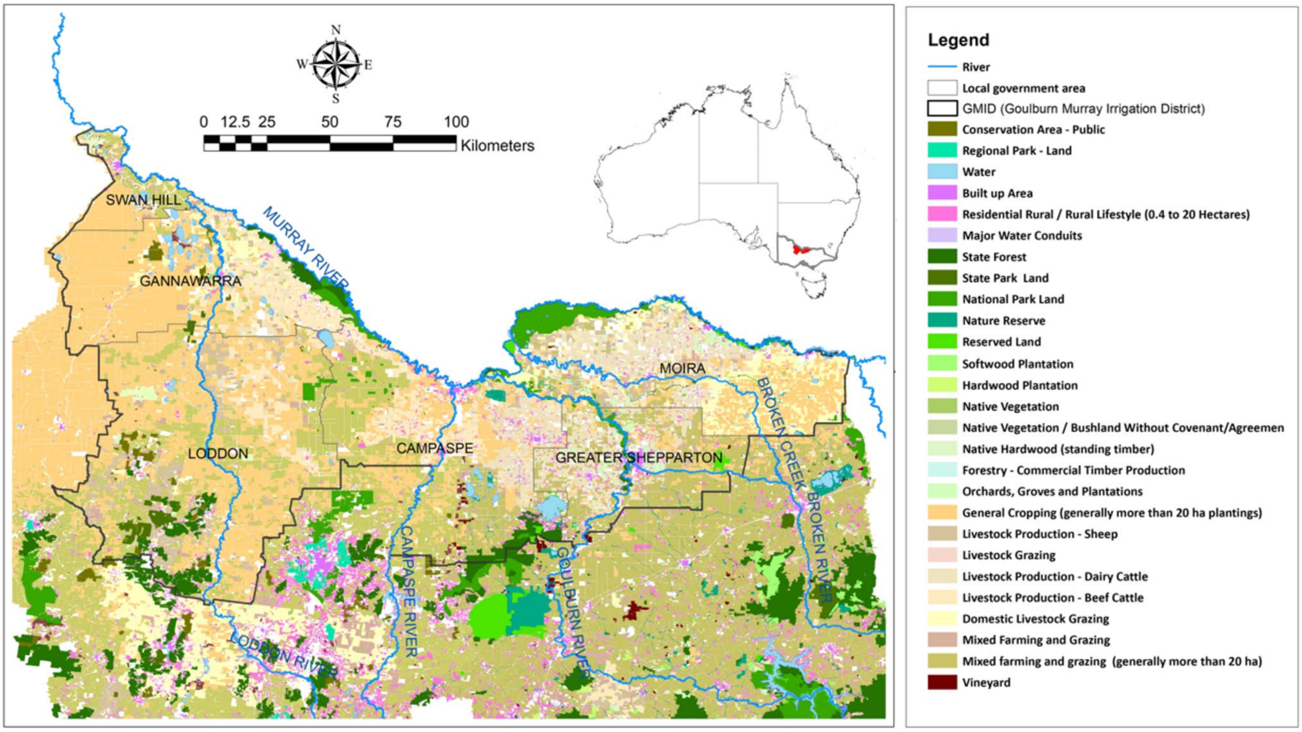

Fig. 1 Land use of the study area. The Goulburn–Murray region is specified with a black boundary. The inset map shows the region location in the context of the state of Victoria, Australia

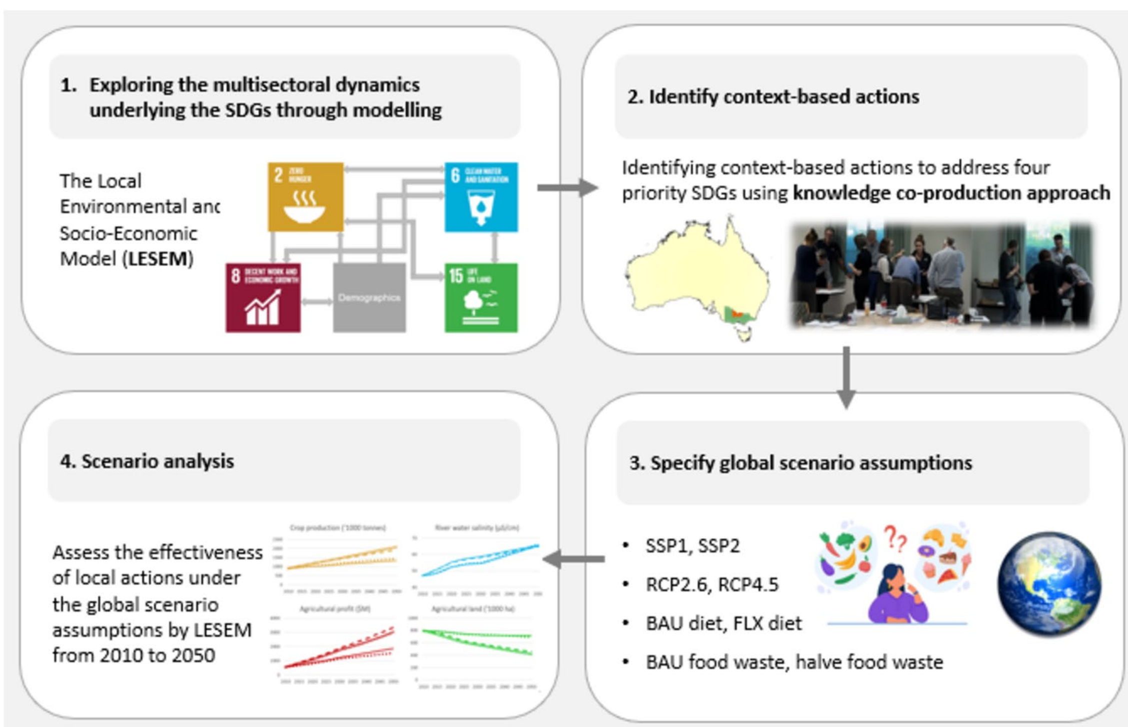

Fig. 2 Overview of methodological steps for implementing local actions under global scenario frameworks using transdisciplinary approaches to local sustainability

Exploring the multi-sectoral dynamics underlying the SDGs through modelling

We employed the LESEM, developed via a participatory approach, with a specific focus on four of the highest priority SDGs in the Goulburn–Murray region: Agriculture (SDG 2), Water Availability (SDG 6), Economic Growth (SDG 8), and Life on Land (SDG 15). These SDGs address socioeconomic development outcomes and environmental impacts. Using LESEM, we modelled priority SDG indicators across four SDGs. The selection of SDGs and their indicators was guided by conducting a comprehensive contextual analysis, which included interviews and workshops with local stakeholders, examination of scientific papers and reports, and review of policy documents (Bandari et al. 2022). The objective was to identify the socioeconomic and environmental issues that held significant importance to the local stakeholders in relation to the SDGs and assess their interactions. The LESEM utilises the system dynamics approach (Sterman 2002) and operates at a local level with an annual timeframe, covering the mid-term to long-term period from 2010 to 2050. The utilisation of system dynamics modelling proves to be a decision support tool for policy-makers and planners. It enables them to analyse local problems through an integrated and holistic lens, ultimately facilitating the pursuit of sustainable development (Moallemi et al. 2021b). By employing system dynamics modelling, policy-makers and planners gain a comprehensive understanding of complex systems and their interdependencies (Bérard et al. 2017). This approach empowers them to make informed decisions, develop effective strategies, and take targeted actions that contribute to long-term sustainability and address interconnected challenges.

In ensuring the credibility of our analysis utilising the LESEM, a thorough validation process was conducted. The model's results under the BAU scenario were validated against historical data, as documented in Bandari et al. (2023). Furthermore, the model development process benefited from continuous engagement with local experts and stakeholders, incorporating their valuable insights to enhance the model's relevance and creditability. Sensitivity analyses, outlined in Bandari et al. (2023), were performed to pinpoint the parameters exerting the most significant influence on the model's behaviour. After recognising model flaws and implementing necessary model modifications, additional rounds of validation were performed. This iterative process allowed us to refine the model, addressing its flaws and leading to a more accurate representation of the system dynamics under investigation for this region. The LESEM consists of seven main sub-models: Demographics, Agriculture, Water Availability, Land Use, Economy, Fertiliser Use, and Water Quality. Further details about the modelling can be found in Bandari et al. (2023). These sub-models capture the essential characteristics and issues of the study area, identified through the knowledge co-production process and contextual analysis. We applied LESEM to simulate and analyse the effects of various local actions under global scenarios to address local concerns regarding water availability, blue–green algal blooms, salinity, land-use change, skilled workforce in agricultural sector, agricultural commodities production, and local economy.

Identifying and parameterising local actions

In addressing the collective sustainability challenges in the Goulburn–Murray region, we have actively engaged in collaboration with the Goulburn–Murray Resilience Taskforce and RM Consulting Group (RMCG). Together, we adopted a comprehensive knowledge co-production approach to better understand the potential impacts of global and local changes on the future of this region. This approach encompassed all steps of the research process, including identifying local challenges and opportunities, co-designing a system dynamics model, devising local actions aimed at advancing four priority SDGs, and analysing results. We conducted three workshops with stakeholders (Fig. 3) where we actively engaged with local experts to identify and understand specific challenges and opportunities.

The first workshop, conducted in March 2022, introduced the project and purpose, discussed how modelling can further the goals of the Goulburn–Murray Resilience, and collected data to inform the model. The Goulburn–Murray Resilience subcommittee members confirmed current regional challenges and aspirations, discussed how the intervention streams align with SDGs, ranked the SDGs according to current priority, and uncovered underlying assumptions to inform modelling. The initial workshop involved 18 local stakeholders representing organisations, such as Murray Dairy, Goulburn Valley Water, the Department of Energy, Environment and Climate Action (DEECA), Agriculture Victoria, Goulburn–Murray Water, Regional Development Victoria, and Goulburn Broken Catchment Management Authority (GBCMA).

In July 2022, Deakin University ran a workshop with a subcommittee of the Goulburn–Murray Resilience Taskforce to develop influential local actions and identify global driving forces that could impact the local sustainability in the future. The subcommittee included ten local stakeholders from organisations, such as GBCMA, North Central Catchment Management Authority, Regional Development Victoria, Goulburn–Murray Water, Goulburn–Murray region action working group, Goulburn Valley Community Energy, and RMCG. A group of local sustainability goals (Table 1) were identified through stakeholder engagement to address four priority SDGs: SDG2 (agricultural activities), SDG6 (clean water and

Fig. 3 Images captured during the knowledge co-production process, featuring the interactions and activities conducted during three workshops held in the Goulburn–Murray region. Permission has been obtained from all stakeholders for including the images above

sanitation), SDG8 (decent work and economic growth), and SDG15 (life on land). These goals were designed to address specific challenges and opportunities within the local context and contribute to achieving the priority SDGs. To further refine these goals, we solicited input from workshop participants regarding the assumption of local actions to be tested, the system parameters they would potentially influence, and the extent of their impact. We specified 11 local actions and assessed their effects on eight SDG indicators. Note that there were implicit assumptions in what is being tested—e.g., increase water-use efficiency by 10% (Table 1). The deliberate choice to focus on eight indicators was intended to establish the groundwork for a more thorough investigation under diverse future uncertainties, addressing immediate gaps and concerns raised by local stakeholders. The selection of specific indicators was meticulously made to mirror the community's priorities, covering crucial aspects, such as water salinity, algal bloom, agricultural productivity growth, agricultural land, and the skilled workforce. The participants engaged in a discussion about the potential scenarios in which the actions might not achieve the desired results. They also determined which actions would be most effective in advancing the aspirations of the region in the short and long term.

In September 2023, Deakin University hosted a hybrid workshop in collaboration with RMCG—both in-person and online—as the concluding session of this project. The workshop was attended by 21 individuals representing diverse organisations and community members. The event was focused on presenting the findings from the modelling phase and discussing about possible futures for the Goulburn–Murray region in 2050. The feedback received was positive, with stakeholders expressing appreciation for the clarity and insights provided by the modelling results. They particularly liked how the model was designed to enhance their understanding of the dynamics and potential outcomes of various local resilience actions. The outcomes of this research and modelling process have been synthesised in the report entitled 'Farming Resilience Futures: Navigating Three Possibilities for the Goulburn-Murray Region' for the Goulburn–Murray Resilience Taskforce. This report explores three potential futures for the Goulburn–Murray region in 2050, offering valuable insights for regional leaders and policy-makers. It has the potential to enhance their understanding of the impacts of different

Table 1 List of local actions, their setting, and examples of detailed on the ground local activities

Local action	Local action setting	Detailed on-ground local activities
Action 1: Improve agricultural productivity	Achieve an annual 2% increase in agricultural productivity	Cultivating drought-resistant crop varieties Embracing agriculture technologies change Managing soil health Implementing pest and weed management Investing in research and innovation Implementing Biosecurity measures
Action 2: Increase water-use efficiency on-farm	Achieve total increase of 10% in water-use efficiency on-farms by the year 2050 (0.25% per year)	Implementing advanced irrigation techniques Adopting precision agriculture technologies Investing in Education and training
Action 3: Increase farm water reuse	Achieve a total increase of 15% in farm water reuse on-farm by the year 2050 (0.375% per year)	Reusing treated wastewater for irrigation or environmental allocation purposes
Action 4: Reduce conveyance water loss	Reduce conveyance water loss by 5% by the year 2050 (0.375% per year)	Modernising infrastructure Lining canals and channels Scheduling and timely maintenance
Action 5: Reduce input costs	Reduce agricultural input costs by 10% via the use of modern technology and promotion of sustainable practices (0.25% per year)	Adopting precision agriculture Managing soil health Integrating pest management Improving energy efficiency Implementing crop rotation and diversification Implementing water management
Action 6: Premium produce growth	Achieve a total increase of 10% in agricultural commodity prices by the year 2050 (0.25% per year) through producing higher quality or premium produce which commands a higher price	Cultivating high-value crop Utilising innovative growing techniques Adopting precision agriculture technologies
Action 7: Increase migration rate	Increase migration rate by 20% by the year 2050 (0.5% per year)	Developing economic opportunities Investing in infrastructure Promoting education and research Affordable housing initiatives
Action 8: Increase birth rate	Increase the birth rate by 10% by the year 2050 (0.25% per year)	Enhancing healthcare access Implementing family-friendly policies Promoting education and awareness Providing housing assistance Establishing community programs
Action 9: Reduce fertiliser application	Reduce fertiliser application by 20% by the year 2050 (0.5% per year)	Adopting precision agriculture Developing nutrient management plans Exploring innovative fertiliser technologies Promoting crop rotation and diversification Providing education and extension services
Action 10: Reduce nitrogen and phosphorous generated from animal manure	Achieve a total decrease of 20% in animal manure and N & P potential loads from dairy shed effluent by the year 2050 (0.5% per year)	Implementing nutrient management plans Utilising manure storage facilities Implementing rotational grazing practices Educating farmers
Action 11: Reduce nitrogen and phosphorous runoff fraction	Achieve a total decrease of 20% in nitrogen and phosphorous loss by the year 2050 (0.5% per year)	Implementing vegetative buffers Employing buffer strips Incorporating cover crops

scenarios on achieving sustainability through the implementation of local resilience actions. The results have also been delivered to the irrigation company Goulburn–Murray Water in an invited presentation to the Board of Directors. The work will contribute to the Board's strategic scenario planning over the next year.

Global scenario assumptions

Our approach involves using both global and local action scenarios to examine different projections of output variables from the perspective of local sustainability and assess their sustainability performance. We characterised global scenarios using two combinations of SSPs (O'Neill et al. 2017; Riahi et al. 2017) and RCPs (van Vuuren et al. 2011). The SSPs and RCPs provided a comprehensive framework for understanding and analysing the potential future scenarios in terms of key socioeconomic and climate driving forces and for characterising global action on sustainability. The SSPs outline different trajectories for future socioeconomic development, offering five pathways encompassing differing levels of climate change adaptation and mitigation, extending until 2100 (O'Neill et al. 2017). The RCPs depict various climate forcing levels that correspond to different potential futures. They offer insights into the potential climate outcomes based on different emissions scenarios and serve as a basis for understanding the range of possible climate futures (van Vuuren et al. 2011).

We characterised two global scenarios: *Global BAU* and *Global ACTION*, and these incorporate assumptions that play a crucial role in shaping future socioeconomic and environmental outcomes for the study area (Table 2). We specified the combination of SSP2 and RCP4.5 for the Global BAU scenario and SSP1/RCP2.6 for Global ACTION. SSP1 and SSP2 were used to estimate food demand based on the gross domestic product (GDP) and population. Temperature and rainfall data were downloaded for RCP2.6 and RCP4.5 using 8 general circulation model estimates from the WorldClim CMIP6 database, and these were averaged to provide

Table 2 List of global scenario assumptions

Global scenario assumptions	Leverage points	Scenario drivers	Description
Global BAU	Food demand	SSP2 BAU diet BAU waste	Food demand under the scenario SSP2-BAU Diet-BAU waste is increasing for all agricultural commodities, including crops, dairy, beef, and sheep by the year 2050 (Table S1)
	Water yield	RCP4.5	According to the projections, the average water yield under BAU scenario (RCP4.5) is projected to decrease by 0.2% annually (Table S5)
	Livestock & crop yield	RCP4.5	Under the BAU scenario, agricultural commodity yields are projected to increase for all agricultural commodities (UNCCD 2017), including both irrigated and dryland commodities by 2050 (Table S3)
Global ACTION	Food demand	SSP1 FLX diet Halve waste	In the context of SSP1-FLX Diet-Halve waste, the demand for FLX products is increasing across various agricultural commodities, except for winter oilseed, summer oilseed, hay (predominantly utilised for non-human consumption), dairy, and beef (Table S2). Notably, the rate of increase in food demand for FLX products in this scenario surpasses that of the SSP2-BAU Diet-BAU waste scenario. In the context of Australia's scenarios, SSP1 exhibits higher population (36.59 million people) and GDP (3130 billion US$2005/year) compared to SSP2, which has a population of 36.03 million people and a GDP of 3008 billion US$2005/year. Interestingly, despite the global population being lower in SSP1 (8459 million) than in SSP2 (9164 million) by 2050, Australia's SSP1 still surpasses SSP2 in both population and GDP. On a global scale, the GDP for SSP1 stands at 244 trillion US$2005/year, while for SSP2, it amounts to 227 trillion US$2005/year by 2050. Despite our expectations of reducing food demand in the scenario SSP1-FLX Diet-Halve waste due to halving food waste, the increase in global GDP and changing the diet to FLX has led to a projected rise in food demand for FLX products
	Water yield	RCP2.6	Based on the projections, the average water yield under scenario RCP2.6 is expected to experience an annual decrease of 0.2% (Table S5)
	Livestock & crop yield	RCP2.6	By 2050, under the RCP2.6 scenario, agricultural commodity yields are predicted to increase for all irrigated commodities and most dryland agricultural commodities, with the exception of dryland beef, dairy, stone fruit, and hay (Table S4). On the other hand, for most agricultural commodities, livestock and crop yields under scenario RCP2.6 are lower compared to scenario RCP4.5, except for irrigated grapes, dryland stone fruit, dryland non-cereal crops, dryland winter oilseeds, and dryland winter cereals. These specific commodities show higher yields in scenario RCP2.6 compared to RCP4.5. In the RCP2.6 (low emission scenario), temperatures are projected to increase by approximately 1.5–2°, while under RCP4.5 (medium emission scenario), temperatures are expected to rise around 2.5–3°

ensemble layers from 2010 to 2050. These layers were then used to calculate potential evapotranspiration using the Priestley–Taylor method (Sharp et al. 2018). Time-series temperature, rainfall, and potential evapotranspiration data layers were combined with a digital elevation model, solar radiation data, and soil data from the Soil and Landscape Grid of Australia to calculate average water yield time series spatial layers at 1 km^2 grid cell resolution under the RCP4.5 and RCP2.6 scenario from 2010 to 2050 using the InVEST model (Sharp et al. 2018). The Global Agro-Ecological Zones (GAEZ) 4 model was applied to quantify the impact of climate change on agricultural productivity and generate the agricultural commodity yield multipliers under the RCP4.5 (BAU) and RCP2.6 scenario compared to the base year of 2010 for various crops, pasture, beef, sheep, and dairy from 2010 to 2050 (Fischer et al. 2021).

Food demand is also a key driver influencing the amount and type of agricultural production in the study area. Food demand consisted of both a diet component (Willett et al. 2019) and a waste component (FAO 2011), and time series demand multipliers were created under the SSP1 and SSP2 scenarios. The total production of agricultural commodities required from the study was calculated using an unpublished panel data time series econometric and gravity model which regresses historical GDP, population and trade relationships with Australian agricultural production. Future Australian production of crops and livestock (including crops used as livestock feed) was projected using this model based on projections of GDP and population under SSP1 and SSP2. Future demand for agricultural production from the study area was then downscaled from this based on the total historical Goulburn–Murray regional production as a proportion of total Australian agricultural production for each commodity. We considered two distinct types of diets: a BAU diet and a Flexitarian diet (FLX), and these change the relative amounts of agricultural commodities demanded. The BAU diet represents the continuation of trends in recent historical conventional dietary preferences. The Flexitarian diet involves predominantly plant-based eating patterns with the flexibility to incorporate animal products in moderation. Finally, we assumed two scenarios of food loss and waste as BAU waste and Halve waste. Reducing the amount of waste under Halve waste means that less total production was required to meet demand (as less is wasted).

Local and global scenario combinations

We combined the Local BAU (Table 3) and Local ACTION scenarios (Table 1) with the Global BAU and Global ACTION scenarios (Table 2), specifying four combinations: Global BAU|Local BAU; Global BAU|Local ACTION; Global ACTION|Local BAU; and Global ACTION|Local ACTION (Fig. 4). In the Global BAU scenario, the model adhered to the Global BAU settings (SSP2_RCP4.5_BAU diet_BAU waste). The Global ACTION utilised the model parameters from the Global ACTION (SSP1_RCP2.6- FLX diet—Halve waste). The scenario SSP1_RCP2.6_FLX diet_ Halve waste referred to the scenario in which we examined food demand under SSP1, the FLX diet, Halve waste, and livestock, crops, and water yield under RCP2.6. On the other hand, the Local ACTION scenario implements Local ACTION by applying each of the 11 local actions parameterised with our stakeholder group. Lastly, in the Local BAU scenario, the model parameters are set based on the BAU trends. By incorporating these four scenarios into our analysis, we aimed to capture a broad range of potential projections and better understand the implications of different future local and global scenarios.

Scenario analysis

After implementing our scenario assumptions (Tables 1, 2, 3, Fig. 4) as specific model parameters, we ran the LESEM for the four scenarios. Our simulations allowed us to evaluate and assess the scenarios based on a comprehensive set of socioeconomic and environmental indicators over time. In our selection process, we identified a total of eight SDG indicators to assess progress towards various sustainability goals (Table 4). In relation to SDG2, the emphasis was on two indicators that measured dairy and crop production. For SDG6, two indicators were considered, reflecting different dimensions of water availability and river water salinity. The SDG8 was examined through two indicators related to economic growth and skilled workforce. Finally, SDG15 was represented by two indicators capturing aspects of environmental conservation through changes in agricultural land and blue–green algal bloom. By selecting these indicators across multiple SDGs, we aimed to gain a comprehensive understanding of progress and challenges in key areas of sustainable development.

Sensitivity analysis

We conducted a sensitivity analysis using the LESEM to examine the percentage change in SDG indicators under Global BAU|Local ACTION scenario compared to SDG indicators under Global BAU|Local BAU. The reference point for comparison was the year 2010. This involved calculating the percentage change in each SDG indicator for the years 2030 and 2050 under the Global BAU. One-by-one, we turned on each local action and compared SDG performance against the Local BAU scenario in percentage terms. The different sectors (i.e., SDGs) within the model have interconnected dynamics, which means that any action implemented in one sector will have ripple effects throughout the entire model.

Table 3 The local BAU scenario assumptions

Parameter	Local BAU settings
Livestock productivity	The livestock productivity, including beef, sheep meat, wool (unit: tonnes/head), and dairy (unit: litres/head) for average of year 2005, 2010, and 2015, as detailed in Table S8
Agricultural commodity yield	The agricultural commodity yields, measured in head/ha for livestock and tonnes/ha for crops, was calculated for average of year 2005, 2010, and 2015, as detailed in Table S9
Water requirement	The water requirement of agricultural commodities (Million litres/ha or Million litres/head per year) for average of year 2005, 2010, and 2015, as detailed in Table S10
Surface farm water reuse rate	Based on historical data from 2015 to 2019, an average surface farm water reuse rate of 0.12 of the total surface water usage across all users was utilised (VSG 2019)
Conveyance water loss	An average conveyance water loss rate of 0.1 of the total surface water storage calculated based on historical data from 2015 to 2019 (VSG 2019)
Migration rate	Based on primary data sourced from the Australian Bureau of Statistics census data, the mean migration rate from 2010 to 2020 stood at 0.00352, representing a portion of the total population in each age cohort (ABS 2022)
Birth rate	Based on primary data sourced from the Australian Bureau of Statistics census data, the mean birth rate is 0.043 from 2010 to 2020 (ABS 2022)
Commodity prices	The commodities in the region were classified into four primary groups, namely crops, sheep, beef, and dairy. We further categorised the agricultural commodities into dryland and irrigated commodities. The irrigated crops comprised 15 crops, including winter cereals, rice, winter legumes, summer legumes, winter oilseeds, summer oilseeds, hay, other non-cereal crops, pears, apples, stone fruit, tropical stone fruit, grapes, vegetables, and citrus. The dryland crops comprised seven crops, including winter cereals, winter legumes, winter oilseeds, hay, other non-cereal crops, stone fruit, and grapes. The commodity prices for base year 2010 is available in Table S6
Input costs	We assumed fixed imputed labour costs (FLC), quantity-dependent variable costs (QC), fixed operating costs (FOC), fixed depreciation costs (FDC), and area-dependent variable costs (AC) for the reference year of 2010 (Table S7) (Navarro & Marcos Martinez 2021)
Nitrogen and phosphorus fertiliser application	Nitrogen and phosphorus fertiliser application (kg/ha) for base year 2010 as detailed in Table S11 (Navarro and Marcos Martinez 2021)
Nitrogen and phosphorus generated with manure per cow	Nitrogen generated per cow is 70 kg per year and phosphorus generated per cow per year is 9 kg per year (GBWQWG 1995)
Total phosphorus and nitrogen generated with manure per sheep	Nitrogen generated per sheep is 10 kg per year and phosphorus generated per sheep per year is 1.5 kg per year (GBWQWG 1995)
Phosphorus and nitrogen runoff fraction in irrigated and dryland areas	Data was gathered pertaining to the runoff fraction from both irrigated and dry land areas, with a particular focus on phosphorus and nitrogen runoff finding its way into rivers and lakes. Based on extensive long-term monitoring data acquired from drained catchments, it has been established that the runoff factor stands at 20% in irrigated areas and 7.5% in dryland areas (GBWQWG 1995)

Results

Scenario realisations

Using the LESEM model for scenario quantification resulted in internally consistent outcomes across seven sub-models and enabled the evaluation of progress towards eight key SDG indicators across four priority SDGs (Fig. 5). The crop production results, indicating progress towards SDG2, revealed that in 2050, the amount of crops produced in Global BAU|Local BAU was 1331 kilotonnes [kt]. This increased to 1442 kt under Global ACTION|Local BAU, 1938 kt under Global BAU|Local ACTION, and 2091 kt under Global ACTION|Local ACTION scenario. In

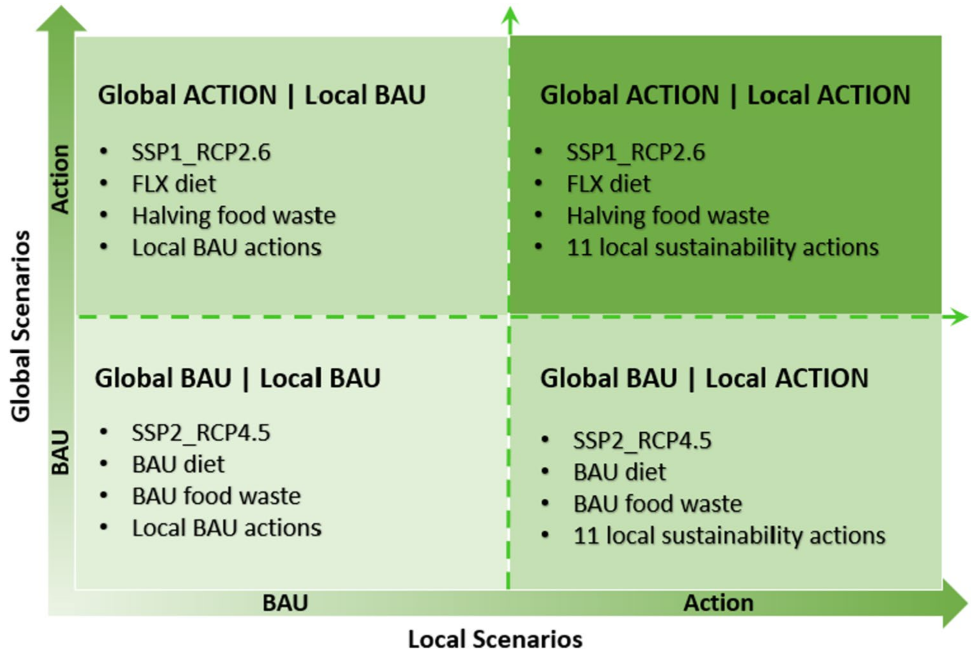

Fig. 4 Scenario specification combining Global ACTION and Local ACTION

Table 4 List of SDGs and related indicators

SDG	Indicator
SDG2. End hunger, achieve food security, and promote sustainable agriculture	Crop production (tonnes year^{-1}) Dairy production (ML year^{-1})
SDG6. Ensure availability and sustainable management of water for all	Net water availability (GL year^{-1}) River water salinity (μS cm^{-1})
SDG8. Promote sustained, inclusive and sustainable economic growth for all	Agricultural profit ($M year^{-1}) Skilled workforce (people year^{-1})
SDG15. Protect, restore and promote sustainable use of ecosystems	Agricultural land (ha year^{-1}) Blue–green algal bloom (units ML^{-1} year^{-1})

the Global BAU|Local BAU scenario, dairy production increased from 1480 ML in 2010 to 1830 ML by 2050. Under Global ACTION|Local BAU, it reached 1236 ML by 2050, showing a decreasing trend due to reduced demand under a flexitarian diet shift. In Global BAU|Local ACTION, dairy production peaked at 2354 ML, reflecting strong global demand for animal-based foods and local efficiency gains. Under Global ACTION|Local ACTION, local actions initially boosted production to 1716 ML by 2031, but the shift towards a flexitarian diet and global actions led to a decline, reaching 1560 ML by 2050.

Under the Global BAU|Local BAU scenario, net water availability (SDG6) decreased from 4350 gigalitres (GL) in 2010 to 3201 GL by 2050. In Global BAU|Local ACTION, a marginal change was observed compared to BAU, reaching 3274 GL by 2050. Similarly, minor differences were observed between the scenarios of Global ACTION|Local ACTION, approximating 3258 GL, and Global ACTION|Local BAU, around 3186 GL. Variations were attributed to water yields under RCP4.5 and RCP2.6, as detailed in Table S5. In the Global BAU|Local BAU scenario, river water salinity (SDG6) rose from 47 μS/cm in 2010 to 66 μS/cm by 2050. The increase resulted from reduced water yield under RCP4.5 and RCP2.6 and heightened food demand, leading to increased agricultural practices. Notably, Global ACTION|Local ACTION and Global ACTION|Local BAU exhibited lower salinity levels than Global BAU|Local BAU and Global BAU|Local ACTION. Despite variations, a convergence towards a common salinity level of approximately 65 μS/cm by 2050 was evident across all scenarios, indicating a consistent trend in water salinity increase.

In the Global BAU|Local BAU scenario, agricultural profit (SDG8) rose from $556 M in 2010 to $1875 M by 2050. Under Global BAU|Local ACTION, it was projected to reach $3351 M by 2050, the highest among all scenarios. The substantial demand for food under the global BAU scenario, especially animal products, and advancements in livestock and crop yield drove this increase. High food demand was perpetuated by BAU food waste under

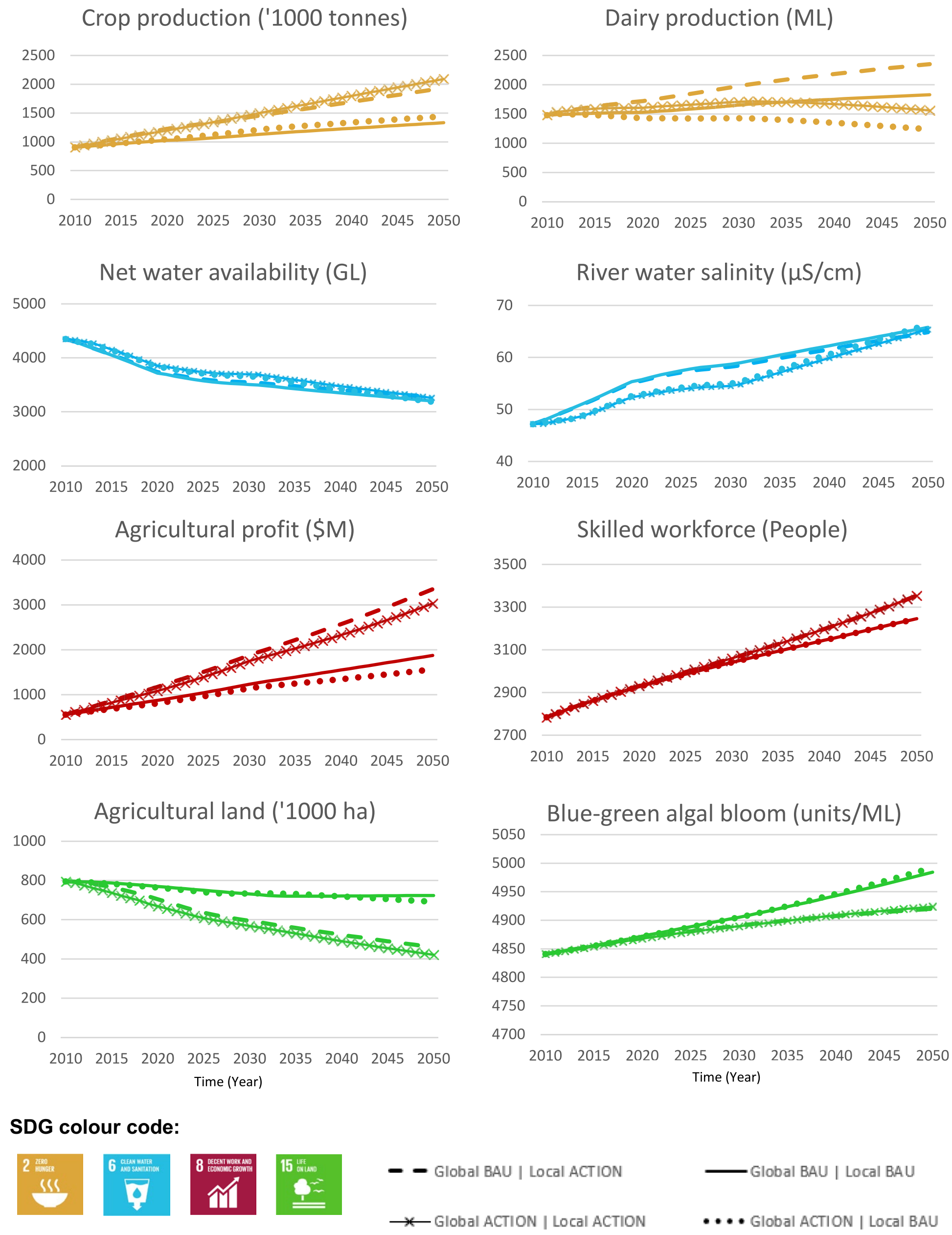

Fig. 5 Projections of eight sustainability indicators under four scenarios of Global BAU|Local BAU, Global BAU|Local ACTION, Global ACTION|Local BAU, and Global ACTION|Local ACTION

SSP2_RCP4.5_BAU DIET_BAU WASTE. In Global ACTION|Local ACTION, projected agricultural profit was approximately $3031 M by 2050, the second highest. Agricultural profit under Global ACTION|Local BAU and Global BAU|Local BAU was lower, with values of $1564 M and $1875 M, respectively, by 2050.

Under the Global BAU|Local BAU scenario, the skilled workforce (SDG8) was projected to increase from 2784 people in 2010 to 3246 people by 2050. Projections indicated a rise to 3354 people under Global BAU|Local ACTION and Global ACTION|Local ACTION, whereas it was projected to be 3246 people under Global ACTION|Local BAU by 2050. The skilled workforce indicator remained unaffected by global scenarios, including Global BAU and Global ACTION. In Global BAU|Local BAU, agricultural land was projected to shrink from 794,000 ha in 2010 to 724,000 ha by 2050. The projections showed a more substantial decrease under Global BAU|Local ACTION and Global ACTION|Local ACTION, reaching 450,000 ha, compared to Global ACTION|Local BAU, projected to be around 691,000 ha by 2050. For SDG15, the blue–green algal bloom, impacting water quality, in Global BAU|Local BAU rose from 4841 units/ML in 2010 to 4984 units/ML in 2050. Projections under Global BAU|Local ACTION and Global ACTION|Local ACTION indicated a minor increase, reaching 4920 units/ML. In comparison, Global

ACTION|Local BAU was projected to be around 4990 units/ML by 2050.

Local action sensitivity analysis

The result of local action sensitivity analysis demonstrated that the most impactful action was agricultural productivity, and this action affected five SDG indicators: agricultural land, agricultural profit, total crop production, total dairy production, and blue–green algal bloom (Fig. 6). Among all SDG indicators, agricultural profit (SDG8) exhibited the highest increase, with a growth of 46% and 35% by 2050 and 2030, respectively. The projections revealed that increasing agricultural productivity was associated with a decrease in agricultural land (SDG15) by 33% by 2050 and 17% by 2030. Additionally, the action of agricultural productivity

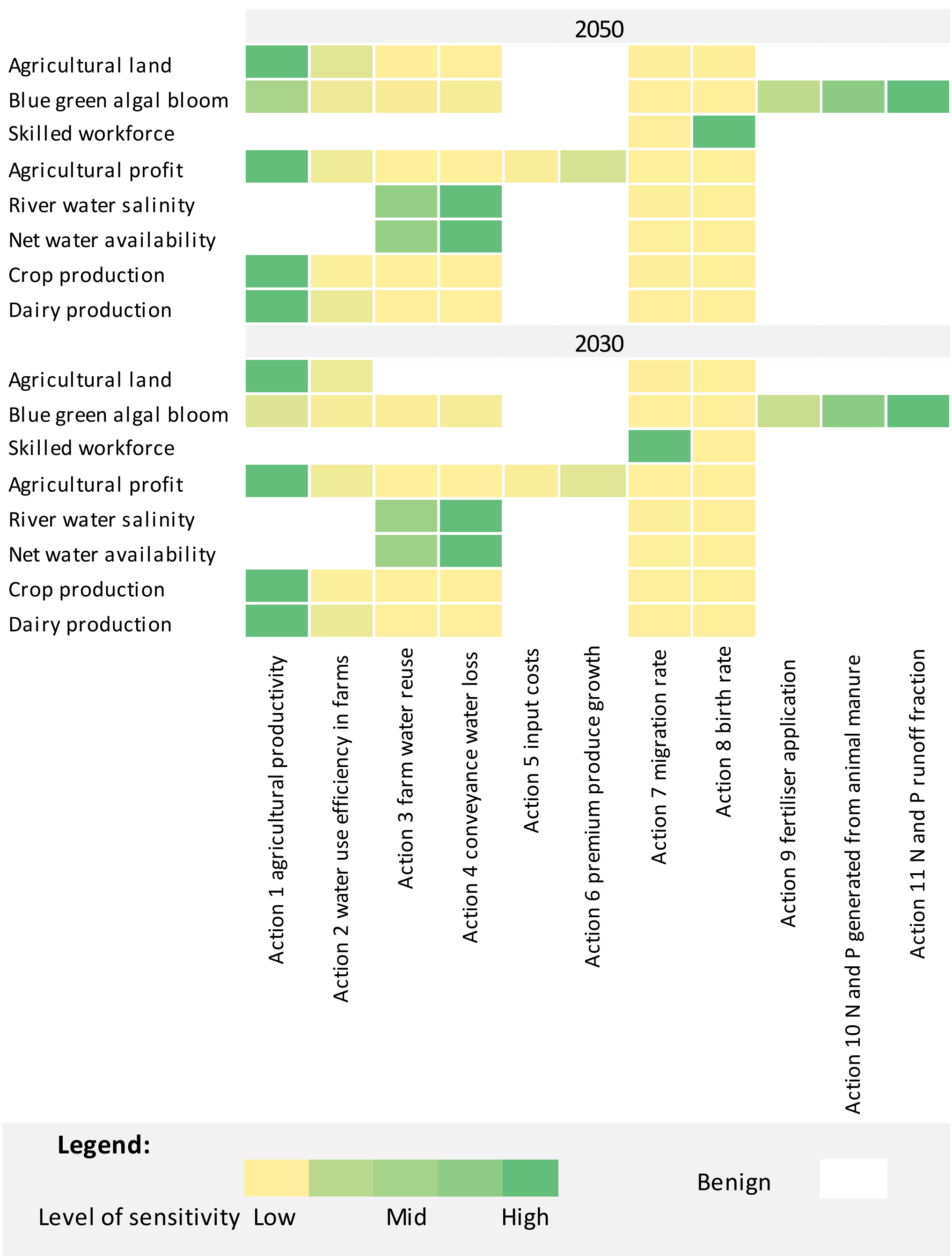

Fig. 6 Sensitivity analysis of SDG indicators under Global BAU|Local ACTION scenarios compared to SDG indicators under Global BAU|Local BAU scenario

had a direct impact on the indicators of total crop production and total dairy production. By 2050, the projections showed an increase of approximately 34% in total crop production and 22% in total dairy production (SDG2) as a result of this action. Similarly, by 2030, there was an estimated increase of approximately 25% in total crop production and 16% in total dairy production. The second most impactful action, Action 6 (commodities price), showed a notable impact on agricultural profit (SDG8) with an increase of approximately 13% by 2050 and 7% by 2030.

Action 2, which focused on enhancing water-use efficiency on-farm, had impacts on multiple SDGs, including total crops and dairy production (SDG2), agricultural land (SDG15), agricultural profit (SDG8), and blue–green algal bloom (SDG15). Our analysis revealed that this action led to a reduction of approximately 7% in agricultural land (SDG15) by 2050 and around 2% by 2030. Actions 7 and 8 had only a slight impact on most of the SDG indicators assessed, indicated their limited influence on the selected indicators. However, these actions exhibited a stronger impact on the skilled workforce indicator (SDG8). Actions 9, 10, and 11 had impacts on the blue-green algal bloom indicator (SDG15). On the other hand, actions 3 and 4 influenced several SDG indicators, including total crops and dairy production (SDG2), net water availability (SDG6), river water salinity (SDG6), agricultural water use (SDG6), agricultural land (SDG15), agricultural profit (SDG8), and blue–green algal bloom (SDG15). Furthermore, the sensitivity analysis was conducted on SDG indicators under the Global ACTION|Local ACTION scenario compared to those under the Global BAU | Local BAU scenario (Fig. S1).

Discussion

We acknowledge the existing rich and well-established resilience and adaptation planning in the region (GBCMA 2013; RMCG 2022; RPG 2020). While existing studies have laid a solid groundwork, our research contributed by assessing both local actions and global scenarios with a system dynamics model (i.e., LESEM as an IAM tool) tailored specifically to the intricacies of the Goulburn–Murray region. This model allowed us to explore a wide range of possible future trajectories and identify key drivers of change. We adopted a transdisciplinary methodology, partnering with local stakeholders who have already been involved in the existing resilience and adaptation planning in the region (RMCG 2022; RPG 2020), to analyse the current dynamics within the Goulburn–Murray system and test proposed resilience actions. We introduced potential future scenarios to enlighten local policy-makers about the implications of various combinations of local and global scenarios pertaining to four key SDGs. Each scale of action serves unique purposes, and in specific SDGs, they share common goals in addressing the diverse array of challenges faced in the pursuit of sustainability. We sought to address a research void by employing a transdisciplinary approach (Moallemi et al. 2020) to guide the development of local sustainability solutions, while enhancing the relevance and credibility of the data sourced from integrated assessment models (Koasidis et al. 2023). The findings offer insights into shaping local sustainability policies amidst global and local uncertainties, while the refined methodologies from this study can equip communities with the tools to harmonise developmental aspirations with resilience strategies in a dynamic future.

Synthesising synergies and trade-offs between local and global action

The Goulburn–Murray region, with its strong agricultural and food production focus (DELWP 2019a), has seen significant changes due to various factors (RPG 2020). Scenario analyses indicated a shift in crop production under the Global ACTION scenario (Doelman et al. 2018). This high demand is influenced by a global economic acceleration and dietary shifts towards a low meat flexitarian diet (UNCCD 2017). Implementing both global and local action resulted in increased crop production. The synergy of global actions, like the increased demand under flexitarian diets, and local initiatives, such as enhanced agricultural productivity (Aither 2019; DAWR 2017), amplified crop production despite the reduction in crop loss and waste. This alignment between local and global sustainability actions also benefits the local region through an expanded agricultural sector. The results highlight the need for proactive global and local measures to boost agricultural productivity, meet global food demand, and promote sustainability.

Dairy is the cornerstone of the region's agriculture (RMCG 2016). Scenario analysis revealed differences in dairy production between the Global ACTION|Local BAU and Global BAU|Local ACTION scenarios. The increase in dairy production under Global BAU|Local ACTION is linked to continued high animal-sourced food demand as per SSP2 (Doelman et al. 2018) and BAU diet, and trend food loss and waste (Alston et al. 2018), while the local action component sees improved farming practices and water-use efficiency contribute to rising dairy productivity to meet burgeoning demand. The Global ACTION|Local BAU scenario sees declining dairy production due to decreased demand and lower productivity and resource-use efficiencies and does not align with the region's dairy-driven economy. This spillover highlights the need for local communities to be aware of the potential influence of cross-scale interactions. To effectively respond to these spillovers, it is essential to incorporate local actions that align with both global and local sustainability goals. The suggestion to incorporate local actions that align with both global and local sustainability goals does not necessarily imply moving away from dairy as a specific action. Instead, it emphasises the need for local communities to consider the broader sustainability implications of their actions. Our results highlighted the vulnerability and sensitivity of certain parts of the system and prudent decision-making would involve diversification and otherwise managing farm business risk. For instance, if the local economy heavily relies on dairy production, the suggestion is to explore sustainable practices within the dairy industry that align with both local economic needs and global sustainability objectives. This could involve adopting more environmentally friendly practices, reducing waste, or diversifying agricultural activities.

Adapting to variable water availability is already integral to the Goulburn–Murray region's agricultural practices (DELWP 2019a; RPG 2020). Given water's pivotal role in agriculture, economy, and the environment, projecting its availability under various future scenarios is crucial for sustainable planning. While local actions offer benefits, they may not suffice in significantly improving net water availability or salinity, stressing the need for broader coordinated efforts and sustainable salinity management (DELWP 2019b). To achieve the SDG6 targets and protect freshwater ecosystems, collaboration between stakeholders, including traditional owners, regional agencies, industry groups, community, and Australian Government is essential, as showcased and outlined by the Goulburn Broken Regional Catchment Strategy (RMCG 2022). Our findings highlighted the importance of multi-level coordination and cooperation for sustainable development, aligning with observations made in various other contexts (DELWP 2019a; Pahl-Wostl 2019).

The economy of the study area is strongly tied to agricultural activities (RMCG 2016). Hence, crafting policies that bolster agricultural profitability is pivotal for local sustainability (RPG 2020). The marked agricultural profit driven by Local ACTION scenario highlights the alignment between region-specific local actions, such as improved agricultural productivity and reduced costs. The agricultural profit increased under both the Global ACTION|Local ACTION and Global BAU|Local ACTION scenarios. However, the trade-offs between Global ACTION|Local ACTION and Global BAU|Local ACTION, particularly in terms of agricultural profit associated with reduced demand for animal-based products under the Global ACTION scenario, were more pronounced compared to the Global BAU scenario. This impact on agricultural profitability in the study area was notable due to its heavy dependence on dairy production (RMCG 2019). Best performance across multiple scales requires harmonising local strategies with global actions (Chassagne 2020). The findings underscored the necessity for strategies that simultaneously enhance the local economy, for example technological changes and diversifying agricultural income through development of agri-tourism opportunities. Embracing technological change increases the resilience of farming enterprises and food manufacturing by enabling them to move up the value chain to higher profitability production. These measures not only contribute to local economic development but also align with broader global sustainability goals, fostering a harmonious relationship between local and global priorities.

The assessment of agricultural land for SDG15 revealed the balance needed between agricultural land development and environmental preservation. Sustainable land-use practices are crucial given how land development impacts biodiversity and landscape (Baral et al. 2014). The projections indicated a more pronounced decrease in agricultural land under the Global ACTION|Local ACTION scenario, as compared to the other scenarios, illuminating the potency and alignment of both global and local actions. The local actions, which might include measures to enhance agricultural productivity or introduce sustainable farming practices, not only bolstered production to meet agricultural targets but also limited the sprawl of agricultural land which is important for environment, as well (Walker et al. 2009). Reduction in land-intensive livestock demand and reduced loss and waste under the Global ACTION scenario also reduced the total amount of land required to meet demand. When global and local sustainability actions align, they not only boost agricultural productivity but also promote sustainable land use, ensuring a balance between development and environmental conservation.

The significant reductions in agricultural land may raise concerns, especially in the context of Jevon's paradox. In the context of Jevons's paradox (Alcott 2005), it is important to note that while the paradox is often associated with increased resource efficiency leading to increased overall consumption, in our study region, the dynamics are more pronounced concerning water use rather than land. This reduction in agricultural land is driven by increased productivity per hectare, enabling the fulfilment of future demand with less land. Additionally, limitations on water extraction play a crucial role, restricting the expansion of irrigated agricultural land due to water scarcity rather than land availability. While Jevons's paradox may apply to some extent in the context of dryland agriculture, this influence is marginal. Factors such as market dynamics, supply outstripping demand, and profitability considerations also play crucial roles in influencing land-use expansion.

Aligning local and global action for achieving the SDGs

In an interconnected world, actions to progress one SDG at one scale or in one region can have spillover effects, influencing other SDGs at different scales or in different regions due to the interlinkages between the 2030 Agenda's goals (Sachs et al. 2020). To truly ensure policy coherence for sustainable development, it is essential to consider all externalities and spillover effects (SDG Watch Europe 2019). Spillovers are influenced by the chosen policies: diverse approaches to achieve an SDG target within an area can result in varying spillover effects (SDG Watch Europe 2019). In response to the need for research that helps local regions identify the spillover effects of their 2030 Agenda implementation (Engström et al. 2021), we showcased how Global Action and Local Action scenarios shape future trajectories, specifically regarding eight local SDG indicators (Fig. 7), and their broader implications for global SDGs. Indeed, there are both trade-offs and synergies involved when considering the implementation of both local and global actions (Moallemi et al. 2020).

Upon evaluating the impacts of local and global actions, we discovered trade-offs associated with the adoption of global actions, such as dietary changes and food waste reduction which caused a decrease in dairy demand. Assessment of agricultural profit and dairy production revealed that these two SDG indicators are influenced by both global and local scenarios. Local actions positively impacted the dairy production and local economy, while global actions in this context had a contrasting effect. Specifically, the shift towards a flexitarian diet, decreasing food waste, and reducing the dairy demand through global actions did not effectively improve the region's economy, mainly due to the significant role of dairy production in the local economy. The decrease in dairy production may not be in line with the aspirations of the local people, who value and rely on dairy farming for their livelihoods and cultural practices (RMCG 2016). Considering potential future global scenarios that might result in reduced demand for animal product foods (UNCCD 2017) or other global sustainability actions conflicting with local benefits, local communities should proactively consider strategies to adapt their agricultural practices, diversify their products, and explore alternative local sustainability actions to be aligned with global SDGs (Ningrum et al. 2023).

The recent report by the GBCMA (RMCG 2022), which focused on four overarching themes including Biodiversity, Community, Land, and Water, specifically identified actions aligned with sustainability goals. They took a systemic approach informed by resilience principles, describing major trends, challenges, and opportunities within those themes. The Goulburn Broken Regional Catchment Strategy also showcased efforts to integrate with other plans and initiatives at different scales, demonstrating local awareness and capacity for cross-scale and cross-sectoral analysis and planning. Being proactive and flexible in responding to evolving circumstances is crucial for achieving long-term Sustainable Development Goals and ensuring resilience in the face of changing global dynamics. By pursuing sustainability approaches that amplify positive effects and diminish negative spillovers, the gap between the 2030 Agenda's global vision and its local implementation is bridged (Engström et al. 2021).

SDG	Indicator	Global ACTION	Local ACTION	Global ACTION + Local ACTION	Local and Global ACTION Interactions
	Crop production	+	+++	++++	Synergy
	Dairy production	----	+++	-	Trade-off
	Net water availability	+	+	++	Synergy
	River water salinity	+	+	++	Synergy
	Skilled workforce	0	++	++	
	Agricultural profit	-	++++	+++	Trade-off
	Agricultural land	+	+++	++++	Synergy
	Blue green algal bloom	-	++	++	Trade-off

Level of effect:

Very Strong Positive Effect: ++++ Strong Positive Effect: +++ Moderate Positive Effect: ++ Mild Positive Effect: +
Neutral Effect: 0
Very Strong Negative Effect: - - - - Strong Negative Effect: - - - Moderate Negative Effect: - - Mild Negative Effect: -

Synergy Trade-off Benign

Fig. 7 Impacts of Global ACTION and Local ACTION scenarios on each SDG indicator

Limitations and future work

We utilised the system dynamics model, LESEM, as a simplified representation of the real-world system, specifically within the Goulburn–Murray context. Although LESEM proved to be a valuable tool for policymaking, further development is needed to encompass a broader range of indicators across all SDGs (Allen 2019). For example, adding energy or circular economy which was suggested by local stakeholders and establishing additional multi-sectoral connections. Parameterisation remains a central challenge in all modelling processes, a task complicated further when addressing systems with societal components (Verburg et al. 2016). In the modelling process, we faced a limitation concerning the model parameterisation and also availability of comprehensive data. We scrutinised the significant uncertainties surrounding various specified model parameters (Bandari et al. 2023). However, we recognised that our study does not encompass all types of uncertainties, particularly those extreme forms characterised by unknown circumstances or a state of complete ignorance, which are inherently unrepresentable in models (Stirling 2010). The trade-off regarding blue–green algal bloom stemmed from the nuanced assumptions within our model. In the 'Global Actions' scenario, which aimed to meet increased global demand, there was not an explicit consideration of direct efforts to limit fertiliser application on a global scale. On the contrary, the 'Local Actions' scenario included specific measures to reduce nutrient inputs (Actions 9–11), potentially leading to a localised decrease in blue–green algal blooms.

As a recommendation for the future, stemming from the engagement activities and knowledge co-production process, we propose testing other global scenarios, such as SSP3, SSP4, and SSP5, to gain a comprehensive understanding of their potential impacts on the sustainability goals. Expanding the range of SDG indicators under each of the four priority SDGs offers a more comprehensive view of progress, potential trade-offs, and allows us to assess interconnections and synergies in sustainable development. Furthermore, we suggest the development of more context-specific and localised actions. This model represents the initial step in quantifying the complex system dynamics of the region. The model and data are entirely open source, allowing the local community to update and build upon this foundation as new data and knowledge become available, uncertainties resolve, and new issues in sustainable development arise.

Conclusion

We used the LESEM system dynamics model to explore potential future trajectories concerning sustainable development in the Goulburn–Murray region of Victoria, Australia. Through the integration of local initiatives and global outlooks, we pinpointed pivotal drivers pertaining to four SDGs, including Agriculture (SDG 2), Water Availability (SDG 6), Economic Growth (SDG 8), and Life on Land (SDG 15). Collaborating closely with local stakeholders via a knowledge co-production approach, we jointly crafted strategies to achieve these SDGs. Our findings underscored the effective influence of local actions such as agricultural productivity and water-use efficiency on priority SDG indicators, simultaneously emphasising the necessity of other complementary synergistic actions, particularly in areas like water resource management, water salinity control, and blue–green algal bloom mitigation. The study's results highlighted the synergies and trade-offs between local and global actions in the pursuit of sustainability. Our results highlighted a strong synergy between global and local initiatives for the majority of SDG indicators. However, specific sectors, such as dairy production, riverine algal blooms, and agricultural profitability, show evident trade-offs. Our methodology is deeply rooted in an inclusive knowledge co-production with local stakeholders bolstered the credibility of our data from the LESEM system dynamics model. This research emphasised the application of system dynamics modelling for scenario projections and assessing the intricate interactions between sustainability goals, and represented a valuable addition to existing research in the Goulburn–Murray region. As a result of our research, local communities are now better equipped with a new quantification of the magnitude and direction of impacts across various priority sustainability indicators. By the results of modelling and future scenarios, we aimed to enhance community awareness and advocate for resilience policies that align with both local and global sustainability goals. Crucially, the data suggested the imperative of crafting policies that cater to both local and global requirements for a sustainable future. For instance, by amplifying agricultural productivity, implementing efficient water management strategies, and mitigating agricultural expenses, we can usher in advancements in food production, economic prosperity, and ecological balance, benefits that have the potential to resonate on a global scale.

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Declarations

Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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