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Greater gains for Australia by tackling all SDGs but the last steps will be the most challenging

Cameron Allen[1*], Graciela Metternicht[1], Thomas Wiedmann[2,3] and Matteo Pedercini[4]

The Sustainable Development Goals (SDGs) combine complex interlinkages, future uncertainty and transformational change. Recent studies highlight that trade-offs between SDG targets may undermine achievement of the goals. Significant gaps remain in scenario frameworks and modelling capabilities. We develop a novel approach nesting national SDG scenario modelling within the global Shared Socioeconomic Pathways, selecting Australia as a use case. The integrated SDG–Australia model is used to project four alternative scenarios that adopt different development approaches. Although we find that Australia is off-track to achieve the SDGs by 2030, considerable progress is possible by altering Australia's development trajectory. A 'Sustainability Transition' scenario comprising a coherent set of policies and investments delivers rapid and balanced progress of 70% towards SDG targets by 2030, well ahead of the business-as-usual scenario (40%). A focus on economic growth, social inclusion or green economy in isolation foregoes opportunities for greater gains. However, future uncertainty and cascading risks could undermine progress, and closing the gap to 100% SDG achievement will be very challenging. This will require a shift from 'transition' to 'transformation'.

The Sustainability Development Goals (SDGs) are an ambitious results-based framework with a broad scope, future time horizon and transformational perspective. Of concern is that the comprehensive scope and inherent tensions and trade-offs among SDG targets will undermine their achievability[1,2]. Several studies have explored these interlinkages using a range of systems analysis tools, from qualitative systems mapping[3,4], to semi-quantitative matrix or network analysis[5–11], to quantitative dynamic modelling[12–15]. Given their capabilities for handling complexity and uncertainty, scenario analysis and modelling have become important approaches for informing sustainable development[16,17] and national SDG implementation[18,19].

Advances in global scenario analysis frameworks and modelling capabilities include the recent development of the Shared Socioeconomic Pathways (SSPs) for human development[20–23]. Although the SSPs comprise five different global futures serving as reference scenarios for other studies[20], their application has mostly been at global/regional scales[22,24,25]. Limited studies apply the SSP framework at the national level[26–28], and the SSPs fail to address the majority of SDG targets quantitatively[29].

Recent modelling studies confirm challenges for the simultaneous achievement of multiple SDG targets;[13,14] however, the scope of such studies remains limited, focusing on a reduced set of inter-related targets. Assessment of SDG interactions across a broad range of targets in different country contexts, as well as national adaptation of global scenario frameworks, remain important research gaps that need to be addressed to facilitate national SDG implementation.

This paper presents a use case of integrated scenario modelling (iSDG–Australia model) combined with a context-based SDG evaluation framework to explore the performance of different development scenarios (see Methods). Our approach nests a business-as-usual (BAU) scenario and four alternative national scenarios: (1) 'Growth at All Costs', (2) 'Green Economy', (3) 'Inclusive Growth' and (4) 'Sustainability Transition' within the global SSPs (Fig. 1), and makes projections through until 2030. A brief narrative description of each scenario is given in Table 1 (and Supplementary Table 1).

Each scenario incorporates a coherent set of policy (for example, tax, subsidy) and investment (for example, public expenditure, private investment) settings (see Methods). We use the SDGs to evaluate the performance of each scenario across all 17 goals (using 52 targets and 97 indicators), highlighting the effects of different development approaches and combinations of interventions for the achievement of the SDGs as well as their synergies and trade-offs. Australia is selected for the study to build on recent research assessing Australia's progress on the SDGs[30] and on previous landmark scenario studies[31]. It also provides a representative use case relevant to national SDG implementation in other countries.

Australia is off-track to attain the SDGs by 2030

On its current development trajectory, Australia is projected to fall well short of achieving the SDGs. Figure 2 presents the performance of the BAU and alternative scenarios on an index scale (from 0 to 100% progress towards targets), with results reported at the goal level. BAU projections for each goal are represented by black dotted lines in Fig. 2. Australia is projected to make, on average, 40% progress towards all 52 SDG targets across all 17 goals. The BAU scenario performs better on key social goals and targets, including Goal 4 on education (~90% achievement), Goal 3 on health (~70%) and Goal 6 on clean water and sanitation (~90%). Performance on environmental goals, including Goal 12 (responsible consumption and production), Goal 13 (climate action) and Goal 17 (partnerships and means of implementation), also lags far behind.

The BAU projections (Supplementary Fig. 1) are based on a continuation of: (1) recent historic levels of migration (~200,000 per annum) and fertility rates (~1.7); (2) recent government expenditure, tax and subsidy settings (proportional to gross domestic product

[1]School of Biological, Earth and Environmental Sciences, PANGEA Centre, UNSW Sydney, Sydney, New South Wales, Australia. [2]Sustainability Assessment Program, School of Civil and Environmental Engineering, UNSW Sydney, Sydney, New South Wales, Australia. [3]ISA, School of Physics A28, The University of Sydney, Sydney, New South Wales, Australia. [4]Millennium Institute, Washington, DC, USA. *e-mail: cameron@smatalabs.com.au

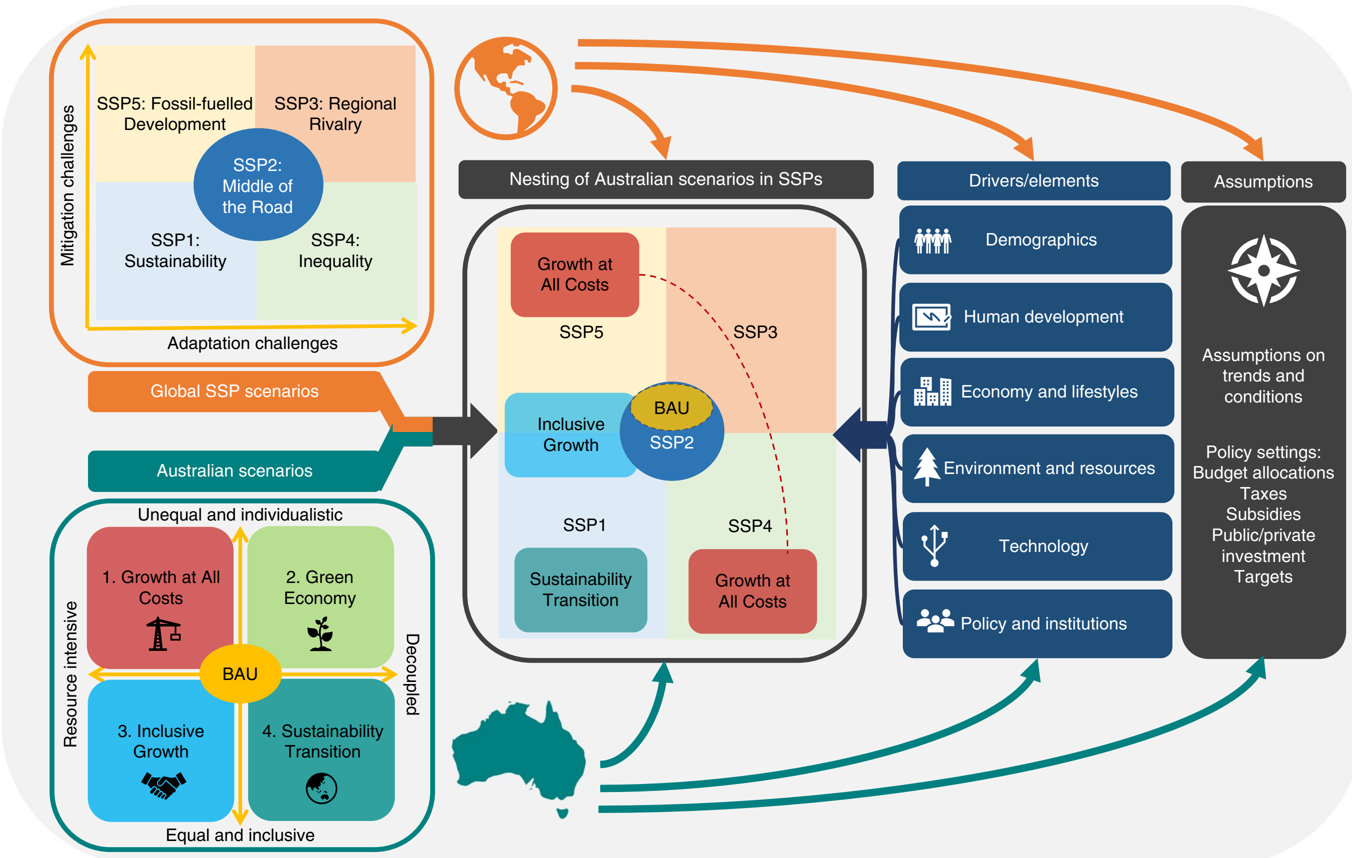

Fig. 1 | The nested approach used to develop national scenarios, assumptions and settings. The national scenarios developed for Australia (bottom left) were overlaid with the global SSPs (centre). Each Australian scenario was populated with corresponding drivers and elements drawn from the SSPs, which included qualitative narrative components and assumptions as well as quantitative settings drawn from global modelling for marker SSPs. Additional qualitative assumptions and quantitative settings drawn from other global projections, and from previous national modelling and data, were incorporated into each scenario to better address the broad scope of the SDGs. A coherent package of policy settings, investments and interventions was then introduced into each scenario in line with the scenario narratives. See Methods for further details.

(GDP)); (3) sustained demand for Australia's resources and exports (and stable prices); and (4) trends in productivity and efficiency gains in line with global averages. No additional policy, investment or other interventions are introduced (Supplementary Table 2).

Greater gains on the SDGs are readily available

While none of the four alternative scenarios achieves 100% progress towards all SDG targets, all scenarios perform better than the BAU scenario to varying degrees (Fig. 2). Of the scenarios, Sustainability Transition (Scenario 4) performs the best overall, with average progress of ~70% towards all SDG targets compared to 40% under the BAU scenario. Green Economy (Scenario 2) also performs comparatively well, with average progress of 63%. Growth at All Costs (Scenario 1) and Inclusive Growth (Scenario 2) perform only marginally better than the BAU scenario, at 42 and 47%, respectively.

Limited improvements on the SDGs by focusing on growth

Differences in performance on the SDGs across the scenarios (Fig. 2) are driven by variations in policy settings and assumptions introduced into the model that relate to key drivers (demographics, human development, economy and lifestyles, environment and resources, technology and governance) and their dynamic feedbacks across the model (Fig. 1 and Supplementary Table 2).

All four alternative scenarios project continued economic growth at or above the BAU level, with total real gross domestic product (GDP) substantially higher under Growth at All Costs and marginally higher under Inclusive Growth (Supplementary Fig. 2a). However, migration policy settings under these scenarios result in more rapid population growth and lower per capita GDP compared to other scenarios (Supplementary Fig. 2c). For Green Economy and Sustainability Transition, slower population growth combined with GDP growth rates similar to those of BAU translate into higher real GDP per capita in 2030. Once taxes and transfers are factored in, Growth at All Costs and Sustainability Transition also project higher real per capita disposable income (Supplementary Fig. 2d).

These differences result from a range of interacting dynamics in the model, including the interplay of population growth, GDP growth, tax and revenue, and government expenditure. These factors also impact substantially on government debt (Supplementary Fig. 2h), which is projected to increase above that of BAU in both Inclusive Growth and Sustainability Transition, and to decline in both Growth at All Costs and Green Economy.

The scenario analysis reveals that, for advanced economies such as Australia, more rapid GDP growth does not translate into substantial improvements on the SDGs. The Growth at All Costs scenario focuses primarily on stimulating economic growth, including through a reduction in taxes on international trade and income and profits (−3.5% GDP per annum compared to BAU), a reduction in government expenditure in social services and redistributive measures (−4.5% GDP), greater expenditure on road infrastructure (+0.5% GDP) and increased migration (Table 1 and Supplementary Table 2). Accelerated GDP growth brings only

Table 1 | Brief scenario narratives

Scenario	Narrative descriptor (applies to Australia and globally)
(1) Growth at All Costs (SSP5, SSP4)	Australia focuses primarily on economic growth as the fundamental development goal. Population rises more rapidly while growth is strongly coupled to resource and energy extraction and consumption, with higher GHG emissions. Emphasis is on free enterprise, and the role, size and expenditure of government is reduced somewhat over time, particularly in provision of social services, redistribution and environmental management.
(2) Green Economy (SSP2, SSP1)	Australia remains focused on achieving sufficient economic growth to support continuous job creation while addressing goals related to sustainable consumption and production, resource efficiency, clean energy and climate change. The rate of population growth slows, and economic value creation decouples from material consumption and final energy demand. Australia's efforts to mitigate GHG emissions are accompanied by global action that reduces climate change impacts. Additional government investment targets environmental objectives. Health and education expenditure remain moderate, and limited attention is given to income distribution, poverty and inequality.
(3) Inclusive Growth (SSP5, SSP1)	Australia is focused on achieving strong economic growth along with goals relating to poverty, gender and income inequality. Population grows more rapidly, and economic value creation remains coupled to energy, water and resource consumption. Larger investments are allocated to health, education, social inclusion, institutions and enhancement of human and social capital. A lower priority for environmental concerns and resource-related goals leads to ongoing environmental degradation, lower investment in renewables and resource efficiency, and higher GHG emissions.
(4) Sustainability Transition (SSP1)	Australia shifts toward a more sustainable path, emphasizing inclusive development within environmental boundaries. An increased commitment to the SDGs, with a focus on goals relating to poverty and inequality, climate change, water, energy and resource consumption, as well as economic development and innovation. Population rises more slowly, economic value creation decouples from resource and material consumption, and global demand for fossil fuels slows. Government policy targets consumption and pollution, as well as redistribution of wealth. A well-resourced and effective government plays a stronger role in steering the transition, with greater political stability.
BAU (SSP2)	BAU projection based on existing trends and policy settings.

marginal improvements in overall performance on the SDGs compared with the BAU scenario (that is, 42% versus 40% progress towards targets) (Fig. 2).

Inclusive Growth focuses on economic growth combined with larger investments in health, education, social inclusion and equality (Table 1 and Supplementary Table 2). Taxes on income and profits are increased (+2% GDP), with the burden shifted towards high-income earners. Additional expenditure is allocated to social services (+1.5% GDP) and subsidies and transfers (+1.8% GDP), along with redistribution in favour of low-income earners. These policies impact on income distribution, resulting in a reduction in the Gini coefficient from 0.32 to 0.28 (Supplementary Fig. 3c). Similarly, poverty rates nearly halve to around 6%. Additional government expenditure is also allocated to health and education (+0.7% GDP per annum above that of BAU), which results in only marginal improvements on these targets. Overall SDG performance for this scenario is slightly better than the BAU scenario (that is, 47% versus 40% progress towards targets) (Fig. 2).

Quick gains and synergies by shifting to a green economy

The Green Economy scenario focuses on delivering sufficient economic growth to support continuous job creation while addressing goals related to sustainable consumption and production, resource efficiency, clean energy and climate change (Table 1 and Supplementary Table 2). Consumption-based taxes are increased (+1.7% GDP), population growth slows and 'green' investments are made to improve sustainability in the transport, water, energy, agriculture and environmental sectors (+1% GDP). Government investment in health and education remains moderate, with a reduction in government expenditure on social subsidies and transfers and inclusion measures (-3% GDP).

The scenario performs considerably better than the BAU scenario across the selected SDG targets (63% versus 40% progress towards targets;Fig. 2). This is primarily due to significant gains on environmental and natural resource targets, including those relating to energy (Goal 7), resource consumption (Goals 8 and 12), cities and infrastructure (Goal 11), climate change (Goal 13) and biodiversity (Goal 15). When compared with the BAU scenario, Green Economy results in an additional 30 percentage points progress towards environmental targets (Fig. 3) and out-performs the BAU and most other scenarios on both economic (+21%) and social targets (+12.5%).

Noteworthy is the improved performance from only modest additional investment, showing that quick gains can be made by Australia through a focused set of green policy interventions. Furthermore, a green economy approach delivers synergies with socioeconomic targets, improving performance on goals relating to poverty (Goal 1), health (Goal 3), economy (Goal 8) and partnerships (Goal 17).

Nevertheless, despite these investments, total greenhouse gas (GHG) emissions are projected to continue to increase, albeit at a slower rate (Supplementary Fig. 4g). The rate of energy consumption slows due to lower population growth and investment in energy efficiency (Supplementary Fig. 4d). Additional investment in small- and large-scale solar energy applications drives an increase in the share of renewables in electricity to around 60% by 2030 (Supplementary Fig. 4e). However, these measures are insufficient to effectively reduce emissions, and the analysis highlights that broader policy and investment responses will be needed across the industry, transport and agriculture sectors to achieve set target levels.

Greatest gains through a Sustainability Transition

Sustainability Transition performs considerably better than the BAU scenario overall (70% versus 40% progress towards targets) (Fig. 2), and consistently out-performs BAU and all alternative scenarios on progress towards economic, social and environmental targets (Fig. 3). Scenario performance across these three dimensions is well balanced, demonstrating that trade-offs can be effectively addressed and managed.

Sustainability Transition foresees an increased commitment to the SDGs in Australia and globally (Table 1), and the emphasis shifts from economic growth toward a broader consideration of human well-being, even at the expense of slower growth over the long term (compound annual growth rate of 2.15% per annum versus 2.55% in Growth at All Costs). The scenario integrates policy settings on economic and social inclusion from Inclusive Growth and on green investment from Green Economy (Supplementary Table 2) in a coherent way, so that performance is improved across almost all goals (Fig. 2).

Fig. 2 | Aggregate performance on the SDGs across all Australian scenarios. Reading from the outside of the diagram inwards, goal icons for each of the 17 goals are shown in the outer circle using official United Nations (UN) logos[32], starting with 'Goal 1: NO POVERTY' at the top centre-right and then proceeding clockwise. Coloured numbers (1–4) in the next circle represent each of the four alternative scenarios as listed in the centre (GC, Growth at All Costs; GE, Green Economy; IG, Inclusive Growth; ST, Sustainability Transition). Moving inwards, the coloured bars show the projected average progress on each goal across all of its SDG targets in 2030, on an index scale from 0% (no progress) to 100% (full achievement). These percentages reflect proportional progress towards all targets (from 0 to 100), rather than the percentage of targets achieved. For comparison, dotted black lines show the level of achievement projected for the BAU scenario. Total average progress for each scenario towards all 52 targets is listed in the centre of the diagram. Credit (SDG icons): United Nations (UN/SDG).

Trade-offs in achieving SDG targets

For Sustainability Transition, the only goal for which performance does not improve is Goal 6 (water), which sees a marginal reduction in performance (–3% compared to BAU). This highlights strong policy coherence at the goal level. However, many trade-offs are evident at the target and indicator levels. Aggregate real GDP is lower in the Sustainability Transition scenario compared to Growth at All Costs, as are private savings, private consumption and nominal investment (Supplementary Fig. 2). Increased government debt is projected to reach over 57% of GDP in 2030 for Sustainability Transition, slightly above the 52% projected in the BAU scenario but considerably worse than Growth at All Costs and Green Economy (Supplementary Fig. 2h). The sustainability of these debt levels, as well as the vulnerabilities they create for Australia in terms of weathering any future shocks to the global economy, need further consideration and analysis. The analysis reveals areas where trade-offs remain (Supplementary Figs. 2–4), requiring further policy attention to improve performance and smooth the transition.

Comparing the other alternative scenarios against the BAU scenario, a range of trade-offs are also apparent (Fig. 2). For Growth at All Costs, improvements in Goal 17 (means of implementation) and Goal 9 (industry and infrastructure), come at the expense of worse performance on goals relating to biodiversity (Goals 14 and 15), income inequality (Goal 10) and gender equality (Goal 5). For Green Economy, advances across sustainable agriculture (Goal 2), energy (Goal 7), cities (Goal 11) and climate action (Goal 13) come at the expense of lower performance on income inequality (Goal 10) and gender equality (Goal 5). For Inclusive Growth, improved performance on goals relating to poverty (Goal 1), gender equality (Goal 5) and income inequality (Goal 10) come at the expense of reduced performance on economic growth (Goal 8) and biodiversity (Goals 14 and 15).

Widespread achievement of SDG targets is challenging

The synthesis of results (Fig. 2) is an index-based assessment of progress towards the achievement of targets (on a scale of 0–100%) rather than an assessment of the actual achievement of target values. Figure 4a provides a summary of the total percentage of targets assessed as 'achieved' across each of the alternative scenarios, as well as indicating the share of these targets categorized as economic,

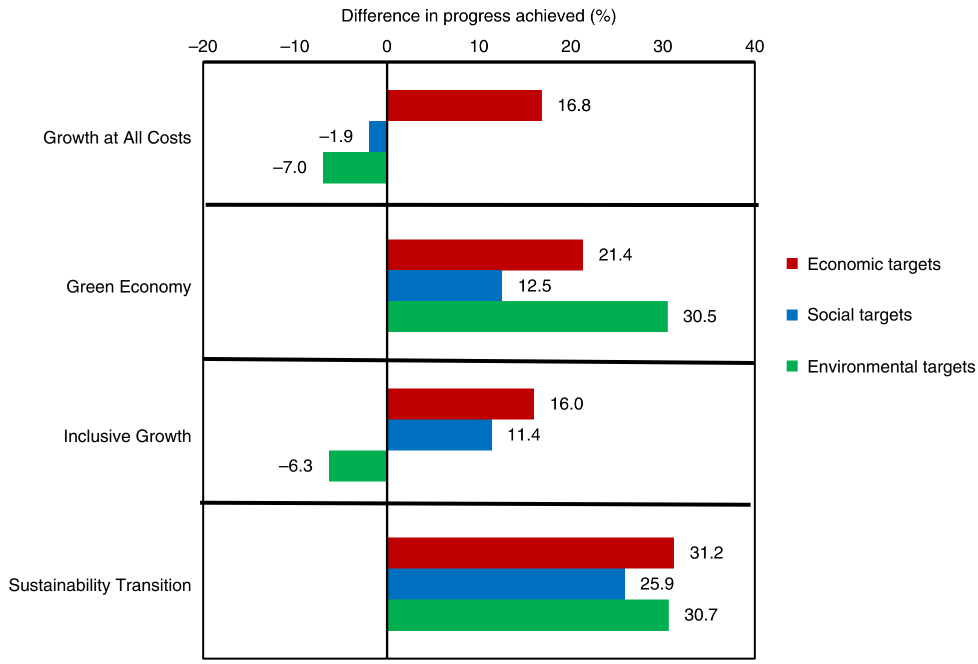

Fig. 3 | Performance of each scenario on economic, social and environmental SDG targets. Coloured bars represent the difference in progress achieved by each scenario on groupings of economic, social and environmental targets when compared to the BAU projections. This is calculated by subtracting BAU progress scores (0–100%) for economic, social and environmental targets from the progress scores for each scenario. Positive scores represent achievement levels for each group of targets that are better than the BAU scenario, while negative values represent achievement levels worse than BAU. Supplementary Table 4 specifies the targets allocated to each category (economic, social or environmental).

social or environmental. For this study, a target is assessed as 'achieved' when it reaches or exceeds 95% of the 2030 target level. The overall performance of the four alternative scenarios is considerably worse using this metric as compared with the index-based assessment of progress. Even the most SDG-oriented scenario (Sustainability Transition) achieves just under 50% of all SDG targets (Fig. 4a). Achievement levels of both economic and environmental targets are particularly low. Gains made in the achievement of additional environmental and social targets for the Sustainability Transition scenario come at the cost of fewer economic targets achieved.

At the goal level (Fig. 4b), none of the target levels set for Goals 8 (economy and jobs), 10 (income inequality), 12 (sustainable consumption and production) and 13 (climate action) are achieved in the Sustainability Transition scenario. We identify these as top-priority SDG challenges for Australia demanding further policy attention and analysis.

Model validation and sensitivity analysis

Validation and sensitivity tests (see Methods) were applied to the iSDG–Australia model. Analysis of the goodness-of-fit of the model simulations to actual time series data corroborates the ability of the model to simulate a range of critical variables over the past 25 years or more including GDP, population and government expenditure (Supplementary Table 3). For example, mean absolute percentage error (MAPE) is generally low and Theil inequality coefficients[33,34] are close to zero, showing that the model is much better than naïve.

Model results are based on assumptions that are parameterized using a range of sources, including global integrated assessment models, scientific literature, time series data and other studies (Supplementary Table 2). Results from the sensitivity analysis (see Methods) show that sensitivity of the simulated SDG performance results to a set of key global assumptions is generally low to moderate (Fig. 5 and Supplementary Figs. 5 and 6). In the period to 2030, sensitivity is higher to mining commodity prices, while sensitivity to average global temperatures and climate change increases over time, suggesting that these effects will become more influential over the longer-term period to 2050 and beyond. Sensitivity to variation in population assumptions is generally low, except for Goal 8 (economy and jobs). Global sensitivity to all three of these assumptions combined (mining commodity prices, temperature, population) is also highest for Goal 8 (economy and jobs), while sensitivity of aggregate goal performance across all SDGs is generally low (Fig. 5).

For the alternative scenarios, extreme-conditions tests project very little improvement in performance of the Sustainability Transition scenario (+1%) despite considerably more favourable global assumptions relating to higher mining commodity prices and reduced climate change impacts (Supplementary Fig. 7).

Discussion, limitations and future directions for research

For advanced economies such as Australia, pursuing a path of economic growth without due consideration of social and environmental objectives is not sustainable, and focusing on more rapid economic growth alone delivers little improvement on the SDGs. This is important, as a 'growth' discourse[35] still dominates the political debate and policy framing in Australia and elsewhere. The analysis of iSDG–Australia scenarios reveals how different approaches to development (green, inclusive, neither or both) alter Australia's development trajectory and SDG performance by 2030. Sustainability Transition shows that it is possible for Australia to make significant advancements (~70%) on the SDGs that would otherwise be missed under the current BAU trajectory. It also demonstrates that economic, social and environmental trade-offs can be managed coherently. Combining national scenario analysis and modelling with the results-based framework of the SDGs can better inform decision-making by highlighting these tensions, as well as co-benefits.

Similar achievements are attained under all scenarios for top-performing goals such as health (Goal 3) and education (Goal 4), despite increased investment. Furthermore, the extreme conditions tests (see

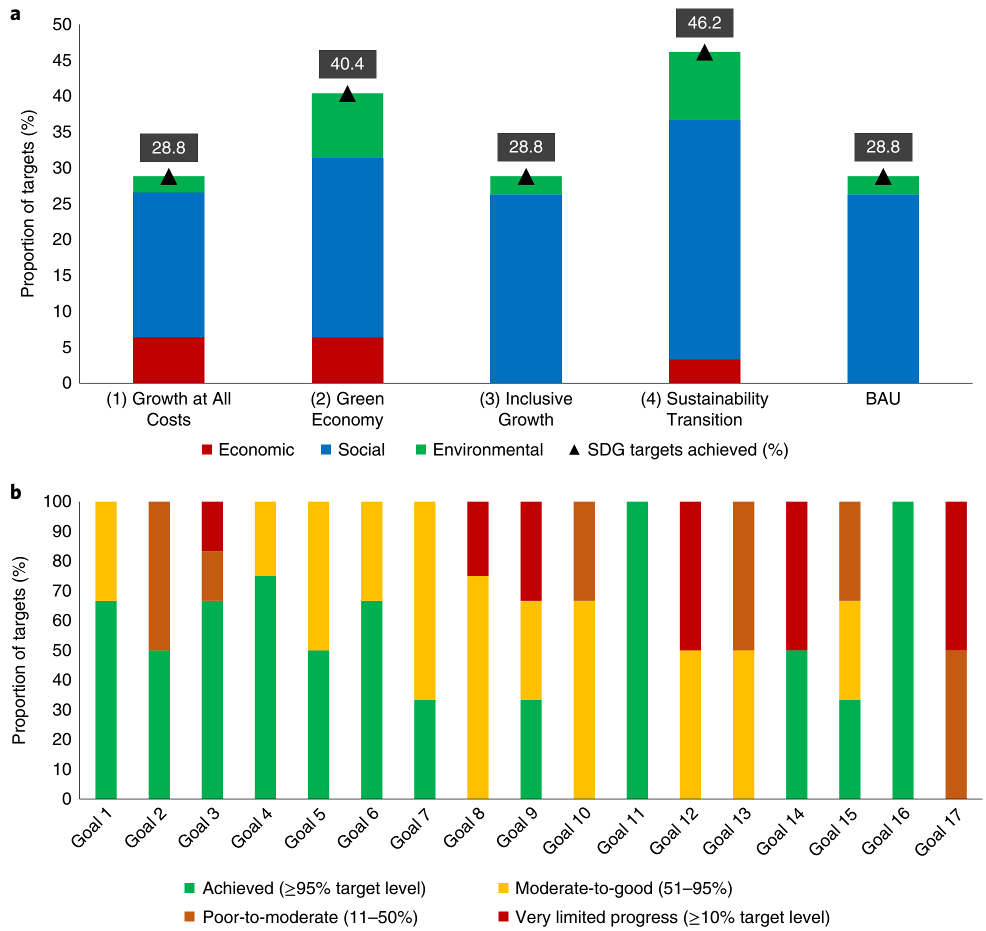

Fig. 4 | The proportion of SDG targets assessed as 'achieved' under different scenarios. a, The proportion of SDG targets assessed as achieved (≥95% achievement of target value) for all goals and for each scenario, and the share of achieved targets for each scenario that are economic, social or environmental targets. For example, for the Sustainability Transition scenario, 46.2% of targets are assessed as achieved with the majority being social targets (blue), followed by environmental (green) and then economic (red) targets. **b**, Sustainability Transition scenario: the proportion of SDG targets in different progress assessment categories.

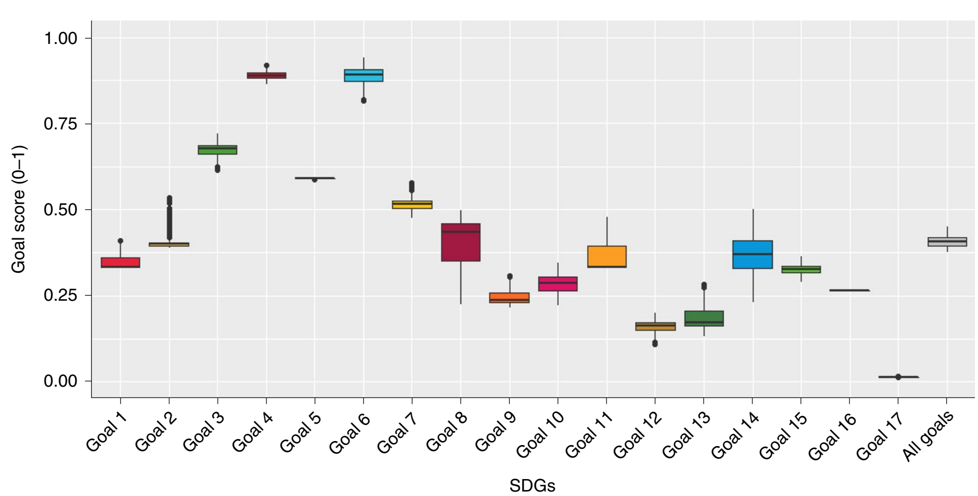

Fig. 5 | Sensitivity analysis of SDG performance results: boxplots of frequency distributions from Monte Carlo simulations. All-at-a-time adjustment of average mining gross value added, average global temperature change and net migration (see Methods). Sensitivity of results to goal scores for each of the 17 SDGs plus the aggregate score for 'all goals' (index scale 0–1, where 1 = 100% progress or goal achieved). Lines in boxes represent the median; the box edges are the lower range (25th percentile (Q1)) and the upper edge (the 75th percentile (Q3)), and the whiskers extend to 1.5 × Q3–Q1). Outliers represent values beyond the whiskers (that is, beyond 1.5 × (Q3–Q1)).

Methods) revealed that much more favourable global assumptions deliver little improvement in SDG performance for Sustainability Transition (Supplementary Fig. 7 and Supplementary Table 5). This suggests diminishing returns per dollar invested, and that closing the gap to 100% SDG achievement will be particularly challenging.

The study reveals that a sustainability-type scenario does not compromise on key economic objectives that are at the forefront of decision-makers' minds, and that we can (and should) consider a far broader range of metrics when evaluating options. Feasible adjustments to the main levers of government (tax, subsidies, expenditure) can deliver a balanced outcome to some of Australia's most intractable challenges. However, closing the remaining gap will require a shift from transition to transformation.

In integrated assessment modelling of complex systems, uncertainty propagates in the elaboration of future global conditions (deep uncertainty), model structure and data, parameterization of model assumptions, and the framework for evaluating simulation performance[36,37]. Calibration of models based on past performance is becoming increasingly challenged, due to escalating or cascading risks from climate change, biodiversity decline and peace and stability[38–42]. The development of multiple plausible scenarios is a common approach in coping with such deep uncertainty[37,43]. Exploratory modelling using scenario discovery or pathways approaches (generating many thousands of simulations) represents leading practice[13,37,44].

We acknowledge the limitations of our study and outline future directions for research. First, the study explores only a small selection of scenarios; there is a possibility that the assumptions used in the scenarios are insufficient to capture the range of uncertainty in all parameters[45]. In addition, the sensitivity analysis and model validation procedures focus on only a selection of key economic, social and environmental assumptions.

Second, the 2030 timeframe is limited in terms of exploring longer-term trends (for example, climate change risks). While the iSDG–Australia model does simulate climate change effects in a range of sectors (productivity, agriculture, infrastructure, health and biodiversity), a high degree of uncertainty remains, particularly as risks escalate further into the future.

Third, while the iSDG–Australia model has capabilities for dynamic modelling of interactions across sectors, it does not capture all indicators of interest for Australia. Furthermore while disaggregation based on gender, age, income, land type, commodities and so on, is considered, the model is not spatially disaggregated. This limits the ability to simulate subnational spatial variability, which is particularly important in sectors such as land, water and biodiversity.

With these limitations in mind, future directions for research include: exploratory modelling and pathways approaches to optimize SDG performance of policy and investment settings under different future conditions; further development of SDG interventions in priority sectors; expansion of the iSDG–Australia model to address spatial variability and additional indicators; and extension of the timeframe of analysis to 2050 and beyond.

Methods

Development of the scenario framework. A common approach to the formulation of scenarios is the use of two 'axes of uncertainty' representing forces and drivers with high importance and high uncertainty, and which serve as the logic and structure for the scenarios[46,47]. Qualitative narratives and quantitative attributes are then formulated for each scenario across each of the drivers. Existing global and national scenarios provide a framework to guide scenario formulation and calibration. Global benchmarks include the SSPs[20,21,23,27] and Representative Concentration Pathways (RCPs)[48,49]. In Australia, existing scenario frameworks include the four 'touchstone' scenarios developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) for Australia's National Outlook[50], the national archetype scenarios developed as part of the Australian Academy of Science's futures project[51] and the scenarios for Australia in 2050 (refs. [16,52]).

The scenario framework for Australia's analysis was informed by these existing studies, as well as a baseline assessment of Australia's progress on the SDGs which highlighted priority areas where Australia is lagging behind[30]. Key challenges for Australia were determined as relating to climate change and resource consumption on the one axis, and social inclusion and rising inequality on the other. These key challenges provided the primary axes for the scenario framework, creating four alternative scenarios: (1) Growth at All Costs, (2) Green Economy, (3) Inclusive Growth and (4) Sustainability Transition; plus a BAU scenario (Fig. 1). The alternative scenarios draw on dominant development approaches and discourses of the past decade[53–56], which have been promoted in the context of international development, Millennium Development Goals and SDGs.

To provide consistency and alignment with global practice, the scenarios were nested within the five global scenarios developed through the SSPs (SSP5: Fossil-fuelled Development; SSP4: Inequality; SSP3: Regional Rivalry; SSP2: Middle of the Road; and SSP1: Sustainability), as well as the RCPs that describe a set of alternative trajectories for atmospheric concentrations of GHGs.

Figure 1 summarizes the approach taken to nest Australia's national scenarios within the global scenarios. Such nesting is not immediate, given the issues of scaling from global to national levels and the focus of the SSPs on mitigation and adaptation. As such, a 'best fit' approach was adopted, consistent with other studies[26]. This resulted in some overlap in characteristics across the Australian scenarios—that is, Inclusive Growth and Green Economy combine aspects of the Growth at All Costs and Sustainability Transition scenarios. This was intentional, to explore how different dominant approaches to development (green, inclusive, neither or both) would alter Australia's development trajectory and SDG performance. The national issues of critical importance used to frame Australia's scenarios (that is, energy and resource consumption and inequality) differ substantively from those used to develop the SSPs (challenges to mitigation and adaptation). Australia's national scenarios therefore align more closely with the SSPs relating to SSP5 and 1, as well as to SSP4 and 2.

Elaboration of qualitative and quantitative assumptions and settings. The main driving forces and elements developed for the SSP narratives[21] were used to frame and elaborate the qualitative and quantitative settings and assumptions for each of Australia's scenarios. As with the SSPs, the main drivers or elements were grouped into six categories (Fig. 1): (1) demographic, (2) human development, (3) economy and lifestyles, (4) environment and resources, (5) technology and (6) policies and institutions. For each driver, a range of assumptions and policy settings were developed which enabled calibration and parameterization of the model (Supplementary Table 2)

The parameterization of quantitative assumptions relating to global conditions exogenous to the model was supported by integrated assessment model projections associated with each of the marker SSPs and RCPs[23], as well as by global projections from other international organizations and research institutes, scientific literature and national modelling and projections undertaken across a range of sectors in Australia (Supplementary Table 2).

Tax, subsidy and expenditure settings for the BAU scenario remained in line with recent time series data (as a proportion of GDP). Policy settings for each of the alternative scenarios were parameterized in line with the scenario narratives and based on the BAU 2030 projections, official time series datasets and available costings studies and reports (Supplementary Table 2). Calibration from historical time series datasets included the use of trends (compound annual growth rates), historic minimum and maximum values and benchmarking of top-performing peer countries (for example, Organisation for Economic Cooperation and Development (OECD) countries) from global datasets (Supplementary Table 2).

Model selection and description of the iSDG–Australia model. Model selection was informed by previous research[18], which found the iSDG simulation model to be well suited for analysis of interactions among competing objectives and policies for achieving the SDGs at the national level. National studies in developing countries that apply the iSDG model have been published for the Ivory Coast[15] and Tanzania[57], but to date there is no published study for a high-income country.

The iSDG tool is an integrated, macro-economic model that is built in the system dynamics modelling language in both Vensim[58] and Stella Architect[59] software. It can represent complex interactions and feedback relationships, nonlinearity and time delays that are fundamental to understanding and analysing development processes from an integrated perspective[60]. The base iSDG model has a stock-and-flow structure and is formulated as a system of differential equations comprising approximately 3,000 variables organized across 30 sectors, covering key economic, social and environmental domains (Supplementary Fig. 8). The base model can simulate a broad range of development indicators, including 78 official SDG indicators covering all 17 goals. All sectors of the model are dynamically interacting, and hence any policy introduced in a given sector has cross-sector impacts that spread throughout the model. It is capable of medium- to long-term projections (through to 2030, 2050 or beyond).

The iSDG model is part of the Threshold 21 family of models, which have been progressively developed over a period of several decades through extensive research of the literature[60] and more than 20 country applications, many of which are published in the academic[15,57,61–65] and 'grey' literature[55,66–69]. This has supported continuous improvement and validation of the model.

A description of each of the sectoral modules, along with their assumptions and source literature, is available in the model documentation[60]. A very brief description of some of the key modules is also provided in Supplementary Fig. 8.

Model calibration and validation. While it may not be possible to fully confirm model validity as a precise replica of a real system[70], a model can be extensively corroborated by exposing it to a series of tests[71]. There is a broad literature applying system dynamics models for integrated assessment and modelling, which are reviewed elsewhere[72–74]. Good practice model verification and validation procedures typically involve both structural and behavioural validation, including parameter assessment, extreme condition tests, sensitivity analysis and comparison to other models[70,72,75–77].

The validation (or corroboration) of the iSDG–Australia model was embedded in the implementation and calibration process and involved both structural and behavioural validation. Before calibrating the model, an extensive database of 25 years of historic time series data was collected for the period 1990 to the most recent year (usually 2015–2017). Data were sourced primarily from official and verified national government sources (Australian Bureau of Statistics and government administrative databases), as well as official data from international databases hosted by the OECD, UN, International Monetary Fund, World Bank and other official sources (Supplementary Tables 2 and 4). The data are used for model inputs, parameter estimations and to test the model's ability to replicate historical behaviour.

Following data compilation the model implementation process is iterative, involving multiple rounds of calibration of model parameters across each module of the model. The calibration process is undertaken using partial calibration cycles[78] whereby individual sector modules are parameterized, replacing exogenous data inputs with endogenous input variables across multiple sectors. In each sector, parameters are calibrated using multi-parametrical optimization which searches for combinations of values that provide the best fit with observed time series data for relevant indicators. Reference parameter ranges are used to support parameterization, based on the expert literature and several decades of empirical experience in application of the Threshold 21 family of models[60], as well as other modelling studies (Supplementary Table 2). Several modules required adjustments or additions to the model structure to reflect Australian conditions or enable greater disaggregation that supported calibration, including in the fertility, industry, material consumption and income distribution modules.

Behaviour reproduction tests were used to evaluate the goodness-of-fit of simulated and actual data using plotted graphs and error statistics, including the coefficient of determination (R^2), mean error, root mean squared error, mean absolute error, mean percentage error, mean absolute percentage error and Theil's inequality coefficient[34,70,79]. In the iSDG model, such tests are particularly important for the evaluation of key economic, social and environmental indicators where good-quality time series data are available, including population, GDP, investment, government revenue and expenditure, life expectancy, energy and water consumption and GHG emissions. Goodness-of-fit statistics calculated for a selection of critical variables for the BAU scenario simulation are included in Supplementary Table 3.

In most applications, system dynamic models are not expected to reproduce outputs at a high accuracy or precision— rather, the emphasis is on replicating system behaviour[72]. As such, measures such as R^2 that describe the fraction of variance in the data explained by the model may not be the most useful[70]. Measures such as mean squared error and root mean square error may be better suited, but penalize large errors more than small ones, while mean absolute percentage error provides a percentage error metric that is easier to interpret. Theil's inequality coefficient provides an evaluation of the quality of the model simulation, where <1 is better than naïve and >1 is worse than naïve[33]. The calibration and parameterization process aims to reduce simulation error and maximize precision for key variables.

Sensitivity analysis is used to support and complement the model calibration exercise, as well as to test model assumptions, by providing insights on how variations in uncertain parameter inputs correspond to variations in the performance metrics that measure the model fit. For very large system dynamics models such as the iSDG tool, good practice is to focus on those relationships and parameters that are both highly uncertain and likely to be influential[70].

Sensitivity analysis of the iSDG–Australia model focused on key assumptions in the economic, social and environmental domains. The national scope of the model does not enable the inclusion of endogenous structure for global drivers such as trade, migration or action on climate change. As such, sensitivity analysis was used to test the sensitivity of model outputs to these key global assumptions, focusing on global commodity prices of mining commodities, global average temperature change and levels of net migration and population growth. The output variables of interest included the aggregate goal performance score, performance scores for each of the 17 goals and real GDP.

We followed the general workflow described in ref. [80], running Monte Carlo simulations in which model parameters were randomly adjusted within a predetermined range (minimum/maximum) using a normal distribution. We adopted one-at-a-time (1,000 simulations, random univariate sampling) and all-at-a-time (3,000 simulations, random Latin hypercube sampling) methods. Sensitivity analysis simulations were produced in the model software and were also exported and analysed in the R statistics software[81] (Supplementary Figs. 5 and 6).

Determining the input variability range (that is, minimum/maximum values) for the sensitivity simulations is a critical step as it can constrain the sensitivity analysis[80]. For each of the input assumptions, these ranges were set based on scientific literature and previous modelling studies (Supplementary Table 5).

Following final calibration of the iSDG–Australia model, the BAU scenario was projected through to 2030 based on a continuation of current policy and expenditure settings. Parameterization of each of the alternative scenarios was based on the settings in Supplementary Table 2. The simulation period for this exploratory study was set as the implementation period for the SDGs (2016–2030) and, as such, alternative scenario policy settings were introduced into the model in 2016. In general, the model uses a delay of 1 year from the introduction of a new expenditure or revenue setting until its delivered effects; however, time delays are also built into specific sectors where effects manifest more gradually. In some cases, policy effects can be seen in the projection results for 2017, such as disposable income and Gini coefficient, which are affected by changes to tax and subsidy settings introduced in 2016, amongst others (Supplementary Figs. 2–4).

It has been suggested[45] that ignoring scenario impacts on output uncertainty in sensitivity analysis can result in an unrepresentative view of model performance and sensitivity. Some final tests were therefore conducted to evaluate the sensitivity of the alternative scenarios to extreme conditions in key assumptions. This was conducted by introducing the minimum and maximum values used in the sensitivity analysis Monte Carlo simulations into the scenarios Growth at All Costs and Sustainability Transition, to explore their effects on overall model results for aggregate SDG performance. Settings for all three sensitivity parameters (mining gross value added, temperature and net migration) were parameterized simultaneously as 'worst case' and 'best case' scenarios, and effects on aggregate SDG performance were analysed (Supplementary Fig. 7).

Finally, the scenario projections were compared and contrasted against summary results from other relevant modelling studies for Australia[13,31,50,82–89]. Interstudy comparison is challenging due to different timeframes (generally 2050 or beyond) and scope (generally a subset of SDGs). However, in terms of projections for economic production, electricity generation, efficiency improvements, and consumption, projections from this study were considered comparable to other studies.

Developing the SDG evaluation framework. The SDG targets and indicators incorporated into the model provide an evaluation framework for assessment of the overall performance of different scenarios. Enhancements to the iSDG–Australia model were made to increase coverage of indicators considered important for Australia's sustainable development, and to remove certain indicators of little relevance. The identification of additional priority targets and indicators was guided by the recent baseline assessment of Australia's progress on the SDGs[30].

The final SDG performance evaluation framework comprised 17 goals, 52 targets and 97 indicators (Supplementary Table 4). Target values for each indicator were formulated by drawing on a range of sources, including the SDG targets themselves (where specific values are given—for example, target 1.2 to halve poverty), additional targets used in Australia's SDG baseline assessment[30], threshold values taken from the global SDG Index[90], alternative international guidelines and benchmarks (for example, WHO guidelines) and OECD averages or top performers. Where target values were not readily available, estimated values were set using a proportional improvement on a 2015 baseline value of 10–50% by 2030. The magnitude of the improvement was calibrated based on the consideration of Australia's historic performance based on time series data, the BAU projection for 2030 and benchmark values taken from international data (Supplementary Table 4). Although the resulting values represent ambitious but credible targets for Australia to reach by 2030, they are not official Australian government targets.

For a balanced assessment, it was also critical to consider the coverage of targets across all 17 goals and the three dimensions of sustainable development. While some targets cross over dimensions, the overall breakdown is approximated as 12 economic targets, 23 social targets and 17 environmental targets (Supplementary Table 4).

Method for assessment of progress towards SDG targets. Australia's SDG performance for each scenario was assessed based on its simulated progress towards each SDG target over the period 2016–2030. A normalized scale (0–100) was used, whereby the baseline value for 2015 was considered the zero point (0% achievement) and the target value for 2030 was considered the final point (reflecting 100% achievement). The simulated performance result for 2030 for each individual target was then calculated along this index scale, and can be interpreted as Australia's proportional achievement of a target (from 0 to 100%). In cases where Australia had already achieved a target level in 2015 (for example, for access to electricity), performance was assessed based on the maintenance of this level of achievement.

Where multiple indicators were included for a single target, the average performance across all indicators for each target was calculated. Similarly, to aggregate the results to assess performance at the goal level, the average performance across all targets for each goal was calculated. Finally, the average performance across all goals was calculated to provide a final 'total aggregated performance' result across all 17 goals.

Data availability

The datasets collected and analysed during the current study are available from the corresponding author on reasonable request.

Code availability

The iSDG simulation model can be made available from the Millennium Institute on reasonable request.

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Author contributions

C.A. led the research and undertook data collection, model calibration for iSDG–Australia, model adjustments, scenario development and simulations. M.P. developed the iSDG base model and provided advice and guidance data, model calibration and adjustment. G.M. and T.W. provided overall study supervision, advice and guidance regarding research framing, scenario development, methods and data sources. C.A. wrote the paper with inputs from G.M., T.W. and M.P.

Competing interests

The authors declare no competing interests.

Additional information

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Correspondence and requests for materials should be addressed to C.A.