Prioritising Sustainable Development Goals, characterising interactions, and identifying solutions for local sustainability

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Abstract

The United Nations 2030 Agenda brings a holistic and multi-sectoral view on sustainability via the Sustainable Development Goals (SDGs). However, a successful implementation of this agenda is contingent on understanding the multiple, complex interactions among SDGs, including both synergies and trade-offs, for informing planning for sustainability at the local level. Using a case study in the Goulburn-Murray region in Victoria, Australia, we prioritised global goals and targets for the local context, characterised the interactions between them, analysed the main synergies and trade-offs, and identified potential policy solutions to achieve local sustainability. We identified the five highest priority SDGs for the region as clean water and sanitation (SDG 6), agricultural activities (SDG 2), economic growth (SDG 8), climate action (SDG 13), and life on land (SDG 15). Across these five priority SDGs and their 45 targets, we found 307 potential interactions, of which 126 (41%) were synergistic, 19 (6%) were trade-offs, and 162 (53%) were benign. We highlight the most salient trade-offs, particularly how unsustainable agricultural practices could negatively affect water resources, the environment, and sustainable economic growth. Also, critical ongoing uncertainties like climate change, local policies on environmental water recovery, international markets, and emerging new technologies could pose risks for the future of agriculture and the economy. Our results provide important insights for local and regional sustainability policy and planning across multiple sectors. Our methodology is also broadly applicable for prioritising SDGs and assessing their interactions at local scales, thereby supporting evidence-based policy-making for the SDGs.

Keywords

Agriculture; water; local sustainability; SDG; synergy; trade-off.

1. Introduction

The United Nations Agenda 2030 for Sustainable Development, signed by all UN Member States, consists of 17 goals and 169 targets representing shared environmental, social, and economic aspirations commonly referred to as the Sustainable Development Goals (SDGs). The 2030 Agenda was adopted to tackle a wide range of challenges and risks for humanity to achieve prosperity and well-being for all (UN 2015). With less than one decade left to achieve the SDGs and implement the 2030 Agenda, the UN called this period the "decade of action" and committed to mobilise financing, enhance national implementation, and bolster local action (UN 2019). However, implementing this agenda strongly depends on capitalising on synergies and reducing trade-offs among SDGs (Kroll et al. 2019; Pradhan et al. 2017).

Although, the SDGs are intended to be implemented as an 'indivisible whole' (UN 2015), planning in a resource constrained context (ICSU 2017) necessitates the prioritisation of those SDGs and targets which are more important and have higher impacts in the region. Hence, it is essential to analyse interactions among priority SDGs to bring about opportunities for transformative action across sectors as evidence of complex SDG interaction mounts (Alcamo et al. 2020; Bryan et al. 2019; Scharlemann et al. 2020). Analysing goals and targets in isolation and ignoring potential interactions can lead to adverse impacts on the overall fulfilment of the goals (Pradhan et al. 2017) and result in incoherent policies where adverse impacts of development policies in some sectors spillover to other sectors (Blanc et al. 2017). For example, using coal to ensure access to energy (SDG 7) in Asian nations can exacerbate climate change (SDG 13) and acidify the oceans (SDG 14) along with increasing air pollution (SDG 3) (Nilsson et al. 2016). Institutional barriers and the individual interests of each organisation, specifically around crucial topics such as food and agricultural activities, water, poverty, health, and energy, can impede collaborations among organisations when implementing the SDGs. Pan-institutional interventions and policies are needed to advance multiple SDGs and avoid the unintended consequences of isolated sustainability efforts.

Studies are increasingly focussing on assessing the interactions among specific SDGs (IGES 2017; Mainali et al. 2018; Van Soest et al. 2019; Weitz et al. 2014). A preliminary exploration was conducted by mapping interactions between SDG 14 (i.e., life below water) and other SDGs (Blanc et al. 2017; Singh et al. 2018). Fuso Nerini et al. (2017) undertook a qualitative study based on published evidence around interactions between SDG 7 (i.e., affordable and clean energy) and other SDGs. UN (2017) developed a comprehensive methodology to assess relationships between clean water and sanitation (SDG 6) and other SDGs using a systems thinking approach. A report by the International Council for Science (ICSU 2017) evaluated key interactions between the targets of SDG 2 (i.e., zero hunger), SDG 3 (i.e., good health and well-being), SDG 7, and SDG 14 with other SDGs using a seven-point scale, without accounting for geographical context. McCollum et al. (2018) conducted a systematic assessment between SDG 7 targets and other SDGs by reviewing energy-related literature and assessing context dependencies. In addition to these studies, Nilsson (2017) discussed SDG interactions between SDG 1 (i.e., no poverty), SDG 2, SDG 3, SDG 5 (i.e., gender equality), SDG 9 (i.e., industry, innovation and infrastructure), and SDG 14 with other SDG targets, focusing on important interactions between the targets of six selected goals rather than all interactions.

Some studies have taken a more comprehensive approach to assessing SDG interactions, focusing at the global (Pradhan et al. 2017) and national scales (Weitz et al. 2018). Weitz et al. (2018) analysed SDG interactions in a cross-impact matrix in Sweden and selected two targets per goal before applying network theory and systems analysis to determine the most influential targets. Pradhan et al. (2017) quantified synergies and trade-offs at global and national scales within and among goals by using SDG indicator data.

Kroll et al. (2019) further analysed trends in future interactions among projected SDG indicators to 2030 by using global SDG indicators between and within the goals. Network analysis and SDG indicators at the national level were used to analyse interactions among some SDG targets (IGES 2017). Blanc (2015) analysed interactions among all SDGs at the global level using network analysis. Van Soest et al. (2019) showed how Integrated Assessment Models can assess synergies and trade-offs among SDGs at the global scale. Herrero et al. (2021) highlighted the potential trade-offs and unintended spatiotemporal consequences of agricultural and food system technologies on multiple the SDGs. Gao and Bryan (2017) used a detailed land-use model to assess the interactions between land-sector SDGs for Australia, finding that multiple SDGs were unlikely to be met due to the inherent trade-offs between socio-economic and environmental objectives.

Although the results of these studies are comprehensive in terms of SDG coverage, they have concentrated on global and national scale interactions, with few studies assessing the nature and characteristics of SDG interactions at the local level. Focusing on local scales is important, as the UN and the scientific community have emphasised that robust actions at the national level should emerge from effective local sustainable development frameworks (Patole 2018; UN 2015). Advocating a similar approach, Nilsson et al. (2016) discussed how "differences in geography, governance and technology make it dangerous to rely on generalised knowledge", highlighting the need to interpret SDGs according to local and sub-national contexts. Moallemi et al. (2019) argued that bottom-up actions, supported by local stakeholders (e.g., local authorities, communities and cities), can pave the way for a *Local Agenda 2030* with the aim to align sub-national contexts with the global agenda and capture synergies and co-benefits between national (and even global) aspirations and the specific needs and priorities of local communities. Local grassroots initiatives could therefore provide opportunities to accelerate progress towards the SDGs (UN 2020). Given the diversity of local conditions (Moallemi et al. 2020), limited budgets, and resource constraints in implementing the SDGs (ICSU 2017), governments and local authorities need to focus on those SDGs with the strongest effects on the prosperity and well-being of people and nature. The prioritisation of SDGs and assessment of their interactions needs to be tailored to the specific conditions of local areas.

In this study, we prioritised SDGs and assessed the interactions among their constituent targets at the local scale through an evidence-based and context-specific assessment of sustainability. As a case study, we analysed SDG interactions in the Goulburn-Murray region in Victoria, Australia, a nationally important area for agricultural production with implications for regional and national sustainability. SDGs were first prioritised using a contextual analysis of key local strategic documents and studies identified with stakeholders. We then conceptualised SDG interactions using a scoring methodology based on a set of evaluation criteria. We focussed on target-level SDG interactions to enable more specific interpretability for policy and planning. We identified positive interactions (i.e., synergies) among targets that can be capitalised upon to achieve the 2030 Agenda. We also identified negative interactions (i.e., trade-offs) indicating challenges in achieving the SDGs, which should be avoided and managed. We discussed potential for capturing synergies and mitigating trade-offs between SDGs via a range of specific management and policy solutions. This study provides a comprehensive view for local policy makers to understand the multiple impacts of specific policy solutions, to take advantage of potential synergies and avoid unintended consequences of sustainability solutions. Our results highlight how local authorities can give effect to the 2030 Agenda by implementing efficient policies and targeting limited budgets on local priority SDGs and their interactions and guiding local sustainability planning across sectors.

2. Methods

The methods included three stages: data collection; defining local priority SDGs, targets, and interactions; and interaction analysis (Figure 1). In the first stage, we collected relevant data for our case study through interviews with local stakeholders and through contextual analysis of key literature. In the second stage, we defined priority SDGs, targets, and identified the most relevant interactions via contextual analysis of documents. In the interaction analysis, we explored the nature of each interaction from the collected documents, evaluated the interactions, and highlighted how implementing specific goals and targets may affect other goals/targets by scoring the effects against semi-quantitative evaluation criteria. Finally, we synthesised the main synergies and trade-offs among priority interactions and discussed potential solutions to achieve local sustainability.

<Insert Figure 1 here>

2.1. Study area

We focused on the Goulburn-Murray region in Victoria, Australia, as a case study. The Goulburn-Murray region is located adjacent to the River Murray in the north of Victoria, covers six local government areas: Moira, Greater Shepparton, Loddon, Campaspe, Gannawarra, and Swan Hill (Figure 2). This region is regarded as Australia's food bowl with extensive cropping, livestock production, and horticulture (GMIDWL 2018). The region hosts the most extensive area of irrigated land in Australia and provides significant employment opportunities, generating more than 10,000 jobs and more than $6 billion worth of agricultural production value each year (GMW 2018; Goulburn-Murray Water 2018; VPA 2019). The main source of revenue in this region is irrigated dairy production. Agriculture and the economy of the Goulburn-Murray region have been significantly impacted by recent economic, policy, and environmental change including climate change, reduced commodity prices, water reform policy, highly variable water prices, drought and variation in water availability, and volatile international markets. The effect of these combined challenges to sustainability makes the region an ideal case study for downscaling and assessing SDG interactions at the local scale.

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2.2. Data Collection

2.2.1. Local contextual analysis

The contextual analysis aimed to capture tacit knowledge to derive interactions among priority SDGs and their targets using a combination of interviews with local stakeholders and a comprehensive review of locally relevant literature including published papers, reports, and policy documents (Szetey et al. 2021a; Szetey et al. 2021b). We attended the Goulburn-Murray Region Action Working Group Meeting in Tatura in May 2019 to identify relevant documents through interactions with the panel of local experts. With the Working Group we assembled a list of published and unpublished historical information; strategic, policy and planning documents; and scenario framing activities. Working Group participants also provided information regarding

other available resources related to the Goulburn-Murray area. Furthermore, we identified selected scientific and grey literature documents relevant to Goulburn-Murray through a snowball procedure. Our documents are mostly related to (1) sustainable development (water, irrigation, agriculture, energy, health, education, gender equality, economic growth, employment, inequality, local community, sustainable consumption and production, climate change, environment, biodiversity, and land degradation), (2) planning (strategic, scenario, management), and (3) local context (e.g., Goulburn-Murray, Murray-Darling Basin, local councils).

These documents included 33 published papers and 93 reports and books (Table C.1) by agencies and organisations in Victoria and Australia such as the Department of Environment, Land, Water and Planning (DELWP), the Murray Darling Basin Authority (MDBA), the Goulburn Broken Catchment Management Authority (GBCMA), the North Central Catchment Management Authority (NCCMA), Goulburn-Murray Water (GMW), the Department of Economic Development, Jobs, Transport and Resources (DEDJTR), the Department of the Environment, Water, Heritage and the Arts (DEWHA), and local shire councils.

2.2.2. Interviews with targeted local stakeholders

We conducted a series of 42 face-to-face semi-structured interviews with targeted local community members, stakeholders, business leaders, industry representatives, and representatives from government agencies in the Goulburn-Murray region (Table 1) to assess the local socio-economic and environmental situation, the relative competitive and comparative advantages of the region, and the possible future opportunities in the Goulburn-Murray. A list of potential participants was developed in collaboration with the Department of Environment, Land, Water and Planning (DELWP) and the Goulburn-Broken Catchment Management Authority (GBCMA), focusing mostly on individuals who had engaged in focus groups and community meetings regarding the need for adaptation and change in local industries and the economy. Additional participants were added via a snowball process as those from the initial list suggested others. Interviews were sought (unsuccessfully) with representatives of the indigenous communities and additional Members of Parliament. Ethics approval was acquired from Ethics Advisory Group. Discussion was prompted via broad questions about the challenges to environmental and socio-economic sustainability in the region specifically around water resources, agriculture, and other industries; opportunities for enhancing future prosperity and wellbeing; and the timeframe, feasibility, and obstacles to the implementation of these opportunities (Table A.1). Participants' responses were collated anonymously and were synthesised to identify a short list of potential opportunities and challenges for sustainable development in the region.

<Insert Table 1 here>

2.3. Defining local priority SDGs, targets, and interactions

We prioritised SDGs and targets for the region by performing a computer-aided review of the literature. For the contextual analysis, we assessed all relevant documents (i.e., 42 interview transcripts, 33 published papers, and 93 reports and books) with the software package NVivo Pro 12 (QSR International Pty Ltd 2018). Through Nvivo, we reviewed the documents and coded and extracted the main concerns and challenges aligned with SDGs across 17 goals and 169 targets (contextual analysis). We identified statements related to each SDG, then coded that content manually by assigning statements to relevant SDGs. As a first stage, we searched abstracts to find statements relevant to each of the 17 SDGs. Some statements were only

associated with one SDG, while others were related to multiple SDGs. For papers and reports where finding statements related to the SDGs in abstracts and summaries was challenging, in addition to abstracts, we also reviewed other parts of the documents (e.g., conclusion) and in some cases the entire documents for relevant statements. Through this review and manual coding process, the priority SDGs were identified from those with the highest number of coded documents.

We complemented these results by analysing word frequency (i.e., a text-mining method) in the same database of documents to better understand SDG priorities. We automatically counted word frequency through all documents using Nvivo Pro 12 software and used this information to generate a word cloud. We associated each word in the word frequency results to the relevant SDGs. Some of these words may be associated with one or more SDGs. For example, the word “water” was associated mostly with SDG 6 and SDG 15. We excluded generic words that can be associated with multiple SDGs (e.g., management, development). This word cloud enabled the visualisation of the most important priorities and concerns in the study area and was used to validate our detailed review and manual coding of the documents.

Interactions among SDGs may be more meaningfully determined via targets as they tend to be more specific than goals (Weitz et al. 2018). Therefore, we conducted the contextual analysis first at the goal level, then at the target level. Relevant targets under each SDG were selected using a screening process to reflect the importance of those targets, their relevance to the Goulburn-Murray region and the level of concern expressed in the literature about those targets. The results of this analysis were a set of local priority SDGs and related targets. We then identified the most relevant interactions for the study area and compiled evidence (i.e., collecting quotations) for each interaction by assessing the relevant documents and evaluating the nature of SDG and target interactions.

2.4. Interaction analysis

Interactions among SDG targets can be categorised as synergies (positive interactions) or trade-offs (negative interactions). Synergies imply that progress in one target also advances progress towards another target, while trade-offs imply that progress in one target hinders progress in another target (Kroll et al. 2019). Nilsson et al. (2016) introduced a seven-point scoring methodology to characterise interactions among SDG targets, ranging from cancelling (-3), counteracting (-2) and constraining (-1) as negative scores, to enabling (+1), reinforcing (+2) and indivisible (+3) as positive scores. A score of consistent (0) is given when two targets do not interact with each other (Table A.2). We applied this Nilsson scoring methodology to assess all linkages between priority SDG targets. Our analysis focused on the direction of influence between goals and targets rather than assessing the achievement of certain quantitative targets or threshold as few definitive statements addressed the achievement of specific thresholds.

In addition to scoring interactions, we used two criteria, namely *evidence* and *confidence*, to evaluate our characterisation of interactions against the literature (Table A.3). We provided supportive statements for scores derived in the contextual analysis as evidence and additionally brought in our own interpretation. These supportive statements were used as evidence and mostly obtained from policy reports and published papers. We analysed the effectiveness and validity of statements in the contextual analysis according to the quality, type, year of publication, and number of literature sources for each interaction. Evidence scores were 'limited', 'medium', and 'robust'. The relevance of information in each source depended on the type of document (e.g., published literature, grey literature, interviews with stakeholders, and internet content).

The confidence evaluation criterion reflected the extent that we believed that our subjective score for each interaction would remain the same if given by others ('low', 'medium', or 'high'). We checked the consistency

between evidence and robustness of evidence, then characterised confidence in the scores assigned for each interaction. Then, to derive an integrated perspective, we mapped how priority SDG targets could interact and create synergies or trade-offs in the Goulburn-Murray region. We constructed a heat map of priority SDGs and targets according to the scores assigned to each interaction. We also represented the interactions among priority SDGs in a network diagram to synthesise the main synergies and trade-offs.

3. Results

3.1. Identifying local priority goals, targets, and interactions

The contextual analysis resulted in a shortlist of priority SDGs and sustainability concerns in the Goulburn-Murray region (Figure 3). The five most frequently coded SDGs across all documents were SDG 6 (i.e., clean water and sanitation; 103 documents), SDG 2 (i.e., agricultural activities; 80 documents), SDG 15 (i.e., life on land; 73 documents), SDG 8 (i.e., decent work and economic growth; 65 documents), and SDG 13 (i.e., climate action; 43 documents). Furthermore, the highest numbers of pairwise SDG interactions across all documents were between SDG 15 and SDG 6 (54 documents), SDG 8 and SDG 2 (49 documents), SDG 6 and SDG 2 (42 documents), SDG 13 and SDG 6 (23 documents), and SDG 8 and SDG 6 (20 documents). We uploaded coded statements to an online repository.

<Insert Figure 3 here>

Word frequency analysis represents the frequency of the top 55 words (Table B.1) within all documents used in word cloud (Figure 4). Word frequency analysis corroborated the priorities identified from the manual literature coding, finding the priorities to be water management, rivers, catchment management, groundwater, and salinity (SDG 6); agriculture, irrigation, farming, and rural production (SDG 2); climate change, resilience, and adaptation (SDG 13); environmental risks, flood, ecosystems, forests, wetlands, and biodiversity (SDG 15); and economy, industry, and investments (SDG 8).

<Insert Figure 4 here>

We added a listing of the targets with a reason for exclusion or inclusion of each one (Table C.2). From a total of 45 targets under these five goals, we refined our selection to 29 targets in the five priority SDGs for analysis (Table C.2). In the context of the Goulburn-Murray, some SDGs or targets may be a lower priority at the current time, but it may change in the future. For example, increasing food production for export to other Australian regions or international markets, or increasing sustainable agricultural activities would be given higher priority over ending hunger (target 2.1) or poverty (SDG 1), or sanitation and hygiene (target 6.2) in the study area.

3.2. Evaluating interactions among Sustainable Development Goals

3.2.1 Target-level interactions

We found 841 interactions among targets (29 × 29), but we quantitatively scored 307 interactions and assessed the level of evidence and confidence in scores assigned for each interaction (Table C.3). We identified 126 synergistic interactions (i.e., 41% of total interactions between priority targets), 19 trade-offs (6%), and 162 benign (53%) interactions among targets for the five priority SDGs (Figure 5). By assessing the robustness of evidence and identifying the lack of knowledge among all interactions, we found robust evidence for 52% of target interactions, medium evidence for 45%, and limited evidence for 3%. Furthermore, high confidence was assigned to 42% of all target interactions, medium confidence to 54%, and low confidence to 4%.

<Insert Figure 5 here>

3.2.2 Goal-level interactions

To understand synergies and trade-offs among SDGs at the goal level, we visualised interactions from the heat map with a network of interactions between priority SDGs (Figure 6). Considering all interactions, our analysis indicates that synergistic interactions among the targets of the five priority SDGs outweigh trade-offs. We highlighted the main trade-off and synergy interactions for SDG implementation by identifying 20 synergies and eight trade-offs among the targets of the five priority SDG goals.

<Insert Figure 6 here>

We focused on the top seven interactions (i.e., three trade-offs and four synergies) among the SDG goals by contextualising them and bringing quotations from relevant documents (Table B.2 and Table B.3) to focus the main trade-offs and synergies in this region. Three trade-offs and four synergies among the five priority SDG goals were selected according to the highest count of trade-offs and synergies among their target interactions. A notable example is SDG 2 (Agricultural activities) which is associated with the highest count of trade-offs across SDGs 6 (Clean water and sanitation), 8 (Economic growth) and 15 (Life on land). In particular, we identified 4 trade-offs between SDG 2 (Agricultural activities) and SDG 6 (Clean water and sanitation), 5 trade-offs between SDG 2 (Agricultural activities) and SDG 15 (Life on land), and 4 trade-offs between SDG 2 (Agricultural activities) and SDG 8 (Economic growth) (Table B.2). For example, implementing some of the targets of SDG 2 (Agricultural activities) is an impediment to implementing some of the targets of SDG 6 (Clean water and sanitation) and SDG 15 (Life on land).

In addition, our analysis indicates that top four synergies are mainly between SDG 6 (Clean water and sanitation) and SDG 15 (Life on land; 20 synergies), SDG 2 (Agricultural activities) and SDG 8 (Economic growth; 16 synergies), SDG 13 (Climate action) and SDG 6 (Clean water and sanitation; 13 synergies), and SDG 6 (Clean water and sanitation) and SDG 2 (Agricultural activities; 10 synergies) (Table B.3). For example, SDG 6 is mainly correlated with synergistic co-benefits among other SDGs and implementing water related

SDG targets can benefit life on land (SDG 15), agricultural activities (SDG 2), and consequently bring economic development (SDG 8) for this region.

4. Discussion

We have presented a practical approach for prioritising, analysing, and contextualising SDG interactions at the local scale to inform sustainability policy and planning. Our results identified SDG interactions in the Goulburn-Murray region in Victoria, Australia, that can allow policy makers to evaluate the implications of single-sector actions and help develop multi-sector solutions to limit trade-offs and capture synergies among SDGs. We identified a shortlist of priority SDGs aligned with the needs and concerns of the Goulburn-Murray region, which was derived from relevant documents and interviews with targeted local stakeholders. We also uncovered the major trade-off and synergy interactions of primary importance to five priority SDGs. We analysed the nature of interactions between priority SDGs and targets using a scoring methodology and assessed them with two evaluation criteria (evidence and confidence), and mapped interactions to demonstrate trade-offs and synergies among sectors.

4.1. Priority goals and interactions in the Goulburn-Murray

In this research, the high number of synergies compared to the trade-offs indicates potential opportunities in the Goulburn-Murray region to leverage synergies and overcome trade-offs among SDGs for successful local implementation of the global 2030 Agenda. However, despite the low number of trade-offs, we acknowledge that some may have strong and pervasive effects that need to be identified and assessed.
Here, we discuss these main interactions among the priority SDGs with enough evidence and confidence which are also critical for achieving local sustainability. Regarding interactions or targets with low evidence and confidence, we were not able to expand on all aspects of those interactions. Hence, while the interaction remains according to our judgment, they were assigned low confidence scores. As an example, easy access to markets and proper functioning of food commodity markets (i.e., Target 2.c) may lead to the expansion of irrigated agriculture and increased agricultural productivity, but this may also lead to deforestation (i.e., Target 15.2). This issue is not widely discussed in the documents and interviews.
The Goulburn-Murray region has been prone to extreme climate and weather conditions and natural hazards such as drought and flooding (e.g., settlements located on floodplains include Shepparton, Tatura, Euroa, Nagambie, and Seymour (Aither 2019)), as well as long-term climatic warming and drying trends. The effects of climate change (SDG 13) have exacerbated uncertainty about water availability and quality (SDG 6), which can significantly constrain agricultural activities (SDG 2) and affect the environmental health of water-dependent ecosystems (SDG 15) (DELWP 2019). Available water has declined by almost 50% over the last 20 years (RPG 2020). In addition to the effects of climate change, increased competition for water across the Murray-Darling Basin and water policy reforms by the Australian federal government (i.e., shifting water from agricultural use to environmental use (SDG 15)); have affected water availability in the Goulburn-Murray region. Increasing agricultural production is strongly dependent on water. Hence, variability in water availability could be a threat to the economy of the region (SDG 8). Climate change could further trigger increases in salinity, turbidity, and nutrients. Extreme droughts may trigger toxicants and pathogens, with high risks for environmental uses (DELWP 2019). Strengthening resilience and capacity to adapt to climate change impacts (SDG 13) could mitigate related environmental issues (SDGs 15 and 6).

Another set of interactions was observed between agricultural activities (SDG 2) and their effects on clean water and sanitation (SDGs 6) and life on land (SDG 15). Boosting agricultural activities (SDG 2) may create potential trade-offs and affect water quantity and quality, changing the condition of water-related

ecosystems (SDG 6) and triggering land and natural habitat degradation (SDG 15). Soil health (SDG 15) is a constraint on the region's agriculture (SDG 2). Increasingly intensive agriculture over the last 150 years has caused severe structural issues in soils, especially in the subsoil (NCCMA 2016). To meet the demands of domestic and global agricultural markets, it will be necessary to improve soil health and subsoil structure while increasing soil carbon, which has declined significantly in the region (NCCMA 2016).

The clearing of native vegetation to cultivate food crops and produce livestock (SDG 2) has also been a key contributor to the disruption of aquatic ecosystems, impacting the condition of water resources, salinity and degradation of both soil and water resources (SDG 6 and SDG 15), causing reductions in the productive capacity of crop yields throughout the region (Aither 2019). Pesticides and fertilisers applied in agricultural activities, organic livestock waste and other waste from plantation crops are major causes of groundwater and surface water contamination and damage to soil health (NCCMA 2016). Grazing animals and pasture production cause erosion and sediment transport, with negative impacts on water quality (Hubbard et al. 2004). Sustainable agricultural practices could mitigate trade-offs between agriculture (SDG 2), water (SDG 6) and environmental (SDG 15) sectors with improvement to soil health and water quality, thereby bringing long-term economic benefits (SDG 8) for the Goulburn-Murray region.

Balanced development is therefore necessary to increase agriculture while protecting and restoring ecosystems. SDG 2 (Agricultural activities) created influential interactions affecting native vegetation and biodiversity (SDG 15). Biodiversity condition (SDG 15), especially in forested areas, has been declining in this region. The native vegetation extent is a critical attribute of biodiversity and while there has been progress in improving the condition of biodiversity in this region, many species are at risk of extinction mainly because of a loss of habitat and ongoing threats (e.g., pest plants and animals) (GBCMA 2016b). Also, recent trends have shown that the long-term target of increasing native vegetation by 70,000 hectares is below what is needed to be achieved by 2030 in the Goulburn Broken catchment (GBCMA 2016b).

Some SDGs showed interactions between their targets. For example, literature on the region unanimously agreed that sustainable development in the agricultural sector (target 2.4) requires significant water-use efficiency improvement (target 2.a). The Shire of Moira in the north-east of Victoria is one example where there is a need to manage threats to water security and meeting water demand through enhancing efficiency, although the impact of the rebound effect and reductions in return flows on water availability should be considered (MSC 2018). Using appropriate policies to enhance water-use efficiency can foster the synergy between SDG 2 and SDG 6 and consequently bring long-term economic benefits with effects on SDG 8.

Another interaction was observed between SDG 2 and SDG 8. The combination of lower-value primary production in the form of dairy farming and high water prices resulted in ongoing challenges for the region's economic sustainability. Dairy production costs have increased in recent years, but financial returns have not changed much. High prices and low allocations of water to dairy farms and pastures in 2019–2020 caused a negative cash flow, affecting the agricultural (SDG 2) and economic (SDG 8) sectors. Many farmers have a cultural attachment to dairy, rather than switching to higher-value agricultural systems with improved water-use efficiency. Although dairy is a large industry in this region, a shift to higher value production systems compatible with variable water availability will be necessary to ensure financial profitability and economic sustainability. High prices for agricultural land in the Goulburn-Murray compared to other regions along with typically small farm sizes, policies reducing water availability, and legacy assets deterring investors from investing capital led to subdued rates of economic return and growth (Downie et al. 2019).

Over recent years, labour demand (SDG 8) and rural populations have been declining as a result of expanding farm scales along with increasing automation and novel technologies in agriculture (SDG 2) (RPG 2020). Another issue relating to agriculture in the Goulburn-Murray is rural population ageing and a reduction in the number of farmers from younger generations, which could threaten future food production (GBCMA 2013). An ageing population and rural depopulation combined with stagnating labour productivity and variability in available water (Aither 2019) along with reduced commodity prices and periodic high water prices could have long-term impacts on economic outputs (SDG 8). This could potentially have knock-on effects on the agricultural sector, especially the dairy industry.

4.2. Policy implications

SDG implementation barriers can have many causes such as opposition from key stakeholders, limited budgets, inadequate human resources, a lack of transparency in responsibility for implementation, and a lack of collaboration between governments and other actors (Weitz et al. 2018). Insufficient knowledge of SDG interactions is also one of the key SDG barriers that we have addressed in this article. This can lead to a lack of coherence between policies, spillover effects of development policies from one sector to other sectors, missed opportunities for synergistic co-benefits, and diverging outcomes in achieving sustainable development (Blanc 2015; Mainali et al. 2018). For example, government policies to increase food and agricultural production (SDG 2 and 8) with limited environmental protection measures have led to consequences in several other sectors such as water reduction (SDG 6), loss of biodiversity (SDGs 14 and 15), and land degradation (SDG15) (Bryan et al. 2008).

The results of this study can benefit policy making and avoid inappropriate policies across sectors. Policy makers in Goulburn-Murray can use the results to trace potential synergies and trade-offs to improve policies by considering interactions. For example, target 2.3 recommends doubling agricultural productivity and incomes of the small-scale food producer. By evaluating Figure 5, we find that with the individual implementation of policies related to target 2.3 (increasing agricultural production), we will face increasing challenges in relation to other targets (e.g., water quality and water-dependent ecosystem protection). We also propose potential solutions which were mostly extracted from local interviews and other policy documents to foster these synergies, tackle trade-offs, and build resilience in the region and align with the global Agenda 2030.

Our results demonstrate how inappropriate policies for gaining economic benefits in the agricultural sector (SDG 2) can create trade-offs for water (SDG 6) and the environment (SDG 15). Sustainable agricultural practices could mitigate potential trade-offs with improvements to soil health and water quality by reducing pollution, thereby bringing long-term economic benefits (SDG 8) for the region. For example, potential solutions include improving soil health by using organic fertilisers to supplement synthetic fertilisers. Nonetheless, the overuse of fertiliser (synthetic or organic) and runoff into waterways would remain a problem which impacts SDG 6 and SDG 15. Hence, the timing and amounts of fertiliser application needs to be appropriately managed, enhancing the proportion of perennial species in pastures, adopting minimum tillage practices to limit unnecessary cultivation, and using appropriate grazing strategies (GBCMA 2016a). Also, another potential solution would be to fence and restore riparian buffer zones to reduce pollutants entering waterways, along with increasing habitat, biodiversity benefits, and waterway health (NCCMA 2018). As another example, focusing on value-add to agriculture or high value crops rather than broad-acre commodities might be a way to reduce land degradation from unsustainable agricultural practices and make the environmental and water related goals more achievable without affecting (or even improving)

agricultural productivity and profitability. However, this recommendation requires some pre-conditions (e.g., agency coordination, high security and reliability water, and community water demand adjustment) as perennial crops are highly dependent on water availability.

Adopting policies to increase agricultural production without promoting agricultural technologies and developing research (e.g., new irrigation technologies and growing drought-resilient crops) could result in water competition and trade-offs between the water and agricultural sectors. Sustainable agricultural activities as an alternative policy could create a balance between the economic benefits of agriculture and protecting ecosystems (ICSU 2017). We acknowledge Goulburn-Murray Water's (GMW) $2 billion Connections Project which ensures the sustainable future of productive agriculture in this region and could mitigate the potential effects of climate change (SDG 13) on life on land (SDG 15), water (SDG 6) and agricultural (SDG 2) sectors. Despite significant efforts in the region to ensure the sustainable future of productive agriculture, mitigating the Murray Darling Basin's alarming environmental condition requires major ongoing reform to reduce total water allocations, and promote additional water-saving measures and new farming practices (Norman 2019) to achieve water saving targets in the future.

Changing the traditional cropping pattern to high-value crops per hectare/mega-litre could be an effective policy for agriculture (SDG 2), water (SDG 6) and the economy (SDG 8). For example, the profitability of farming enterprises or products could be increased by cultivating crops with the opportunity to process raw products into oils or other niche products. The Goulburn-Murray region currently accounts for the most valuable export dairy commodities which could be affected by domestic and international markets such as Asia (GVWRRG 2017). The region could also focus more on international market needs especially on demand for fresh fruit from Asia (NCCMA 2016), the production of high-value products, and post-processing of agricultural production to complement current industries and achieve SDG 2 and SDG 8. This would require the development of new product lines, supply-chain logistics, and reform of political relations between governments.

Other proposed solutions focus on the development of high-value production practices such as glasshouse production, protected cropping, and permanent fruit plantings such as the recent increase in planting new apple and pear varieties for export markets. Glasshouse production (SDG 2) is appropriate for improving water-use efficiency (SDG 6) but is dependent on technology and technical expertise. Glasshouse production could benefit market-driven exports and produce fruits and vegetables. There are opportunities for both fresh and processed products such as nuts, plums, olives, citrus, pears, prunes, and apricots. Suggested crops also include corn, grapes, tomatoes, brassicas, chillies, zucchini, eggplant, and broccoli (Downie et al. 2019). It is necessary to adopt appropriate policies and regulatory structures to encourage transformation in the Goulburn-Murray region to develop enterprises with high-value production, with benefits for SDG 2, 8, 6, and 15. Furthermore, developing policies to link the agricultural sector to agri-tourism or aquaculture production for animal feed could diversify farming incomes to maintain economic productivity (SDG 8). Tourism could bring significant income to the region and reduce reliance on agricultural activities (SDG 2).

Adopting incentive policies such as land aggregation and scaling to enhance the attractiveness of land parcels for large-scale investors and facilitate the investment process are likely to be profitable ways to achieve SDG 8, SDG 2 and some targets under SDG 6 and SDG 15. However, aggregating land parcels will force those smallholders out of business who often struggle financially leading to negative spillover effects on human aspects of sustainability, e.g., reducing poverty (SDG1) and inequality (SDG10). Development of industry precinct(s) to coordinate investment in value-adding to agricultural/food/industrial produce could also

contribute. By planning effectively and building social licence about the types and areas suitable for new development, costs for the agricultural sector could be decreased by sharing access to water, renewable and low-cost energy, high speed internet, and access to markets.

4.3. Innovation and contribution

Our work builds on existing studies by prioritising SDGs according to local area needs rather than focussing on global or national levels (Fuso Nerini et al. 2017; ICSU 2017; Mainali et al. 2018; Singh et al. 2018; UN 2017). Previous studies have presented a comprehensive quantitative assessment of SDG interactions using SDG indicators (Kroll et al. 20 19; Pradhan et al. 2017). We built on these assessments by assessing interactions between goals and targets tailored to a local context. This qualitative richness includes characterising interactions at a finer level by collating multiple sources of information for each interaction.

This approach can be broadly applied to other local areas as it allows for the identification of priority SDGs and the main interactions using contextual analysis of related literature and interview with local stakeholders. This approach can support policy making with a high degree of confidence and transparency, leading to more coherent policies which promote synergies and limit trade-offs across the SDGs, and ultimately achieve a better, more holistic implementation of the 2030 Agenda. Although our outcomes are context dependent, our results among some SDG interactions enhanced the knowledge base of SDG interactions and could help bring a common understanding of interactions that is applicable to other areas.

4.4. Limitations

The Goulburn-Murray region is a strategic area for both state and federal governments and it has been the subject of many planning, scientific, and strategic investigations, creating a rich source of data and literature for the region. We did not undertake a comprehensive assessment of all available documents via a systematic literature review due to the vast amount of material involved. Instead, we used a local participatory approach using local expertise to target those documents which are critically important for the local stakeholders to achieve the best local results.

The evaluation of the vast number of documents assessed in this study can be inevitably impacted by potential biases in the scoring approach. Biases in scoring could be reduced by having multiple people score the interactions. However, this was simply not possible this due to the very large amount of work involved in scoring many goals, targets, and interactions. This is a challenge when working with interactions because they increase exponentially as additional SDGs and targets are considered. However, we do not believe that this limitation would have had a material effect on the results and conclusions because we also mitigated this bias and uncertainty and made it explicit by scoring confidence levels. A future research could rescore the interactions between targets in our article to verify and expand the outcomes.

There was often no clear-cut boundary between targets. SDG targets can be broad, span different sectors and can overlap each other. For example, target 6.6 (“protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes”) and 15.1 (“ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands …”) significantly overlap each other. Although in most of the interactions, the confidence criteria were directly affected by the evidence criteria, in some cases there is uncertainty about the assigned scores. In addition, some evidence was relevant to more than one interaction, but we generally looked to find the most relevant interaction for allocating each evidence score.

We acknowledge that the prioritisation of some SDGs, while essential for targeting scarce management resources and investment, may reduce the focus on other SDGs and this might be perceived against the UN's intention of the SDGs as an indivisible whole. However, we emphasise that such prioritisation should not exclude or diminish other goals and sustainability issues which are currently perceived to be less urgent or less threatened locally. Also, interventions and actions that achieve co-benefits for other SDGs or at least do not adversely affect them should be preferred.

5. Conclusion

The SDGs provide a holistic framework for trade-off analysis with a balanced representation of different priorities as they cover 17 goals and 169 targets spanning society, economy, and environment. The priority of these goals and targets can, however, change at the local scale due to their relevance to the local region and the local availability of resources. We prioritised SDGs at the local level and characterised their interactions for informing policy and planning as a critical step in achieving sustainability in the Goulburn-Murray study area. Our results highlighted SDG 6 (Clean water and sanitation), SDG 2 (Agricultural activities), SDG 8 (Economic growth), SDG 13 (Climate action), and SDG 15 (Life on land) as highest priorities. We found more synergies than trade-offs among priority SDGs and their constituent targets. We discussed policy solutions that leverage synergistic interactions and limit the trade-offs for the successful implementation of priority SDGs. Our results highlighted that the Goulburn-Murray region is subject to ongoing changes in climate, agricultural commodity prices, international markets, and water policy reforms that may impede the achievement of the SDGs. Most trade-offs related to SDG 2 (Agricultural activities) and SDG 8 (economic growth) were associated with unsustainable agricultural or economic activities. Our analysis indicated that SDG 13 (climate action) and SDG 15 (life on land) were linked to other SDGs with only synergistic co-benefits. SDG 6 (Clean water and sanitation) was also mostly related to others through synergistic co-benefits. Understanding interactions among SDGs and targets is essential for local policy makers to achieve policy coherence to fulfil multiple SDGs and to minimise side-effects. Although our results are context-dependent, our practical approach is transferable to other areas for assessing local sustainability though the lens of the SDGs and provides a simple and reproducible methodology for assessing SDG interactions.

Supplementary material

Supplementary material associated with this article was provided for methods and results.

Data availability

The datasets generated during this study are available from http://dx.doi.org/10.17632/bv9cpw7tyn.1. Further information and requests for resources and reagents should be directed to and will be fulfilled by the corresponding author.

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Tables

Table 1. Description of participant organisation representatives and individual interviewees.

Groups or individual participant
• Agribusiness executive
• Industry research and development representative
• Irrigation industry group representative
• Various industry group representatives including farming, dairy and fruit growing
• Farmers in the dairy, fruit growing and horticulture industries
• Regional consultants
• Regional partnership board member
• Government council board members from multiple jurisdictions
• Farmer advocacy group representative
• Representative of water services committee
• Financial and economic consultant
• Investment broker
• Corporate strategist
• Water provider representatives
• Business development manager
• Representative in the management of environmental water
• Local council/shire representatives (Victorian and NSW)
• Catchment management agency representatives (past and present)
• Water consultant
• Water trading consultant
• Media business representative
• Public service representatives – state (NSW, VIC) and federal
• Project manager
• Member of Parliament
• Higher education institution representative

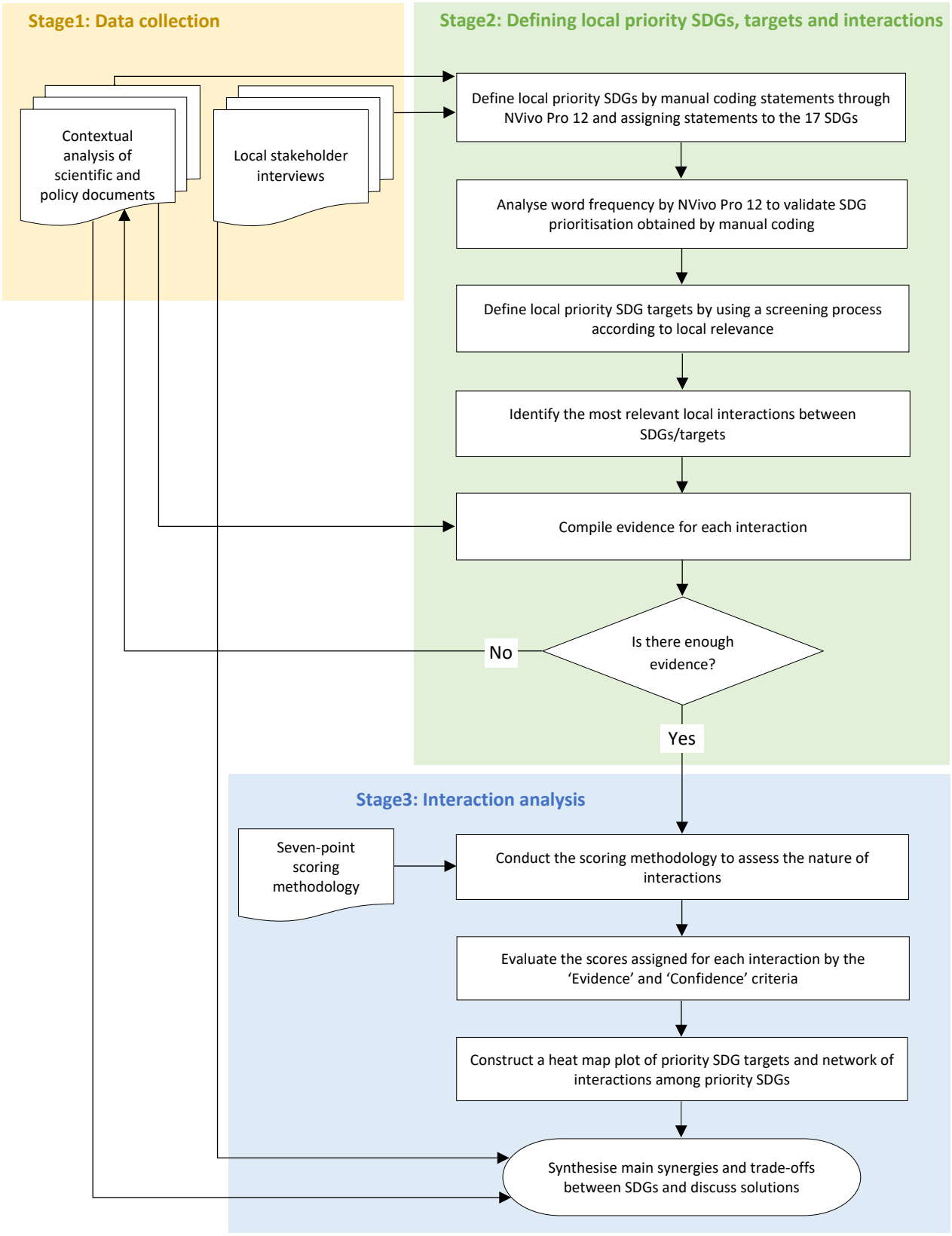

Figure 1. Overview of the methods used to prioritise and map interactions among local priority SDGs and targets. Our judgment of 'enough evidence', was mainly qualitative and based on our understanding of the quality of available evidence (i.e., documents) for a given interaction between SDG targets/goals (e.g., the explicit mention of SDG interactions would constitute strong evidence) and whether the available evidence was sufficient support discussion of the given interaction.

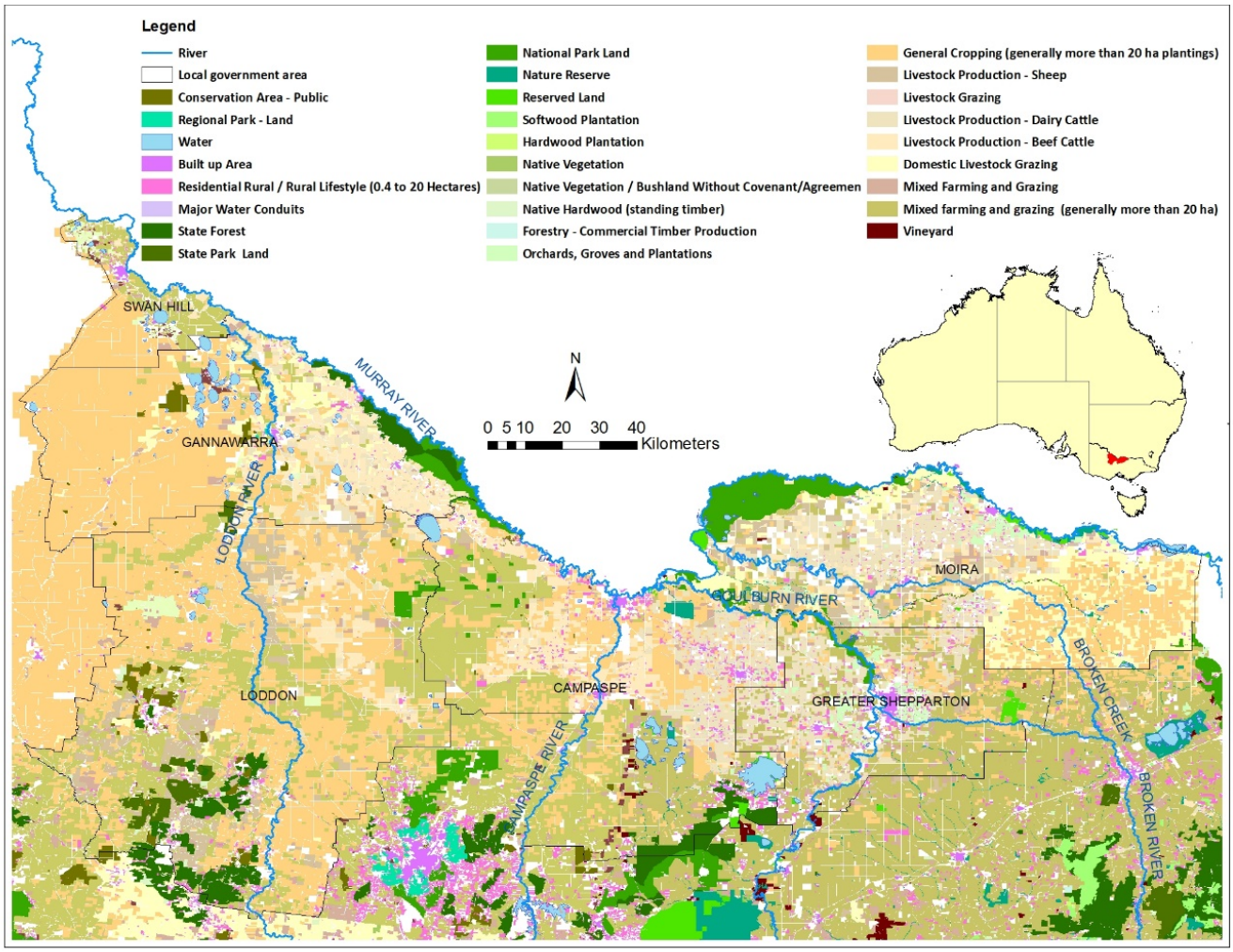

Figure 2. Map of land-use in the Goulburn-Murray in Victoria, Australia, (source of the land use shape file: land.vic.gov.au). Colours should be used for this figure in print.

SDGs	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
SDG 1: No Poverty	0																
SDG 2: Zero Hunger	0	80															
SDG 3: Good Health and Well-Bing	0	1	6														
SDG 4: Quality Education	0	1	1	5													
SDG 5: Gender Equality	0	0	0	0	2												
SDG 6: Clean Water and Sanitation	0	42	1	0	0	103											
SDG 7: Affordable and Clean Energy	0	0	0	0	0	1	4										
SDG 8:Decent work and economic growth	0	49	1	1	0	20	0	65									
SDG 9: Industry, Innovation and Infrastructure	0	6	0	0	0	6	0	8	23								
SDG 10: Reduced Inequalities	0	0	0	0	0	0	0	0	0	6							
SDG 11: Sustainable cities and communities	0	1	0	0	0	1	0	1	1	0	16						
SDG 12: Responsible Consumption & Production	0	3	1	0	0	10	2	1	0	0	0	21					
SDG 13: Climate Action	0	10	0	0	0	23	0	5	2	0	0	0	43				
SDG 14: Life below Water	0	0	0	0	0	0	0	0	0	0	0	0	0	1			
SDG 15: Life on Land	0	22	0	0	0	54	1	10	2	0	1	8	12	1	73		
SDG 16: Peace, Justice and Strong Institution	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	15	
SDG 17: Partnerships for the Goals	0	2	0	0	0	2	0	3	1	0	1	0	0	0	2	1	17

Figure 3. Heat map of the number of documents coded through contextual analysis for the 17 Sustainable Development Goals and their interactions. Colour scale from white (0, no documents) to dark green (103 documents). The diagonal of this matrix shows the number of documents relevant to only one SDG. Off-diagonal cells display the number of documents relevant to two SDGs. Colours should be used for this figure in print.

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786 **Figure 4.** Word frequency analysis in the selected literature. Font size is indicative of word frequency.

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Figure 5. Heat map of 29 Sustainable Development Goals targets and their interactions in the Goulburn-Murray region. See Table C.3 for a definition of interaction scores, here displayed with a colour scale and see Table C.2 for description of each target. For each interaction, evidence is shown in the top circle and confidence in the bottom circle. Blank cells indicate interactions not assessed in this study. Note the matrix is not symmetrical along its diagonal. The heat map matrix is not symmetrical along the diagonal, as some interactions were unidirectional. For example, target 2.3 (doubling agricultural productivity) affected target 6.3 (water quality), and target 6.3 affected target) 2.3 (i.e., bidirectional interaction). On the other hand, target 2.4 (Agricultural activities) affected target 6.3 but target 6.3 did not affect target 2.4 (i.e., unidirectional interaction). Colours should be used for this figure in print.

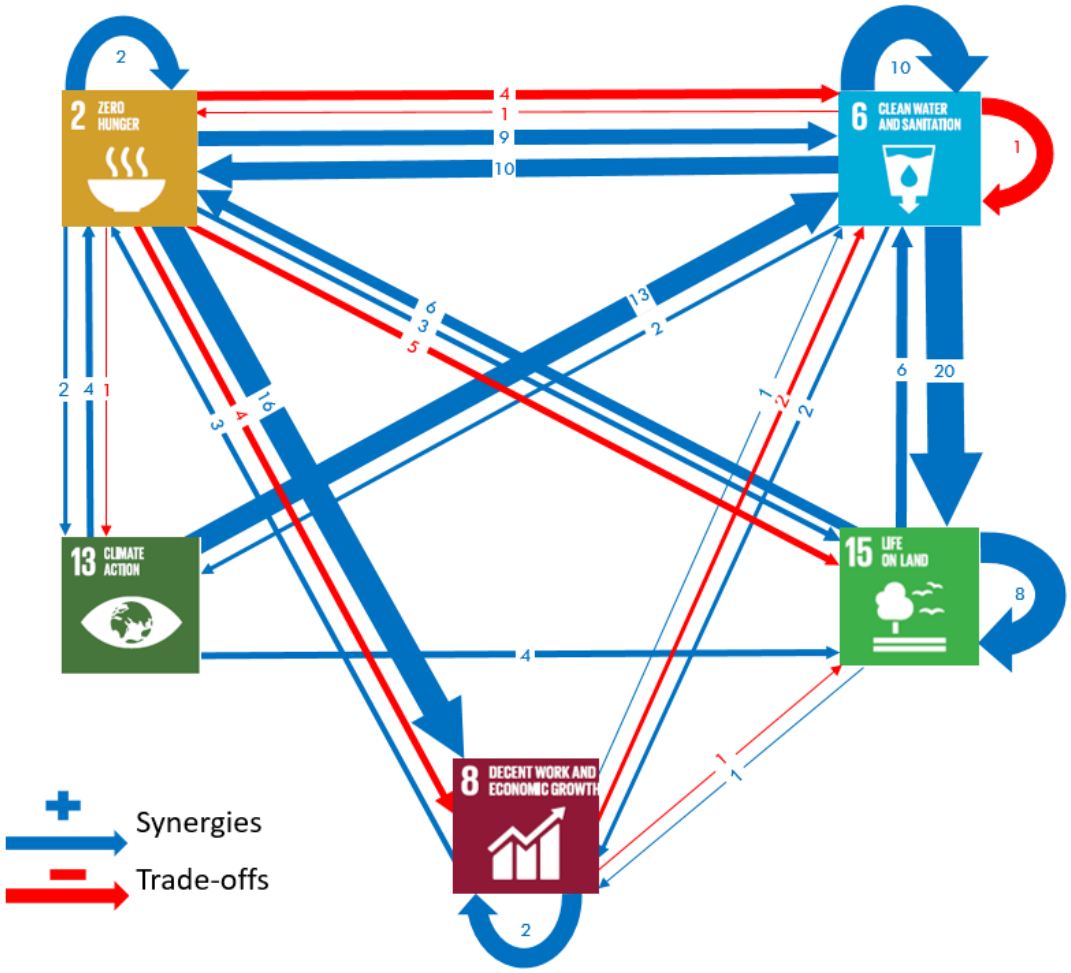

Figure 6. Network of interactions among priority Sustainable Development Goals (SDGs) in the Goulburn-Murray region. Each priority goal is a node that connects with other goals via blue (synergies) or red (trade-offs) arrows. Arrow thickness denotes the strength of links (i.e., number of target interactions) between two goals. Loop arrows show how one target can also (synergies or trade-offs) impact other targets under the same SDG. The SDGs icons are the courtesy of the UN SDGs communications material. Colours should be used for this figure in print.