Australia's National
Science Agency

Tracking Darwin

A framework for Monitoring, Evaluation and Learning about change in Darwin and the impact of the Darwin Living Lab

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Australian Government

NORTHERN TERRITORY GOVERNMENT

CITY OF DARWIN

About

This report was delivered as part of the work of the Darwin Living Lab. The Darwin Living Lab was established to foster improvements in the liveability, sustainability and resilience of the city. The Darwin Living Lab is an initiative under the Darwin City Deal and is a 10-year collaboration between CSIRO and the partners of the Darwin City Deal: Australian Government' Northern Territory Government and the City of Darwin. The City Deal was signed by the Prime Minister of Australia, Chief Minister of the Northern Territory and Lord Mayor of the City of Darwin in November 2018.

More information and contacts available at: https://research.csiro.au/darwinlivinglab/

Acknowledgement

We acknowledge the Traditional Owners of the greater Darwin region, the Larrakia people, and recognise their culture, history and connection to this land and water. We pay our respects to their Elders past, present and emerging.

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Glossary

Monitoring

Tracking actions and their consequences – including technical information and stakeholders' perspectives:

- What is happening? What has changed, if anything?
- What else happened?

For example, in a cool pavement trial, one might monitor the road surface temperature before and after application of the coating to see if it has changed and whether there had been any other unanticipated effects. One could also document the experiences of those involved in the trial – how did that happen? This can help develop or update understanding of how things work i.e. hypotheses, test assumptions etc.

Evaluation

Finding out what actions/outcomes were 'of worth/value', for who and why:

- Did things go as we thought/hoped they would? e.g. are people feeling cooler in the Darwin CBD?
- What was of value to you from this activity/output/outcome? (scientist, planner, citizen etc)
- Why is it important to you? e.g. how does it improve things for you?

All of which lead to 'Are we doing the right things to get the outcome we want?'. For example, one might explore how beneficial the City of Darwin and road users / passers-by thought the cool pavement was and why and the level of interest in applying the coating more widely. One could also explore the experiences of those involved regarding how the trial was designed/conducted. What went smoothly? What was difficult? Why?

Together with monitoring information, results can be used to understand what is important for different stakeholders and why and to inform processes and decision-making about what to pursue/change/stop.

Learning – as a process (verb)

That is, people experiencing learning. Understanding what enables learning (outcome) is one of the key things to be explored as part of the monitoring, evaluation and learning to be undertaken by the Darwin Living Lab.

For example, the results of the monitoring and evaluation of the cool pavement trial could be used to inform the decision about whether/where to use the coating more widely and if so, how to implement that decision effectively. The insights from what did and didn't go well in setting up and implementing the trial could also be used in other trials and contexts, enabling improvements in efficiency and performance.

Learning – as an outcome (noun)

Can be individual and/or collective (i.e. among a group):

- Implementation of what has been learned (i.e. acting on the insights from monitoring and evaluation to adjust what and how things are done)
- new knowledge or understanding about a situation (e.g. how things work/what is needed)
- new ability to do something, including working together with others

Executive Summary

There is a growing demand from citizens and governments for cities to 'innovate' in order to address increasing and unprecedented challenges such as climate change and population growth and to build resilience. One way of facilitating this innovation is through the 'living lab' approach. Living labs use purposeful experimentation to 'translate visions into concrete actions and practices' that are embedded within transformative governance approaches and have an emphasis on both learning and reflexivity.

The establishment of the CSIRO-led Darwin Living Lab (DLL) is a collaboration between CSIRO and the three layers of government (Commonwealth, Northern Territory and City of Darwin) involved in the Darwin City Deal. The DLL will build on city deal investments by using latest science to identify and test best-practice approaches to tropical urban design and liveability, including supporting heat mitigation work being pursued under the city deal.

Evaluation is a core aspect of living labs. Long-term evaluation aims to identify the most promising interventions that will achieve transformation in a particular context and determine the most effective way to implement these interventions. One of the priority projects for the DLL was to establish a 'Tracking Darwin Framework' that could be used to monitor and evaluate progress towards the envisioned changes in Darwin, learn and refocus where required, and report on the impact of the DLL.

This report presents a framework for the monitoring, evaluation and learning that will be conducted under the DLL. The objectives of the framework are:

- monitor, evaluate and learn from the activities and outcomes of the DLL to inform and enhance its performance over time
- monitor the trajectories of Darwin's liveability, sustainability and resilience, building the data infrastructure and analytics for tracking change over time and informing decision making.

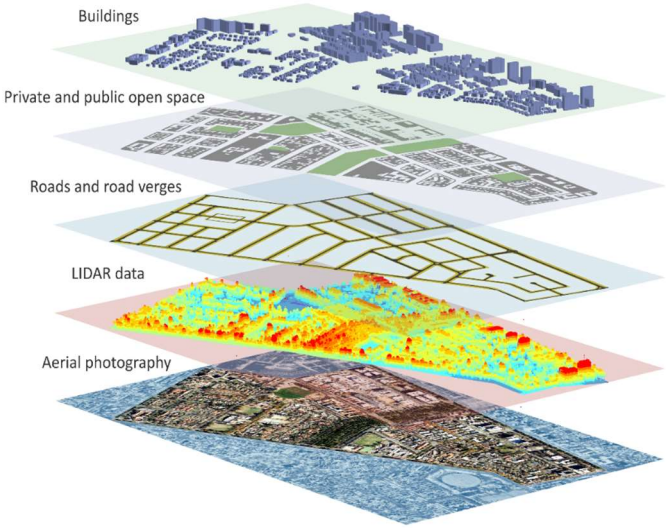
As the Tracking Darwin Framework is currently designed, it will be used to:

- collate and analyse previously collected data for a limited number of high level socio-economic and biophysical indicators (see Table 2) for Darwin
- where directly related to a DLL project or not accessible from other sources, collect and analyse data for a limited number of key measurable indicators of the 'state' of Darwin as related to the DLL
- collect and analyse data that assists with attribution and causality from DLL projects and activities, as well as lessons from within the Lab and with key stakeholders.

This framework will *not* be used to:

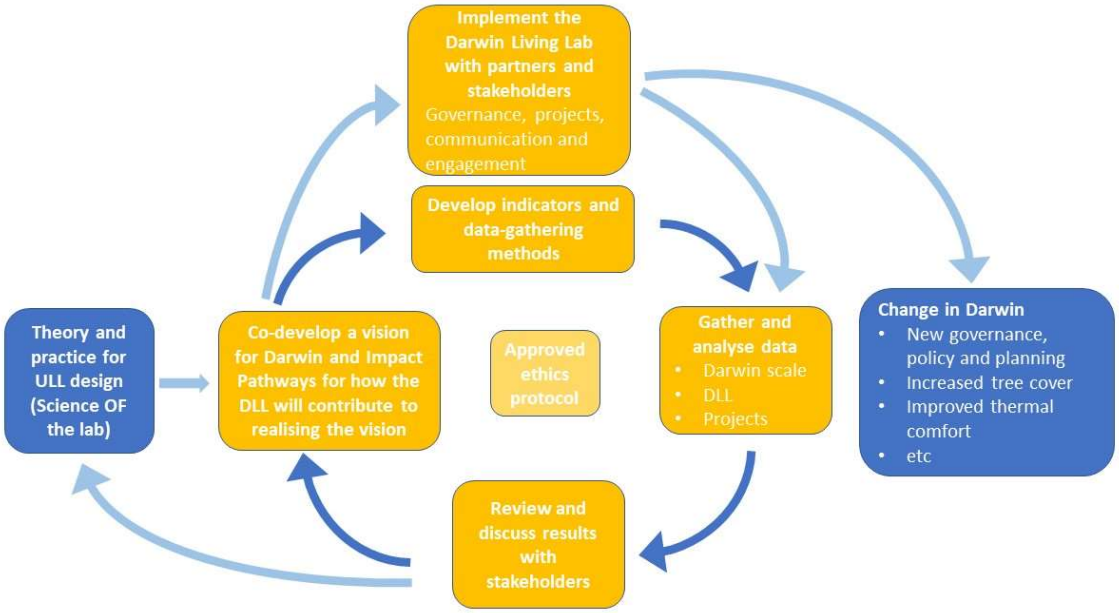
- collect and analyse data for all socio-economic and biophysical indicators for the whole of Darwin (i.e. DLL has a focus on cooling and associated overlaps with the key objectives of liveability, sustainability and resilience and is not responsible for capturing everything that occurs)
- collect data that enables specific attribution and causality of City Deal projects and activities
- collect data that enables specific attribution and causality of Switching on Darwin activities.

As captured schematically in ES1, the DLL will assemble, collate and integrate quantitative datasets within a spatial-temporal platform (that works towards a Digital Twin for Darwin). This will facilitate data access and analysis to assist with reporting, dialogue and decisions regarding the liveability, sustainability and resilience of Darwin, and allow exploration of the complex trade-offs when navigating change.



ES1. Schematic of spatial layers of different types of datasets, the foundation of Digital Twin for Darwin (Source: Schandl et al, 2020).

Figure ES2 outlines the proposed Tracking Darwin Framework and how monitoring and evaluation, data gathering and collective review, will contribute to learning by the participating partners of the DLL and will continually inform future operations and activities.



ES2. Tracking Darwin Framework and how it informs ongoing development of the DLL and contributes to change in Darwin.

Methodology

The steps involved in developing the Tracking Darwin Framework were:

1. Vision to reality: co-develop a 'Theory of Change' for Darwin with the DLL stakeholders. The Theory of Change is a description of how change could occur progressively over time to achieve the vision for Darwin, showing possible contributions from the DLL.

2. Projects to impact: Develop a set of 'impact pathways' for the DLL, building on the Theory of Change. Impact pathways are plausible narratives that describe how the activities and outputs of the DLL are envisaged over time to contribute to change for Darwin towards the 'thriving cool capital of the north'.
3. Measuring change: Develop indicators to track the progress of the DLL and changes across Darwin over time. The indicators are designed to track the effectiveness of collaboration within the DLL, its outputs and impacts, and key changes in the state of Darwin, such as changes in green cover, thermal comfort, as well as the policy environment which can affect these changes.
4. Techniques and timeframes: Identify methods and scheduling for data gathering, analysis and synthesis and review and discussion of the results with stakeholders, to determine any changes needed.

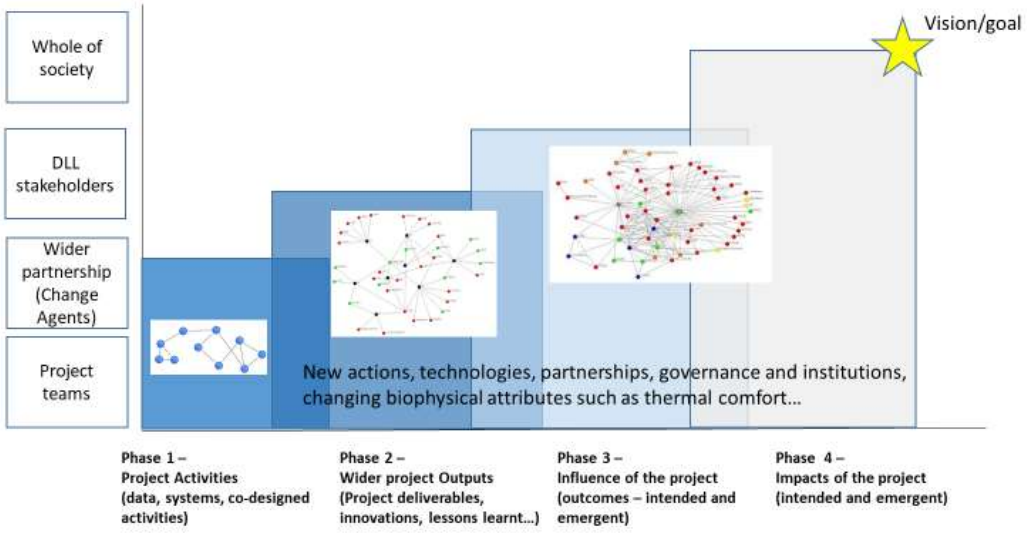
Impact Pathways

Building from the Theory of Change, four impact pathways have been developed for the DLL:-

1. Develop and foster innovation in urban heat mitigation for Darwin that improves liveability and grows the economy
    - In partnership with government, industry and community, identify and test new ideas and approaches
    - Work with the Larrakia people as the traditional custodians of the Darwin region, to respectfully learn from their cultural knowledge about living with heat
2. Develop infrastructure and analytics for tracking change in Darwin's liveability, sustainability and resilience
3. Build the capacity and networks for collaborative governance to guide urban transformation
4. Use effective co-production processes to develop and deliver outputs that are tailored to user needs and attract wider involvement from across CSIRO and participating DLL partners.

Indicators

Two sets of indicators were developed; those that track the outputs and the social and institutional dimensions of change influenced through the DLL (Table 1) and those that track quantitative measures of change in Darwin's liveability, sustainability and resilience (Table 2). The first set of indicators reflects successive levels of change along impact pathways (see ES3), where intentional change is conceptualised as a process of collective capacity building (see Avenharju et al. 2018, Butler et al. 2016, Hummelbrummer et al. 2013).



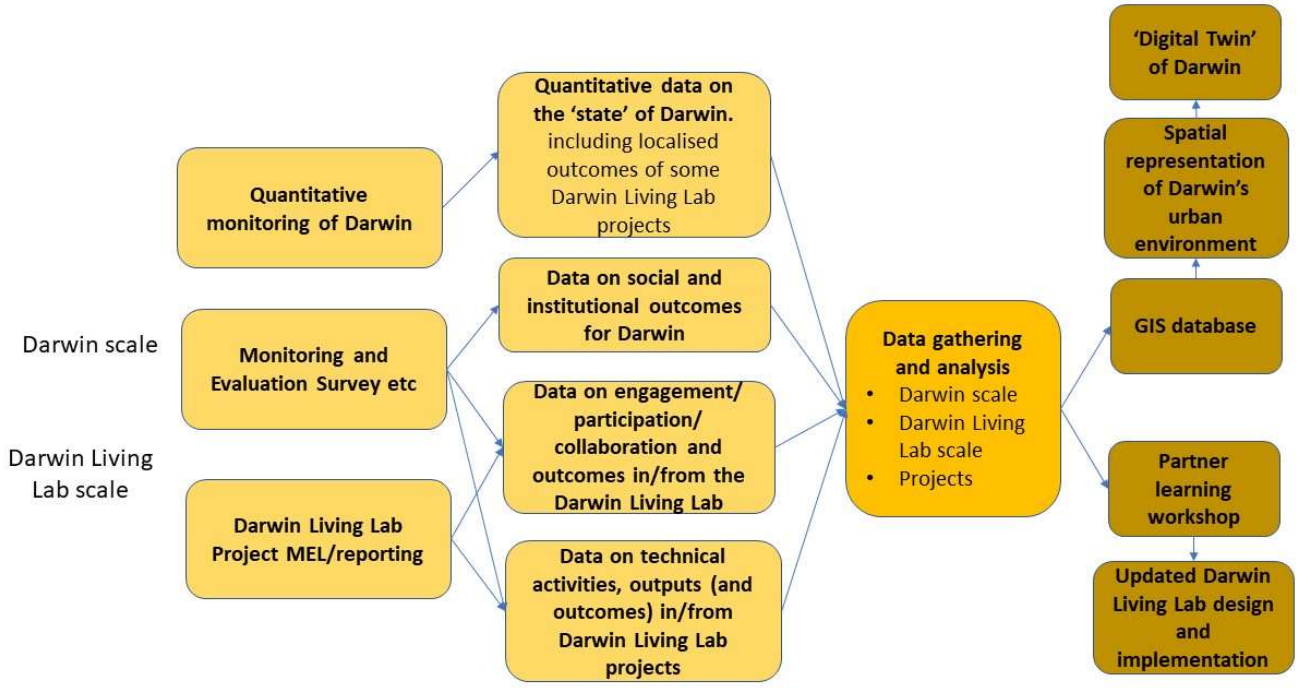
ES3. The four concurrent impact phases of the DLL, highlighting the growing stakeholder participation and networks

The quantitative indicators of the 'state' of Darwin in terms of liveability, sustainability and resilience are designed to measure desired outcomes at the 'whole of Darwin' scale but may also show changes at a more localised scale e.g. heat mapping and vegetation mapping, which will assist in attributing the effects to localised experiments.

Importantly, changes in Darwin will be influenced by a range of initiatives at different scales, including those implemented under the City Deal, as well as other Northern Territory Government and City of Darwin activities and projects that are developed and implemented outside the DLL. Therefore, to tell a holistic story of how Darwin is changing, there is a need to draw on monitoring of initiatives and context beyond the DLL.

Data collection, analysis and use

Methods and sources of data for 'Tracking Darwin' and products from the data are summarised in the figure ES4.



ES4. Data streams being drawn upon for the data collection

Qualitative data will be collected via surveys, interviews and focus groups, and may include the use of existing datasets where relevant. Data about project outputs will be collated from project reporting. Quantitative data for the monitoring of changes in Darwin will be generated via instrumentation used in the DLL and other projects and will draw on pre-existing datasets (e.g. population, canopy cover, human movement patterns etc). Data for these indicators may be sourced from a range of different custodians (see Appendix A.2 for further information).

Data collection will occur iteratively and in parallel to the projects and activities, to test and evaluate, with results shared and discussed within the DLL and with stakeholders to derive lessons and co-innovate.

Developing insights from the monitoring and evaluation results about what has occurred and why and using those insights to inform the development of the DLL is the key step in the learning cycle, illustrated above. Ideally, this will be achieved through a 'reflection and next steps' workshop with a group of DLL stakeholders closely involved with the lab such as the Advisory Group and Management Committee. The monitoring and evaluation results will be collated into a readily accessible format and shared with participants in preparation for this type of workshop. Over the life of the DLL, this will foster collaborative learning among partners and stakeholders on creating change in Darwin towards a thriving cool tropical city.

Summary and next steps

The Tracking Darwin Framework provides an approach to monitoring, evaluation and learning for the DLL, the core of the 'Living Lab' approach to learning and creating change with partners around a common vision/goal

Next steps in the further development and implementation of the Tracking Darwin Framework include:

- First iteration of the Tracking Darwin monitoring, evaluation and learning survey and interviews (Dec 2020).

- Partners' learning workshop (Apr-May 2021)
- Towards a digital twin of Darwin:- integrate available key environmental and socio-economic data into a GIS database (June 2021) and develop a baseline spatial representation of Darwin's urban environment relevant to liveability, sustainability and resilience indicators (Jan 2022).
- City of Darwin sensor network and integration with Digital Twin, smart applications, analyse urban microclimate and air quality in the City of Darwin, including analysis of spatial and temporal trends during the period June 2019 – Apr/May 2021 (June 2021).

Data from the spatial-temporal data platform (Digital Twin), supported by monitoring, evaluation and learning, will provide key inputs to support communication for regular (i.e. every 3 years) public-facing 'Tracking Darwin' reports that communicate the dynamics of Darwin's 'state'; including observed changes and ongoing challenges:

- Evaluation of the DLL's contribution to the heat mitigation strategy and future trials. Lessons learned will be applied to future activities and inform future projects in the Darwin City Deal (Jun 2021).
- Report on DLL contributions to changes in liveability, sustainability and resilience of Darwin (Dec 2021).

1 Introduction

The Darwin Living Lab (DLL) is an initiative of the Darwin City Deal (Australian Government et al. 2018). The DLL was created to support the Darwin City Deal partners, including; Australian Government, the Northern Territory Government (NTG) and the City of Darwin (CoD) to achieve their ten year plan to realise the vision of a vibrant, connected, tropical and attractive Darwin, that is enabled by enduring collaboration between governments, businesses and the community. CSIRO leads the DLL and developed a Theory of Change with key stakeholders through a workshop in early 2019 (Williams et al. 2019), which has guided the formation of the DLL and refinement of the vision for Darwin in the context of heat mitigation and tropical urban design.

This refined vision for Darwin developed in the 2019 workshop was for Darwin to become the 'thriving, cool[1] capital of the north', with participants mapping the various activities and partnerships that would be required for this vision to be realised and associated changes to occur. One of the priority projects for the DLL identified in this workshop was the scoping of a Monitoring Evaluation and Learning (MEL) framework that could be used to 'track' the impact of the DLL and progress towards the changes in Darwin that have been envisioned. This report presents the findings of this project, guided by the following MEL objectives:

- To monitor, evaluate and learn from the activities and outcomes of the DLL in order to inform decision-making within the DLL
- To monitor the trajectories of Darwin's liveability, sustainability and resilience, building the data infrastructure and analytics for tracking change over time and informing decision making.

1.1 Methods and approach

The starting point for the project was a literature review of MEL approaches that have been taken in other living labs or similar place-based, multi-sectoral collaborations around the world.

Key characteristics of living labs identified in the literature review are consistent with those identified by DLL stakeholders in developing the DLL Theory of Change:

- Bring stakeholders together to work collaboratively and inclusively in ways which grow the social and institutional networks needed to build the capacity for Darwin to realise its vision and be open to new information and ways of doing things
- Co-develop new approaches to technical innovation by involving the citizens of Darwin in ways that ensure their perspectives are heard and taken into account in experimentation and decision-making
- Collaboratively develop and trial options for heat mitigation, reducing energy use, improving tropical urban design, and creating new smart city knowledge products
- Learn from these actions so that we can evolve and improve the way we work over the life of the lab.

[1] Adapted from the vision for Darwin articulated in the City Deal. 'Cool' is intended to mean greater thermal comfort as a result of effective heat mitigation measures rather than an expectation that the Darwin climate would become cooler in the future. Advisory Group participants in the DLL start-up workshop also used 'cool' to mean 'funky' – reflecting an aspiration for the Darwin character and lifestyle that would make it an appealing place to live.

The MEL framework developed in this project has been constructed as a collection of testable hypotheses about how the DLL can assist Darwin to become more liveable, sustainable and resilient, aligned with the four key points outlined above. These hypotheses (expressed as impact pathways and described more fully in Section 2.3) contain explicit and implicit assumptions that a given set of activities or outputs will actually lead to a desired near-term outcome. The design and implementation of the MEL framework will allow these assumptions to be tested so that the hypotheses (impact pathways) can be updated over time, based on new understanding about the system as well as how change can be brought about.

The steps involved in developing the MEL framework were:

1. A workshop was held with the DLL Advisory Group to develop a Theory of Change (ToC) for Darwin; a description of how change could occur progressively over time in order to achieve the vision for Darwin, showing possible contributions from the DLL. Developing a ToC collaboratively enables participants to develop a shared vision for the change that is sought and to share and discuss their perspectives on what is required to realise it. Assumptions about how change occurs are also revealed, along with barriers and enablers, which can be tested through implementation of the MEL framework.
2. A set of impact pathways was developed for the DLL, building on the ToC. Impact pathways are plausible narratives that describe how DLL activities and their outputs are envisaged over time to lead to desirable outcomes and then to impacts, making a contribution to realising the vision for Darwin.
3. Indicators were developed to track the progress of the DLL and Darwin over time. Indicators were derived from the ToC, the impact pathways and the scientific literature. The indicators were designed to track social and institutional change arising through the activities of the DLL as well as key measurable changes in Darwin.
4. Methods and scheduling were developed for data gathering, analysis and synthesis and review and discussion of the results with stakeholders. This will assist stakeholders to develop a shared understanding of how well the DLL and Darwin are progressing towards their objectives and identify any changes needed.

2 How will the DLL make a difference in Darwin?

2.1 Influencing system change

The DLL is endeavouring to influence and enable change through working with key stakeholders (including citizens in some instances) to develop, test and potentially implement Darwin-appropriate innovations. Innovation is both technical and social; while it may involve technical information and technologies, it also involves people making sense of and interacting with technical information and technologies and with each other. Perspectives can be many and varied, depending on values, resources, politics, networks, and dependence on existing ways of doing things. Innovation includes changes in how people interact with, access and use resources and in the management and regulation of those interactions.

Innovation occurs at multiple scales. In the context of sustainable urban development, there is a growing understanding of the barriers to and enablers of innovation (Quezada et al. 2016, Quezada and Harman 2016). It is now also recognised that for the scale of urban transformation that is required to address the United Nation's Sustainable Development Goals (SDGs) by 2030, cities will need to do things differently (Elmqvist 2019). Typically, within Australia, as with other countries around the world, the main mechanism

for improving the sustainability performance of the built environment is through the lifting of minimum performance standards (Moore et al. 2020). Standards are important but are a slow pathway to change.

Place-based, multi-sectoral urban sustainability collaborations with a focus on experimentation and learning are attracting global interest as a way of de-risking and accelerating innovation (Elmqvist et al. 2019). They are seen as a strategic response to urban policy problems of a complex nature (McGann et al. 2019) that appreciates the role for science and scientists in helping to close the gap between the stated goals of sustainability and what is often delivered in practice (Webb et al. 2018). Such collaborations aim to foster stakeholder interactions and build flexibility and adaptability in urban governance, through a focus on the testing and evaluation of innovations 'on paper' or in 'pilots and trials' to inform decision making.

Little is known about how social and institutional arrangements co-evolve with urban experimentation (Raven et al. 2017). Doing things differently and involving different people happens over time. We view this as a learning process at both the individual and collective scale – not in the sense of striving for a learning goal that has been set externally but in the sense of discovery. We anticipate that as diverse people and partners in Darwin wrestle with ideas and the constraints of prevailing norms, they may develop new perspectives and ways of working that enable different decisions to be made. Tracking systemic change is about tracking and learning from this change process. It enables adaptive management, whereby there is a feedback loop, so the plans and actions within the DLL can be continually improved, as needed.

2.2 Initial 'Theory of Change' for Darwin

As noted earlier, an initial Theory of Change (ToC) for Darwin was developed at a workshop held in Darwin in March 2019 (Williams et al. 2019), with a range of DLL stakeholders who now comprise the core of the DLL Advisory Group. This ToC provides a description of how the DLL Advisory Group and CSIRO researchers envisioned what needs to happen in order to achieve the vision for Darwin and how the DLL potentially contributes.

The development of a ToC is used widely in international development for project and impact planning (Maru et al. 2018). ToCs are often used to develop a shared understanding of how a desired change might come about, by working backwards from a shared vision to flesh out the activities and interventions that are needed for that change to occur. A clear ToC narrative can help those involved in a project reflect on the relationships between different activities and interventions, and how that might affect achievement of the desired change, as well as challenge the prevailing underlying assumptions. A ToC can be used to guide the planning and development of projects that are targeted towards achieving certain desired outcomes.

2.3 Impact pathway narratives for the DLL

Since the ToC workshop in 2019, implementation of the initial DLL projects has enabled the development of a clearer set of impact pathway narratives for the DLL (listed as 1-4 below); plausible narratives about how DLL activities and their outputs can, over time, make a contribution to realising the vision for Darwin. Together, the impact pathways reflect the range of strategies being employed through the DLL. Additional impact pathways will be developed in the future as the domains of activity in the DLL expand (e.g. building energy performance).

It is important to note, that as the DLL is one of several initiatives aimed at achieving the vision for Darwin (see Appendix A.1), any changes at city scale will be a result of the cumulative effect of multiple initiatives.

1. Innovations in urban heat mitigation for Darwin that improve liveability and grow the economy

The heat mitigation impact pathway has three intersecting sub-pathways:

1) In partnership with government, industry and community, identify and implement equitable, evidence-based and climate-appropriate interventions, as well as good practice governance and urban planning and design, in response to the challenge of increasing temperatures and extreme heat. This may include planning and retrofitting for heat mitigation through the strategic use of cool building design and materials, water sensitive urban design, and increasing vegetation cover.
2) Trial new ideas and test approaches, in context-specific ways, drawing on experiences from other cities with similar wet/dry tropical climates. This will foster a culture of experimentation in Darwin through an iterative process of learning-by-doing, helping to de-risk and accelerate uptake of innovation, and translate the vision for Darwin into shorter-term and more concrete action and practices.
3) Learn to live with heat, which will include working with Larrakia as the traditional custodians of the Darwin region, to respectfully learn from their cultural knowledge about living with heat and enable behavioural changes, so that people are better able to adapt to hotter conditions.

Collectively, these sub-pathways are anticipated to lead to new jobs (construction, research, and 'living with heat' export industries'), reduce electricity use and emissions, and lead to better health outcomes for all resulting from improved urban design for the wet/dry tropics, advanced technologies for urban cooling and behavioural changes. If people feel cooler in Darwin, that will lead to increased human wellbeing and productivity. Darwin will be recognised as a more attractive place to live, work, study, do business and visit, leading to an increase in both population and visitors, with residents spending more time in the city (particularly outdoors), growing the local economy and improving the quality of life in Darwin.

2. Infastructure and analytics for tracking change in Darwin's liveability, sustainability and resilience

Developing and tracking a core set of indicators for Darwin that align with the DLL impact pathways will provide information on the cumulative impact of investments in Darwin on improvements in liveability, sustainability and resilience. This includes investments in Darwin as part of the DLL, the broader City Deal, and beyond. The focus is not on attribution of change to particular investments as in many cases it will not be possible to untangle the cumulative effect that multiple initiatives have on liveability, sustainability and resilience. Instead, developing and tracking a core set of indicators for Darwin will allow CSIRO to:

- provide better understanding of the factors that contribute to Darwin's urban environs feeling cooler to live in, which will assist with the identification of ways to achieve that outcome.
- report on changes in the 'state of Darwin' with respect to aspects of liveability, sustainability and resilience, which will help DLL partners assess progress towards the vision for Darwin.

3. Building the capacity and networks for collaborative governance to guide urban transformation

Working together collaboratively in the DLL will build the capacity (knowledge, tools and competencies) and multi-sectoral networks of partners and stakeholders across sectors (industry, community, research and government) and levels (i.e. city, Territory, national and international) so that DLL participants will:

- be better able to understand their own information gaps and needs and how to find and access this information
- improve their understanding of the system/context that they are intervening in, enabling them to better identify what needs to be addressed and how to do that to achieve their goals

- be more likely to feel a sense of ownership of and support for DLL activity among partners and their wider stakeholders so that they are more likely to use insights generated from the DLL
- develop capacity to work together, embracing new ways of knowledge sharing and decision-making, leading to transformed, more socially inclusive governance in Darwin.

4. **Utilising effective co-production processes to develop and deliver outputs that are tailored to user needs and enhance engagement from current partners and stakeholders and entice new collaborations to emerge**

Working collaboratively with our multiple partners and co-producing where possible takes considerably more time and resources than regular science projects. However, if done effectively, it will contribute to more effective outcomes for Darwin, so that DLL projects build on and contribute to each other over the ten-year life of the City Deal, with the contribution of the DLL becoming more than the sum of its parts:

- partners see the living lab as an exemplar way of working and celebrate the DLL in announcements, use findings to improve policy and practice and help secure additional funding/resourcing
- benefits to all partners and stakeholders in the DLL:
  - that participants learn from each other and their partners (e.g. social learning, tools, approaches, and insights) leading to the development of new projects, more impactful projects and development of new knowledge and capacity
  - The DLL becomes a desirable initiative to be a part of and is recognised as an impactful mode of collaboration
  - partners and project teams perceive the benefits they are experiencing from participating in the 'Living Lab' are greater than if they had separate, isolated projects occuring concurrently (i.e. the benefits outweigh the additional time/effort of working through the Living Lab delivery approach).

3 Proposed 'Tracking Darwin' framework

3.1 Design and process overview

Studies have explored the conditions that enhance effectiveness of living labs, however there are increasing calls to improve monitoring, evaluation and learning. In part, this is due to the focus on individual project evaluation, rather than what the lab achieves as a whole (i.e. meta-learning). As a result, there is limited understanding of the success of living labs and their role in driving wider systemic change, with an increasing number of labs that fail to lead to transferability or wider systemic change/sustainability transitions (van Geenhuizen, 2018, von Wirth et al., 2019, Van Geenhuizen, 2019).

Living lab MEL challenges or gaps identified by others include:

- a lack of understanding of how the co-creation and co-production takes place within living labs and how the co-creation and role of partnerships influences impact (Puerari et al., 2018, Culwick et al., 2019)
- Understanding what the enabling governance arrangements are (von Wirth et al., 2019)
- Understanding how urban resilience strategies are actually implemented in practice (Fastenrath et al., 2019)

- how these experiments inform wider urban sustainability transitions (Culwick et al., 2019, Schäpke et al., 2018)

Figure 1. outlines the iterative 'Tracking Darwin' process that is proposed here and how monitoring and evaluation data gathering and collective review contributes to learning by those participating in the DLL and informs ongoing updating of the DLL operations and activities. It is envisaged individual DLL projects will be engaged in MEL activities at the project scale, contributing to the MEL of the DLL initiative as a whole.

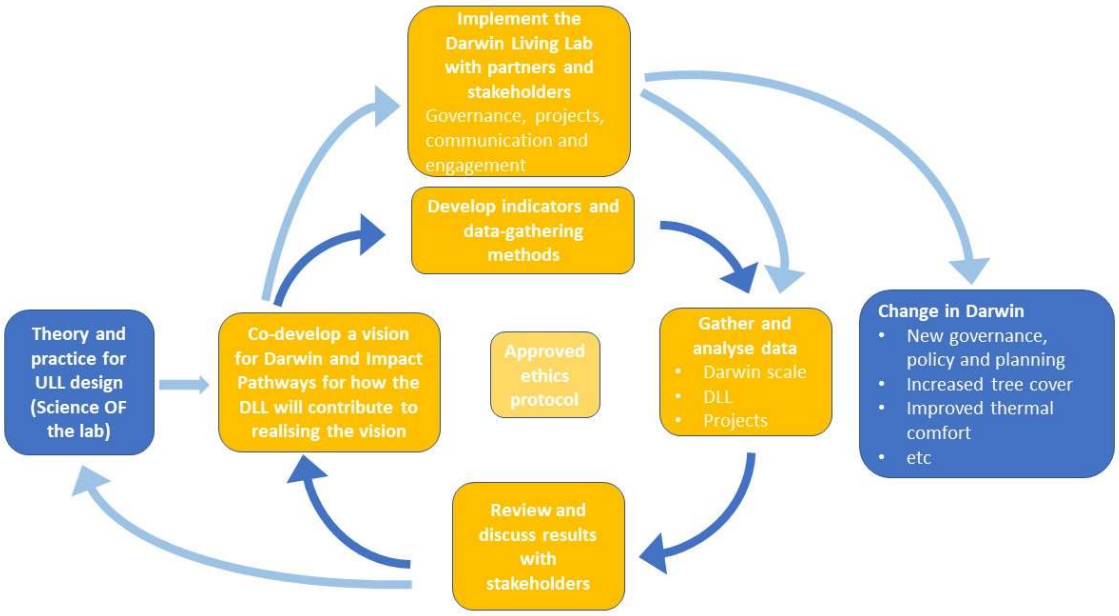


Figure 1 Summarised Monitoring Evaluation and Learning process and how it informs ongoing development of the Darwin Living Lab and contributes to change in Darwin

It is important to note that within DLL projects, investigation of the effectiveness of particular technologies to mitigate heat in the city and to make it more liveable, sustainable and resilient will be monitored according to scientific experimental designs which may consider different variables than those being monitored at the whole of Darwin scale. Furthermore, changes in thermal comfort in Darwin could be influenced by a range of initiatives at different scales, including those implemented under the City Deal, as well as other NTG and CoD activities and projects that are developed and implemented outside the DLL.

For example, through implementation of its Greening Darwin strategy, the City of Darwin is seeking to increase the tree cover in Darwin. This is anticipated to contribute to cooling Darwin as well as enhancing the aesthetic appeal of the city environment, both of which aim to enhance the attractiveness/liveability of the city for residents and visitors. Other cooling initiatives outlined in Appendix A.1 are targeted at more localised scales, such as shifting car parks underground to reduce the amount of asphalt at street level and trials such as the Cavenagh Street shade cover and cool pavement trial. Therefore, to tell a holistic story of how Darwin is changing we are likely to draw on monitoring associated with initiatives delivered by others in the city.

3.2 Identification of indicators

A key part of 'Tracking Darwin' is the identification of indicators. Two sets of indicators are described in this section; those which track the outputs of the DLL and the social and institutional dimensions of change

influenced through the DLL (Table 1) and those which track quantitative measures of change in Darwin's liveability, sustainability and resilience (Table 2). The indicators reflect successive levels of change along the impact pathways (Figure 2), where intentional change is conceptualised as a process of collective capacity building (see Avenharju et al. 2018, Butler et al. 2016, Hummelbrummer et al. 2013).

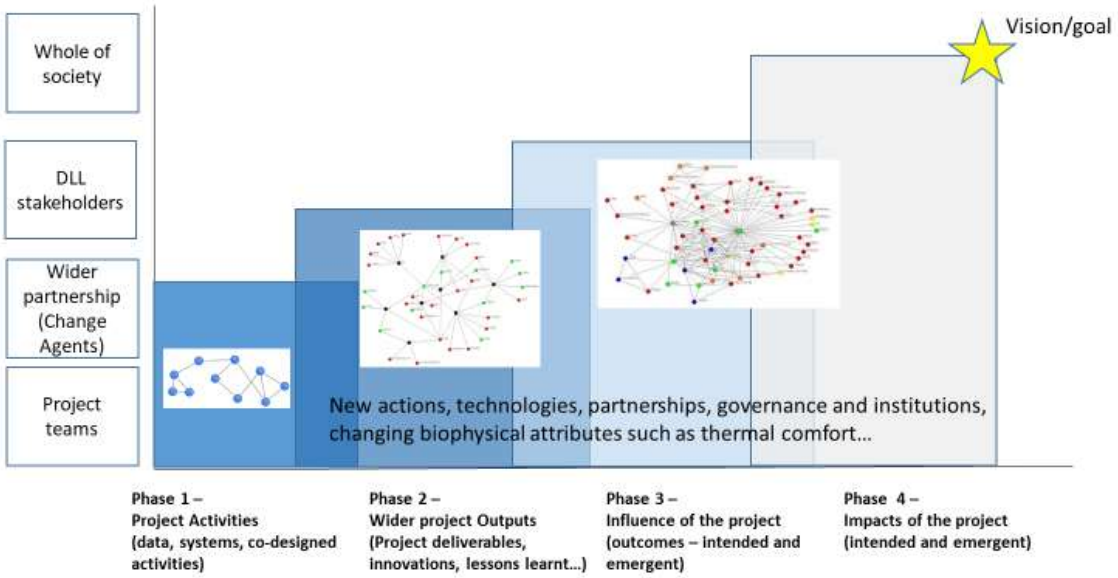


Figure 2 The four concurrent impact phases of the Darwin Living Lab, highlighting the growing stakeholder participation and networks

The indicators of the 'state' of Darwin in terms of liveability, sustainability and resilience are designed to capture desired outcomes at the 'whole of Darwin' scale but may also show changes at a more localised scale e.g. heat mapping and vegetation mapping, which will assist in attributing the effects of localised experiments. These indicators were developed through consideration of the UN Sustainable Development Goals (SDG's; United Nations, 2015) with relevance for Darwin, drawing on a number of leading and nationally-relevant indicator frameworks (Arundel et al., 2017; AURIN, 2019; Chan et al. 2014; Commonwealth of Australia, 2017; ISO 2014) and using the impact pathways as a filter.

3.2.1 Indicators of change associated with the DLL

Table 1 outlines the high-level indicators that will enable the tracking of how the DLL activities contribute to change in in Darwin.

Table 1 Indicators of change aligned with Darwin Living Lab impact phases over time

Alignment with Project impact phases (time)	Indicator	What we hope to learn	Rationale for choice of indicator
Phase1 - Project Activities	1. Participation	Capacity building and other participation activities: • numbers who participated in workshops, training etc. • have we got the right people? • which stakeholder group they come from? *Aligned to Impact Pathway 3*	Involving partners and stakeholders in DLL activities is a first step in building the awareness and trusting relationships necessary to implement a DLL.
	2. Stakeholder Engagement	How well the DLL CSIRO project team has engaged city, Territory and Commonwealth stakeholders in the development of the lab: • were we able to engage people effectively? • did people like the way they were engaged? *Aligned to all Impact Pathways*	Effective engagement and communication outputs builds/changes the participating stakeholders' understanding of what Darwin could be like as a thriving cool capital of the north and provides them with new ways of talking about that (and how this vision for Darwin might be achieved).
	3. Trust created	The extent to which people are willing to share their insights with each other within and across the project team and DLL stakeholders. *Aligned to all Impact Pathways*	Effective collaboration processes build trust and provide opportunities for shared learning, in a virtuous cycle (i.e. positive and reinforcing loop).
	4. Leadership emerging or changing	The extent to which people are sharing their insights about the DLL and its projects with others outside the projects and suggesting and initiating activities *Aligned to all Impact Pathways*	Darwin-based support for and leadership of initiatives are key steps towards innovation becoming self-sustaining in Darwin.

Phase 2 - Wider project Outputs	5. New knowledge created	What knowledge outputs are being generated through the DLL? e.g. outputs that are useable and useful, salient, credible and legitimate. These will be co-generated through the project activities of the research teams working with their partners. *Aligned to all Impact Pathways*	Knowledge outputs can be a key precursor to identifying and selecting actions and projects for the DLL and Darwin (e.g. the Heat Mitigation Strategy, the Tropical Design Guide, the information generated through developing and monitoring key indicators in Darwin, the MEL output). Generating useful outputs is a tangible indicator of achievement through the DLL and will be essential for the DLL to be valued by stakeholders.
	6. New technical innovation options developed and trialled	What technical innovations are being trialled through the DLL? e.g. cool materials and products, urban retrofitting, planting green infrastructure, etc). These will be co-generated through the project activities of the research teams working with their partners. *Aligned to all Impact Pathways*	Trialling technical innovation options is a precursor to being able to inform wider-scale change. Trialling of options that have been suggested through the DLL (e.g. in the Heat Mitigation Strategy, Tropical Design Guide, etc) can be attributed to the influence of the DLL. This is because it requires agreement from Darwin stakeholders and is therefore an indication that the DLL is being supported and is able to progress.
	7. New capacity built	How the capacity of partners, decision makers and key Darwin stakeholders to undertake systemic change is developing. Core skills include the ability to work together across boundaries, systems thinking, learning, strategic, normative and critical thinking, future thinking, openness, ability to manage ambiguity. *Aligned to all Impact Pathways*	These are core competencies for enabling systemic change which need to develop through people working together and sharing their knowledge.
Phase 3 Outcomes Influenced by the DLL (outputs to outcomes)	8. New cross-scale networks establish, old networks strengthened	The extent to which Government (multi-level), communities and business are increasingly operating in collaborative arrangements where learning is a valued output. New networks are established or old networks are strengthened within the project/partnership teams and the direct participants /stakeholders (i.e. second impact scale – see Figure 2). *Primarily aligned to Impact Pathway 3*	Innovation requires stakeholders in the problem domain to collaborate effectively, including people who may not usually work together. The development of these new networks is a key step in that process.
	9. New perspectives on what needs to change to achieve the vision for Darwin and how that might be achieved.	Whether different understandings of Darwin's challenges and how to address them are emerging? For instance, are people changing the way they think, their views, or expectations about: • what makes a thriving city? • What needs to change? • Who needs to change what they are doing and how? *An outcome along all Impact Pathways*	Innovation can arise through new ways of defining the problem leading to new options for addressing it. New problem definitions can emerge through constructive dialogue between the science, the public and private sectors and community.

	10. Decision makers feel empowered to bring about change.	Whether and how decision-makers and communities are open to acting differently and recognise that they have a role to play in making Darwin thrive. *Aligned to Impact Pathways 1, 3 and 4*	Systemic change affects everyone. It is likely to require changes in policy and legislation, in how organisations operate, and in how people live. It requires people to feel able (allowed, capable) to do things differently. Note: A decision maker is any person who makes a choice, whether that is a high-level decision maker who is responsible for an initiative, policy or plan or a citizen trialling new technology in their home.
	11. Creation of new ways to undertake planning and management, as well as changes to institutions etc (Governance and Institutions)	The extent to which there have been changes in formal or informal institutions (rules) or new ones introduced. This can include guidance, policy, legislation, regulations, governance (i.e. decision-making processes and who's involved) for urban sustainability. *Aligned to Impact Pathways 1 and 3*	Systemic change requires changes in governance, policy and legislation.
	12. Changes in investment, potentially in partnership with the private sector	The extent to which new funding models and funding are available to facilitate the changes required to mitigate heat, improve tropical design, and reduce energy use in Darwin. *Aligned to Impact Pathways 1 and 3*	Implementation of change in Darwin will require new or re-directed funding, which could be enabled through new policy and/or new funding models such as public-private partnerships.
	13. New partnerships formed	The extent to which increasingly collaborative and systemic approaches to the (re)vitalisation of Darwin develop between the DLL partners and stakeholders (e.g. MOUs, new projects etc). *Aligned to Impact Pathways 1 and 3*	Innovation will require new partnerships, realised through initiatives in which the partners work together, potentially enabled by policy changes and contributing to new funding models.
Phase 4 Impacts contributed to by the DLL	14. Darwin feels like a better place to live	The extent to which Darwin feels like a better place to live: • Perceived improvement in thermal comfort • Sense of Darwin being safer • Increased contribution of community voices to decision-making • Enhanced pride in the city As measured using relevant indicators identified in Appendix A.2 and summarised in Section 3.2.2 following.	Stakeholder perceptions of how Darwin is changing affect their view of Darwin.

3.2.2 Indicators for quantitative tracking of change in Darwin

Developing a set of indicators for quantitative tracking of change in Darwin allows CSIRO to report on changes in the 'state of Darwin' with respect to liveability, sustainability and resilience. Such a framework needs to holistic (i.e. be able to integrate liveability, sustainability and resilience) and also needs to place Darwin in a global context with respect to sustainability, resilience and comparative liveability. The UN Sustainable Development Goals (SDG's; UN, 2015) was deemed to provide a suitable and relevant framework to represent global and holistic targets (i.e. has 17 goals and 169 targets/indicators) and provided a suitable starting point for evaluating indicators of particular relevance to Darwin and its context (Cork et al., 2016). Several leading and nationally relevant frameworks (Arundel et al., 2017; AURIN, 2019; Chan et al. 2014; Commonwealth of Australia, 2017; ISO 2014) were reviewed for indicators of potential use for describing the SDG targets. These indicators were then filtered against the impact pathway narratives, paying attention to the attributes required for Essential Variables (EVs) (Reyers et al., 2017). EVs seek to reduce the number of primary observations that are required in order to describe a system. They also seek to be independent of changing policy priorities.

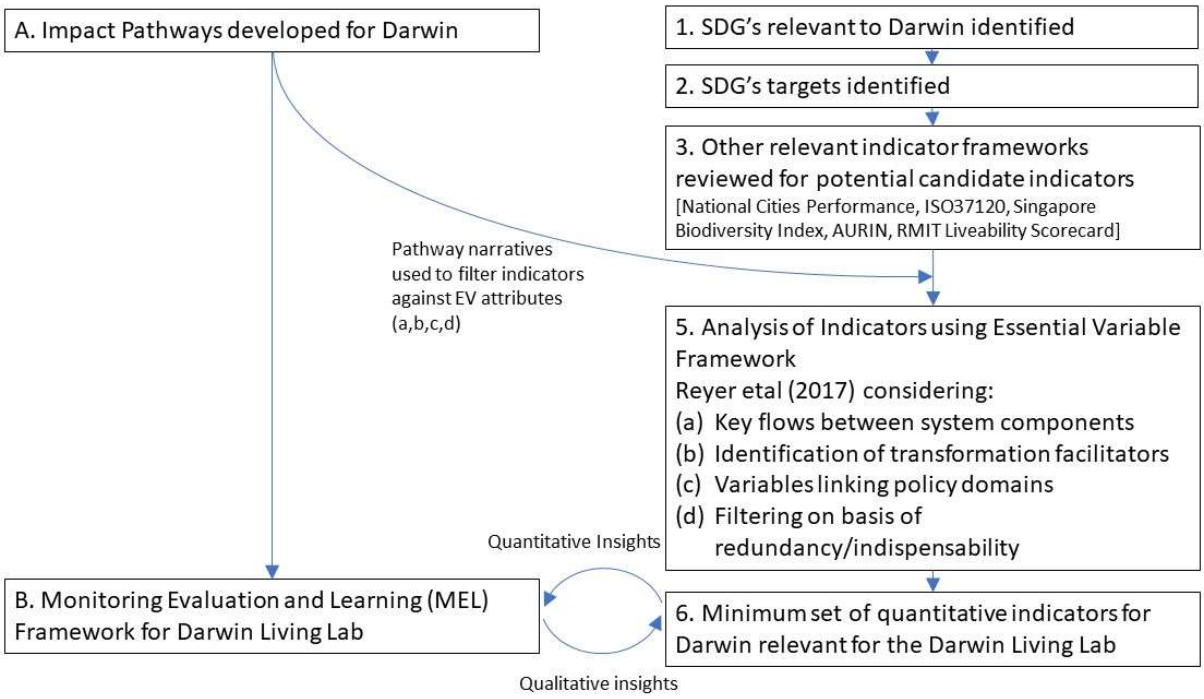


Figure 3 Process for defining the scope for an initial indicator framework for quantitative measurement of change in Darwin

A primary set of 22 indicators has been identified, as outlined in full detail in Appendix A.2. Table 2 provides a summary representation of these initial indicators for measuring change in Darwin.

Table 2. Summary of indicators for tracking the 'State' of Darwin's liveability, sustainability and resilience.

Outcome	Assumed hypotheses and knowledge	Primary Indicators	Primary Observations	Secondary Indicators
Darwin becomes more liveable Attributes of liveability are assumed to be thermally comfortable, healthy and inclusive (equitable for all).	A city with increased thermal comfort has reduced absorption of solar energy i.e. it will reflect, it will have more shade, it will use vegetation and water to cool via evapotranspiration (assisted by wind), dehumidify at ground level using energy, decrease HVAC exhaust (more energy efficient buildings and efficient HVAC) and increase the height of building HVAC exhausts. Changes within the city to mitigate heat will lead to increased thermal comfort and city use. The city will be used more actively (active transport). Liveability and the use of outdoor areas is also impacted by poor air quality during the dry season, and both heat stress and air quality will impact on human health and impact on hospital admissions. A healthy and inclusive city will provide advice and refuge for all of its users to avoid heat stress and poor air quality; it will be safe and exhibit good behaviours. Its people will have a voice to maintain their culture and values, and its people will have pride in the city.	**1. Vegetation cover** **2. Vegetation height** **3. Shade** **4. Land Surface Temperature** **5. Thermal Comfort (to be determined)** **6. Integrated amount of people in the CBD**	**To inform Thermal Comfort. Wind speed, direction, humidity, ambient temperature, pressure, Wet bulb T** **Daily Hospital Admissions** **Mode of transport**	**Particulate matter** **Number of new buildings built to climate appropriate standards/ frameworks** **%age of impervious surfaces across the City**
Darwin becomes more sustainable Attributes of sustainability are low carbon emissions, energy-efficiency, water-efficiency and waste minimisation.	Significant energy is required for HVAC systems for cooling. Increased amounts of renewable energy are required, with options including solar, wind and biogas generation. Behavioural changes in Darwin may lead to buildings being thermally controlled to higher temperatures, resulting in energy-efficiencies. More efficient Improved synergies between building design and HVAC operational efficiency will decrease HVAC usage. It considers embodied energy within infrastructure over the lifetime of the assets. Water is required for cooling and greening the city and reducing urban heat island. Effective implementation of WSUD will decrease demand for potable water. Increased greening will lead to increased volumes of green waste and can be used to generate biogas (in conjunction with other biodegradable wastes, i.e. food).	**7. Electricity use and per capita use:** residential and commercial **8. Embodied energy (CO_2) in building and pavements** **City carbon emissions?**	**Potable Water use and per capita use** **Building temperature setpoint data** **Albedo of non-permeable surface** **Percentage of permeable surface**	**Volume of waste and type** **Volume of renewable energy generated from biogas**
Darwin becomes more resilient	Implementation of innovations climate appropriate urban design, urban tree-planting etc (that is enabled by effective governance and embraced by residents) will make Darwin a more appealing place to live, work and for recreation, and spend an increased amount of time in the city. Increased city use and visitation will increase business investment. Water is required for cooling and greening the city and reducing urban heat island. Effective implementation of Water-Sensitive Urban Design (WSUD) will improve the resilience of green infrastructure measures. Improved thermal comfort and interaction with nature (more trees) are anticipated to draw people to be outdoors and engage in active lifestyles and active transport, all of which can improve wellbeing through improved physical and mental health. The number of jobs and their diversity, particularly knowledge-based jobs and the population of Darwin will then increase, so that Darwin will become the thriving cool capital of the north. Darwin has the effective collaborative governance in place for planning for the future and responding to future shocks and challenges	**9. Percentage of repurposed stormwater (water reuse more generally? As indicator of drought resilience?)** **10. Neighbourhood Heat-Health Vulnerability Index (NHVI)**		**Knowledge-based jobs: Sector share of employment (ABS, quarterly data)** **New business entrants and exits and type (ABS annually)** **Population change**

As a general rule, not all indicators carry the same weight; the importance of an indicator to stakeholders varies depending on their areas of responsibility, values and interests (Mitchell, 1996). Table 2 provides a reflection of indicator relevance to the ambitions of the Darwin City Deal and the Darwin Living Lab. For example, vegetation cover is of **primary** relevance to both due to the strategic focus on urban greening and heat mitigation. Other indicators will be of **secondary** interest to the Darwin City Deal and Darwin Living Lab, such as the volume and type of waste generated by Darwin. Nevertheless this particular example is an important indicator for understanding Darwin's sustainability and responding to national and global challenges around the circular economy, resource production and consumption.

In some instances, the observations recorded in Darwin may seek to provide the necessary inputs (as a proxy) in the absence of an appropriate indicator. For example, the Darwin Living Lab seeks to cool the city and this may interpreted in different ways; e.g. the average Land Surface Temperature may decrease, the ambient temperature may decrease, the apparent temperature may decrease. Hence, there are several observations of interest that can be used to enable a richer understanding of what it means to cool Darwin, with meteorological observations of humidity, wind speed and direction also likely to be required to build a comprehensive picture. As such, it is envisaged that with the place-based focus of the DLL, there may be the need over time to develop a unique 'aggregate' indicator of cooling, specific to the Darwin context.

It should also be recognised, that some indicators will not be available until further work is conducted within the DLL (i.e. embodied energy or the percentage of re-purposed stormwater, as examples).

3.3 Data Gathering: methods, data sources, roles

3.3.1 Ethics

Any research with or about people or their data within the DLL requires human ethics approval. This applies to 'Tracking Darwin' and means that all activities must be approved by the CSIRO Social and Interdisciplinary Science and Human Research Ethics Committee (CSSHREC) before they commence. Importantly, this will ensure that any potential emotional and/or psychological risks to people that are involved in the activities of the lab are considered and adequately addressed through the design of lab engagement activities. A human ethics protocol has been developed for the DLL, which includes a process for invitees to be able to choose whether and how they wish to be involved, as well as a process for those involved to provide their informed consent, if they choose to participate, with details of what this entails.

3.3.2 Data collection

Methods and sources for data collection for 'Tracking Darwin' are summarised in **Error! Reference source not found.** and Table 3.

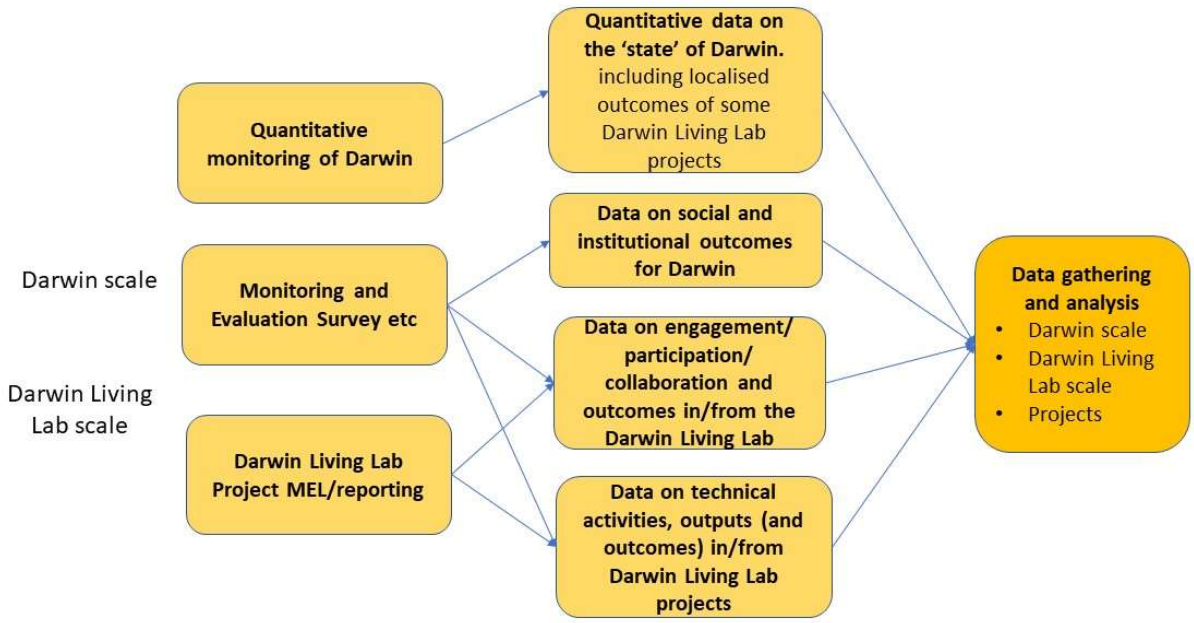


Figure 4 Summary of data streams feeding into the data collection

Qualitative MEL data will be collected via instruments such as surveys, interviews and focus groups, and may include the use of existing datasets where relevant. The main data collection instrument for tracking the influence of the DLL will be a survey that is repeated over the life of the lab, with questions designed to elicit data to address indicators 1-14 in Table 1. The survey may be administered online, using a platform such as Survey Monkey, with respondents invited to complete the survey via an email. The survey will be supplemented with a small number of interviews with key stakeholders in the DLL, across the diversity of stakeholder groups participating in the DLL (e.g. three levels of government, researchers, advisory group).

Interviews provide the opportunity to acquire a more nuanced, in depth understanding of respondents' experiences and to explore patterns that may be arising from the survey data. However, data collection through interviews is more time intensive than a survey, so interviews will be strategically targeted.

Focus groups may be used on occasion. They can be helpful for canvassing the range of experiences in relation to a particular issue or in relation to a specific project, provided people are comfortable to speak openly. The added potential value of a focus group is for participants to hear the perspectives of others, which may be different to their own. In that sense, focus groups can enable social learning among participants.

Data about project outputs will be collated from project reporting.

Project-specific MEL (technical and social) will primarily be the responsibility of projects. Where projects involve large-scale participant engagement, the DLL MEL team will be able to support the development of data collection instruments such as surveys, focus group or interview questions, but with roles and effort distribution negotiated during project scoping. Additional personnel may be required in some instances.

Quantitative data for the monitoring of changes in Darwin will be generated via instrumentation used in the DLL and other projects and drawing on pre-existing datasets (e.g. population, canopy cover, human movement patterns etc). Data for these indicators may be sourced from a range of different custodians, such as partner agencies or other stakeholders (see Appendix A.2 for further information).

Data collection will be undertaken iteratively and in parallel to the projects and activities, in order to test, evaluate and co-innovate, with results and lessons shared within the DLL and with stakeholders. This feedback loop will enable refinement of goals, visions, methods, alignment to stakeholder needs, and overall effectiveness, with lessons building knowledge and helping avoid pitfalls of implementing 'best practice' solutions that are not contextually appropriate.

3.3.3 Quantitative data assembly and integration

The DLL will assemble, collate and integrate quantitative datasets within a spatial-temporal platform (Figure 5). This will facilitate data access and analysis to assist with reporting, dialogue and decisions regarding the liveability, sustainability and resilience of Darwin, and exploration of the complex trade-offs when navigating change.

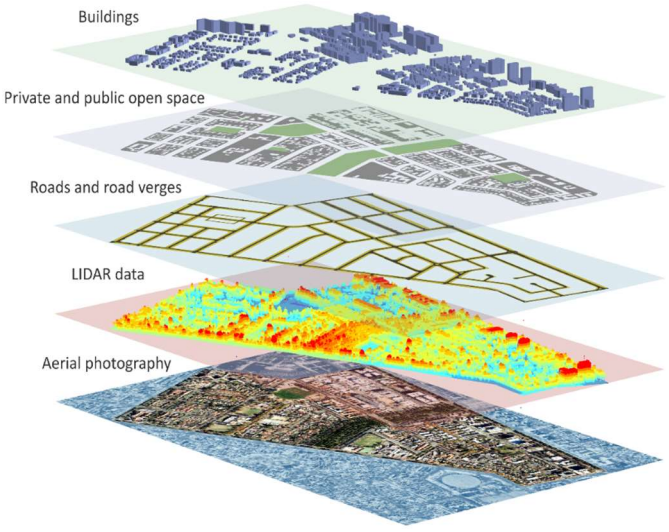


Figure 5. Series of spatial layers of different types of datasets (Schandl et al, 2020).

More specifically, the spatial-temporal data platform will provide a key infrastructure within the DLL that will help to support communication and decision making, including in both digital and written formats:

- Constructions of 3D datasets that can be used to progress towards a Digital Twin for Darwin
- Public-facing reports that communicate the dynamics of Darwin's 'state'; including observed changes and ongoing challenges, along the lines of the Greater Phoenix Regional Atlas (ASU, 2003).

Table 3 Summary of the approaches for data gathering and processing

Data Collection Rationale	Data Sources	Data Collection Methods	Who collects/synthesises at project scale	Collection Frequency	Who Synthesises (Lab scale)	Link to MEL And if so - how
Monitoring (quantitative) and learning from change in Darwin Tracking how and the extent to which Darwin is changing at the city scale	Multiple – e.g. sensors, remote sensing data, project data, partner inputs.	Multiple	Multiple – to be confirmed	Mixed - depends on data source i.e. sensor data from e.g. Smart Darwin (twice yearly), census data (5yrs)	Technical experts to make sense of the data collected MEL team to integrate it into whole of lab results	State indicators (Table 2)
MEL of the DLL Understanding and learning from the extent to which people are thinking/doing differently and perceiving change through DLL activities, including DLL outcomes and impacts, Indicators 1-14	Perspectives of project co-design participants, including researchers (differentiating between perspectives on projects and on the lab)	Survey (Focus groups, interviews on occasion)	DLL MEL team, with support of Project Leaders (PLs)	At the end of projects	MEL team	Part of MEL
	Perspectives of Management Committee Perspectives of Advisory Group	MEL Survey	DLL MEL team	Annually	MEL team	Part of MEL
Understanding and learning from the progress and outcomes of DLL activities	Perspectives of other key stakeholders – as the lab evolves	MEL Survey	DLL MEL team	See schedule	MEL team	Part of MEL
Project Achievements	Project reporting	As appropriate to the project	PL/Project Team	As appropriate to the project	MEL team with PL support	Output/outcome reporting
Additional project evaluation (MEL) where required e.g. large projects with large numbers of stakeholders e.g. the Annual Darwin Living Lab Symposium	Perspectives of project co-design participants, including researchers, (+ other participants if present)	(Focus groups, Interviews on occasion) Surveys where appropriate	PL with DLL MEL team support (projects with large citizen participation may need additional support) Roles/contributions between project and MEL teams to be discussed	At the end of projects Annually for longer projects For specific events e.g. workshops if scheduled	MEL team	Yes – from synthesised data

3.4 Data analysis, synthesis and management

In addition to the MEL activities outlined above, the DLL MEL team will need to interact with several other groups in order to: clarify what other data is being gathered and what could inform Tracking Darwin; assemble data; and collate it in a format suitable for reporting (Table 4). Four groups identified are project leaders, people gathering/synthesising quantitative monitoring data, those conducting other monitoring / MEL activities in relation to the City Deal, for example, and the communications and engagement team.

Processes are yet to be resolved with each of these groups. Potential reporting frequencies are below.

Table 4 Sources of data to inform Tracking Darwin in addition to that gathered by the Monitoring Evaluation and Learning team

Group	To work through with DLL MEL team	Proposed frequency of data sharing with the DLL MEL team
DLL MEL team	Methods for pulling data together, creating an integrated narrative and reporting format.	Annual data collection
Project Leads	Project MEL reporting format. Suggest a traffic lights report against project MEL indicators, including explanatory text for ratings (Rubrics).	Annually
Quantitative monitoring data assemblers	Collation and synthesis of quantitative monitoring data via spatial and temporal layers, including bringing in other monitoring in Darwin e.g. connecting to Switching on Darwin and related activities. Summary reporting of data (i.e. heat maps, tree canopy cover) around integrated narratives of urban liveability, sustainability and resilience.	Varied timing; 6 monthly, where necessary, to contrast seasonal extremes
Comms and Engagement team	Areas of overlap and who does what, via discussion of the Comms and Engagement plan, meeting in Darwin and ongoing discussion. The Symposium will be a useful test case.	Annually
Management Committee et al.	MEL team reporting of results	Annual

3.5 Learning together: what do we need to do differently?

Developing insights from the MEL results about what has occurred and why and using those insights to inform how the DLL develops is the key step in the learning cycle. Ideally, this will be achieved through a 'reflection and next steps' workshop, held annually, with a group of DLL stakeholders closely involved with

the lab such as the Advisory Group and Management Committee. The MEL results would be collated into a readily accessible format and shared with participants in preparation for this type of workshop.

As the 'Tracking Darwin' framework is currently designed, it will be used to:

- collate and analyse previously collected data for a limited number of high level socio-economic and biophysical indicators for Darwin, such as those outlined in the indicators in Table 2
- where directly related to a DLL project or not accessible from other sources, collect and analyse data for a limited number of key measurable indicators of the 'state' of Darwin
- collect and analyse data that assists with attribution and causality from DLL projects and activities, as well as lessons from within the Lab and with key stakeholders

This framework does not include:

- collection and analysis of data for all socio-economic and biophysical indicators for the whole of Darwin (i.e. the DLL has a focus on cooling and associated overlaps with the key objectives of liveability, sustainability and resilience and is not responsible for capturing everything that occurs)
- collection of data that enables specific attribution and causality of City Deal projects and activities
- collection of data that enables specific attribution and causality of Switching on Darwin activities

We recognise that there is interest in, and potentially a role for CSIRO, to undertake the monitoring, evaluation and learning of wider City Deal activities and Switching on Darwin. If this additional MEL is desired, options for delivery would need to be explored, to ensure appropriate design and resourcing.

4 Next steps

Next steps in the further development and implementation of the 'Tracking Darwin' framework include:

- First iteration of the Tracking Darwin survey and interviews (Nov-Dec 2020).
  - Schedule and run a 'reflection and next steps' workshop with a group of stakeholders from the Advisory Group and Management Group, drawing on the survey and interview findings (Apr-May 2021)
  - Combine survey and MEL findings with workshop outputs as input into the annual report
- Towards a digital twin of Darwin:- This project will produce a spatiotemporal prototype used to visualise and analyse baseline social, environmental, and economic conditions. It seeks to provide a foundation for improved decision making where key facets of planning (people, society, economy, and environment) are presented and examined together under one platform. Initial development will focus on:
  - Integrating available key environmental and socio-economic data into a GIS database (June 2021).
  - Develop a baseline spatial representation of Darwin's urban environment (including green infrastructure and a selected set of social, environmental, and economic inputs) relevant to liveability, sustainability and resilience indicators (Jan 2022).
  - Valuation of benefits of stocks and flows of ecosystem services of urban forests in Darwin and comparison with establishment and maintenance costs (June 2022).
- Analysis of City of Darwin sensor network and integration with smart applications:- This project provides a foundation for sensor networks to contribute to Darwin becoming a truly smart city through evidence-based decision-making, where government, community and stakeholders are empowered to take actions to mitigate and manage exposure to heat and air pollution. Initial steps include:

- Assessment of City of Darwin sensor network performance in conjunction with NT EPA/BoM reference sites
- Documented QA/QC and data analysis steps required to produce reliable data streams
- Analysis of the urban microclimate and air quality in the City of Darwin, including analysis of spatial and temporal trends during the period June 2019 – Apr/May 2021 (June 2021). This will provide new understanding of Darwin's microclimate and inform future data collection for integration with the Digital Twin.

The Tracking Darwin framework seeks to support the DLL and its partnerships to inform and effect positive change in Darwin. Due to the iterative, ongoing nature of monitoring, evaluation and learning, some components of the framework will evolve with time as new insights emerge (Figure 1). As such, Tracking Darwin should be viewed as a 'living' framework; it is anticipated that updates to impact pathways and indicators will occur as needed throughout the lifetime of the Darwin Living Lab.

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A.1 DLL in the context of other initiatives in Darwin

The Darwin Living Lab is situated within a wider, active change context aiming to make Darwin a Thriving, Cool Capital of the North.

There are a number of initiatives underway and planned in Darwin addressing Darwin's liveability, sustainability and resilience, besides the Darwin Living Lab. An outline of these initiatives and the stakeholders involved is included in Table 5. This high-level stakeholder context map will be updated over the life of the lab.

Table 5 Stakeholders' involvement in other initiatives in Darwin and existing and potential links to the Darwin Living Lab

Stakeholders	Scale / Objective focus	Contracts	Expressed Interest in DLL	CSIRO potential additional offerings
City of Darwin	Darwin LGA	City Deal Switching on Darwin Darwin Living Lab	- Want CSIRO to assist them to maximise use of Smart Darwin data for benefit of their constituents - Cooling and greening - coordination with NTG - Increased business and local jobs	Broader to regional and national science Improved methods of tree asset management, tracking their investment into greening initiatives, CBA or similar for multiple benefits.
Northern Territory Government	Darwin CBD	City Deal Activate Darwin Darwin Living Lab	- Cooling and greening coordination - Long term monitoring of impacts of combined initiatives for	- Assistance in putting in place appropriate monitoring and evaluation of actions and strategies

Stakeholders	Scale / Objective focus	Contracts	Expressed Interest in DLL	CSIRO potential additional offerings
			cooling and greening the CBD - A shared Heat Mitigation Strategy between three levels of government for Darwin - Help to demonstrate Darwin as an innovative and forward thinking place - Increased business and local jobs	- Assistance in thinking through adaptive pathways
Federal Government – Department of Infrastructure, Transport, Cities and Regional Development	Darwin as part of a network of city deals	City Deal	Thriving, cool capital of the North Economic resilience Liveability, sustainability and resilience	
CSIRO	The DLL Monitoring change in Darwin	DLL which is linked to the City Deal Potential future links to Switching on Darwin	- Broader area for analysis - Bring science and coordination - Advance towards Liveable, Sustainable and Resilient Cities	
Charles Darwin University Research Institute for the Environment Livelihoods (RIEL) and a Centre for Renewable Energy (CRE)	Wide ranging focus from various researchers from vulnerable groups to socio-economic modelling and survey work.	Ongoing local research in Darwin	Interested in continued work with the DLL if funding is available	
University of NSW	Focused on the CBD, and especially project level monitoring.	Contracted to Monitor the Cavanagh Street green implementation	Would be interested in continued work with the DLL if funding is available	

Stakeholders	Scale / Objective focus	Contracts	Expressed Interest in DLL	CSIRO potential additional offerings
		Previous contracts to collect meteorological data from the CBD area Contract with CSIRO to work with CSIRO for data access, participate in the symposium and other meetings we have.		

The City Deal

While the deal primarily focuses on Darwin's city centre it will also support future development of the Frances Bay and Stokes Hill precincts with a vision to connect the harbour foreshore to the city. Activities include:

- Education and civic precinct on Cavenagh Street, including:
    - A new city campus for CDU
    - Student accommodation
    - Moving of Council Chambers and offices to the precinct
    - A new integrated library
    - the showcasing of world class tropical design and embedded cooling and greening initiatives, including the Cavenagh Street shade structure and the cool pavement pilots which have already been implemented. Future activity such as additional shade structures and street tree planting are planned.
- Redevelopment of State Square
    - $37 million upgrade which includes the replacement of bitumen carparks with green space, landscaping and cooling reflection pools, and the construction of a multi-level car park below State Square
    - The development of a new art gallery which aims to attract more tourists to Darwin
- Connecting people and place
    - Renewed sense of place enhanced through a connection to, and celebration of, Larrakia culture
    - Improve connectivity within the city, revitalise laneways and walkways providing safe and easy access through the city
    - Establish a calendar of events, festivals and activities in Darwin. This will be led by a New City Activation and Promotion Entity who will also work with Darwin's tourism sector to further enhance visitor experiences

Darwin Living Lab

- Collaboration with researchers, industry, governments and the community
- Co-create solutions to challenges
- Maximise opportunities for innovation and learning
- Test, monitor and evaluate improvements in Darwin's liveability, sustainability and resilience
- Focus on cooling and greening for heat mitigation, tropical urban design, energy efficiency
- Showcase and extend capacity of the city, practitioners, institutions and community

Smart Darwin

One significant project is 'Switching on Darwin' which:

- Aims to deliver smart technology to encourage innovation and enhance community life
- Includes the installation of environmental sensors which measure a range of environmental factors including humidity levels, wind speed, temperature etc. Data from these sensors will be fed into a dashboard where it can be analysed by City of Darwin and made available to other organisations on request. A snapshot of key data will be publicly available on City of Darwin's website. https://www.darwin.nt.gov.au/council/transforming-darwin/key-projects/switchingondarwin

Specific activities include:-

- Upgrading 912 CBD street lights to LED smart lighting
- Extension of free Wi-Fi network
- 138 CCTV cameras in CBD
- Sensors for vehicle and pedestrian movement analysis
- Smart parking technology
- Microclimate monitoring systems
- A smart city platform

In addition to the change initiatives identified above, there are a number of strategic planning documents for Darwin and Northern Territory including but not limited to:

- Darwin City Masterplan
- The NT Government Dept Infrastructure, Planning and Logistics (DIPL):
  - ***Planning for a Vibrant Future*** (NT_Government, 2018) sets out a vision for the NT and is done in consultation with community
  - are utilising a design guide for renewal of older residential and commercial development (Northern Territory Government, 2000)
- Urban Greening Strategy (City of Darwin, to be released next year)
- Low Carbon Strategy (City of Darwin)
- Environment and Biodiversity Strategy (City of Darwin)

Heat Mitigation Strategy

- Heat Mitigation study of Darwin, by UNSW Prof Mat Santamouris, commissioned by the NT Government. Heat mapping of Darwin using thermal imaging and drone aerial monitoring identified hot spots and areas that retain heat

A.2 Liveability, sustainability and resilience indicators for Darwin

Outcome	Assumed hypotheses and narratives	SDG's relevant to Darwin	SDG targets relevant to Darwin	Candidate Observations	EV lens / Potential Science Outcomes	Minimum set of City scale key quantitative indicators	Qualitative indicators	How we will measure [and when]	Linkages
Darwin becomes more liveable Attributes of liveability are assumed to be thermally comfortable, healthy and inclusive (equitable for all).	A city with increased thermal comfort has reduced absorption of solar energy, i.e. it will reflect, it will have more shade, it will use vegetation and water to cool via evapotranspiration (assisted by wind), dehumidify at ground level using energy, decrease HVAC exhaust (more energy efficient buildings and efficient HVAC) and increase the height of building HVAC exhausts. Changes within the city to mitigate heat will lead to increased thermal comfort and city use. The city will be used more actively (active transport). Liveability and the use of outdoor areas is also impacted by poor air quality during the dry season, and both heat stress and air quality will impact on human health and	Goal 3 Ensure healthy lives and promote well-being for all ages. Goal 11 Make cities and human settlements inclusive, safe, resilient and sustainable. Goal 16: Promote peaceful and inclusive societies for sustainable development, provide access to just for all and build effective, accountable and inclusive institutions at all level	**3.9** Substantially reduce the number of deaths and illnesses from air contamination (and heat). **3.D** Strengthen the capacity for early warning, risk reduction and management of national and global health risks. **11.7** Provide universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities. **11.C** Support least developed countries, through technical assistance. **16.7** Ensure responsive,	(3.9) Particulate Matter, Heat (T, RH) or heat stress. Hospital Admissions. Deaths. (11.7) Green land cover, Reported cases of antisocial behaviour, noise pollution. Walkability to public spaces, Number of people hours spent in green spaces. (11.C) exported knowledge. Connections to other Aw climate zones. (16.7) Increases in shared strategy. Use of participatory processes.	**Thermal Comfort:** At present there is no simple way of describing thermal comfort in Darwin (i.e. it is more than temperature) and a Darwin-relevant measurement for heat stress would help the population and visitors to navigate heat extremes. Measurement of ambient temp., humidity, wind speed and direction, land surface temp., wet bulb temp, and associated parameters of dew point and apparent temp will allow clarification of thermal comfort for Darwin. **Cooling innovations:** The use of heat mitigation measures such as high albedo materials, increased tree canopy, water features, modified design, and energy-enabled cooling will	**1. Vegetation cover** **2. Vegetation height** **3. Shade** **4. Land surface temperature** **5. Wind speed, direction, humidity, ambient temperature, pressure, particulate matter** **6. Wet bulb T** **7. Daily Hospital Admissions** **8. Integrated amount of people in the CBD** **9. Mode of transport**	**10. Perceived Thermal Comfort** **11. Safety** **12. Community voice** **13. Pride in the city**	Aerial photography (Urban Monitor) to measure (1,2,3,4) [Baseline, 3 yr] LiDAR to contribute additional knowledge to (1,2,3) Landsat/ASTER to measure (4) [Baseline done, 3 yr] CoD environmental sensors to measure (5) [6 monthly assessment of data quality and systematic reporting] Installation of Wet Bulb T (6) in conjunction with a CoD station [as needed] Survey (10): is How comfortable is	Tree indexes (CoD) Airport Data BoM PWC Wunderground sensors Air quality: NT EPA, CSIRO Gunn Point Switching on Darwin CDU (student projects) Dept Transport Data CoD pedestrian counting Visitor numbers (Tourism NT) Menzies School of Health University of Sydney Coolmob

	impact on hospital admissions. A healthy and inclusive city will provide advice and refuge for all of its users to avoid heat stress and poor air quality; it will be safe and its people will exhibit good behaviours. Its people will have a voice to maintain their culture and values, and its people will have pride in the city.		inclusive, participatory and representative decision-making at all levels.		lead to local effects which will be detected as changes in land surface temperature, ambient temperature and perceived thermal comfort. **Vegetation cover:** The type of vegetation cover influences its cooling properties. For example, shade trees are more effective at offering shade and continued cooling via evapotranspiration compared to lower vegetation. **Shade:** Shade is achieved by many different objects (i.e. Engineered structures, Balconies, Trees) and leads to significant local cooling. Measurement of the degree of shade at a larger scale across the city will be an important contributor to Cooling Darwin and perceived thermal comfort. **How people use the city:** It is assumed that thermal comfort thresholds can be assessed by correlating climatic conditions with the number of people in			it? Darwin getting cooler? NT Health (7) [3 yr] CoD CCTV movement (8,9)	Troppo PlaceScore UNSW Model for Darwin Darwin Digital Twin CSIRO Spatiotemporal modelling (of change)

					outdoor areas (as can be inferred from randomised CCTV data). **Healthy city:** Both heat stress and air quality have known impacts on public health. Darwin is known to have poor air quality at certain times of year and may impact on hospital admissions. The mode of transport around the city (walking, jogging, cycling, motorbike, car, bus) will provide an indication of active and healthy transport choices.				
Darwin becomes more sustainable Attributes of sustainability are low carbon emissions, energy-efficiency, water-efficiency and waste minimisation.	Significant energy is required for HVAC systems for cooling. Increased amounts of renewable energy are required, with options including solar, wind and biogas generation. Behavioural changes in Darwin may lead to buildings being thermally controlled to higher temperatures, resulting in energy-efficiencies. More efficient Improved synergies between building design and HVAC operational efficiency will decrease HVAC usage. By also considering embodied	Goal 6 ensure availability and sustainable management of water and sanitation for all. Goal 7 ensure access to affordable, reliable, sustainable and modern energy for all. Goal 11 Make cities and human settlements inclusive, safe, resilient and sustainable.	**6.4** Increase water-use efficiency across all sectors to reduce the number of people suffering from water scarcity **6.5** Implement integrated water resources management. **6.A** Expand cooperation and capacity-building support to developing countries in water technology **7.2 I**ncrease substantially the share of	(6.4) Potable water use and per capita efficiency. (6.5) Percentage of stormwater utilisation. Percentage of wastewater reuse. (6A) export of knowledge. (7.2) Percentage of renewable energy generation. (7.3) Electricity use and per capita use. Gas and fuel use.	**Electricity use and per capita use:** Improved building design, uptake of energy-efficient design (including shade from trees, cool roofs) and innovation will lead to decreased energy use for both commercial and residential. **Water use and per capita use:** Stormwater and recycled water are used to irrigate green spaces and provide cooling for Darwin all year round. The presence of adequate water in Darwin allows wind to play a	14. **Electricity use and per capita use:** residential and commercial 15. **Potable Water use and per capita use** 16. **Percentage of renewable energy:** residential and commercial 17. **Volume of waste and type** 18. **Volume of renewable energy generated from biogas** 19. **Building temperature setpoint data** 20. **Embodied energy (CO2) in building and pavements** 21. **Percentage of permeable surface**	Integrated policy	Reported annual values (14,15,16) [collate every 3 yrs] Possibly a secondary dataset and acquired as necessary from CoD and other data sources (17,18) Survey or collect data from partners (19) Develop in conjunction with Spatiotemporal model of materials (20) Urban Monitor (21,22)	Coolmob UNSW University of Adelaide

	energy within infrastructure over the lifetime of the assets improved decisions can be made to lower resource consumption and improve building design. Water is required for cooling and greening the city and reducing urban heat island. Effective implementation of WSUD will decrease demand for potable water. Increased greening will lead to increased volumes of green waste and can be used to generate biogas (in conjunction with other biodegradable wastes, i.e. food).	Goal 12: Ensure sustainable consumption and production patterns. Goal 13: Take urgent action to combat climate change and its impacts	renewable energy. **7.3 D**ouble the rate of improvement in energy efficiency. **11.B I**ncrease the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change. **12.2** By 2030, achieve the sustainable management and efficient use of natural resources **12.5** By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse.	(11B) Increases in shared strategy development. (12.2) Embodied energy, water and materials. (12.5) Reduced consumption of materials. Waste generation. Percentage of Waste recycled.	more effective role in cooling. Potable water usage and per capita usage will not be affected by the need to use water for cooling in Darwin. **Renewable energy:** the percentage of energy that is derived from renewables will increase and the way that energy is used will be used for cooling will change as a result of the energy transition. **Waste to Energy:** increasing green/biodegradable waste can be converted to biogas, creating increased amounts of renewable energy. **Building energy efficiency:** Personal preference of Darwin residents allows temperature setpoint to be set higher. **Embodied energy:** through changes in building design and construction, the embodied energy (CO2 equivalent) of new buildings can contribute to energy efficiency, as can a reduction road surface area.	22. **Albedo of non-permeable surface**			

					Permeable surface and albedo: an increased area of permeable surface will allow Darwin to have greater cooling via evapotranspiration, as will an increased albedo of non-permeable surfaces				
Darwin becomes more resilient	Implementation of climate appropriate urban design, urban tree-planting etc (that is enabled by effective governance and embraced by residents) will make Darwin a more appealing place for work and recreation, and people will spend an increased amount of time in the city. Increased city use and visitation will increase business investment. Water is required for cooling and greening the city and reducing urban heat island. Effective implementation of Water-Sensitive Urban Design (WSUD) will improve the resilience of green infrastructure measures. Improved thermal comfort and interaction with nature (more trees) are anticipated to draw people to be	Goal 8 Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all. Goal 9: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation. Goal 11 Make cities and human settlements inclusive, safe, resilient and sustainable. Goal 13: Take urgent action to combat climate change and its impacts. Goal 16: Promote	**8.2** Achieve higher levels of economic productivity through diversification, technological upgrading and innovation, including through a focus on high-value added and labour-intensive sectors. **8.4** Improve progressively, through 2030, global resource efficiency in consumption and production. **8.9** By 2030, devise and implement policies to promote sustainable tourism that creates jobs and promotes local culture and products. **9.1** Develop quality, reliable, sustainable and	(8.2) Knowledge-intensive services, business entrances/exits. (8.4) Percentage of water recycled, Percentage of waste repurposed. (8.9) Number of people in the CBD [due to tourism]. (9.1) Thermal comfort in outdoor spaces, more people in CBD. Green infrastructure is healthy year round (against wind and heat). Neighbourhood Heat-Health Vulnerability Index (NHVI). (11.3/B) Community is engaged in decision-making and strategies	**Darwin is a more appealing place:** residents have a sense of pride. **More people actively using the city:** A more liveable, cooler Darwin leads to more people in the outdoor spaces (from local, students, tourism), particularly those that are vulnerable as identified by the NHVI. **Climate-independent water:** Implementation of WSUD leads to increased use of rainwater and stormwater, assisting to provide a climate-resilient water cycle. More climate-resilient green infrastructure will promote improved biodiversity resilience. **Sector share of employment, New**	**Integrated number of people in the city (8)** 23. **Percentage of repurposed stormwater** **24. Sector share of employment (ABS, quarterly data, Professional Technical Services)** **25. New business entrants and exits and type (ABS annually)** **26. NHVI**	**Pride in the city (13)**	Undertake analysis of WSUD implementations and changes to the urban water cycle. (Baseline, then report as appropriate for 23). Acquire ABS data for industry and employment data (24,25) Acquire ABS data to update NHVI (26)	NTG (Treasury/Finance) NT Tourism (contextual information from visitation data) CoD (population and demographics) Access ABS SA2 annually Knowledge intensive services (ABS - Labour Force Survey, Regional Population Growth, DIIS monitor) New business entrants and exits GINI (2021,2026) Biodiversity baseline Vegetation resilience against cyclones and drought

	outdoors and engage in active lifestyles and active transport, all of which can improve community resilience and wellbeing through improved interactions. The number of jobs and their diversity, particularly knowledge-based jobs and the population of Darwin will then increase, so that Darwin will become the thriving cool capital of the north. Specific resilience against cyclones includes forethought on the selection of appropriate tree species, robust design of structures and the ability for innovations to recover post cyclone. Specific resilience against storms includes forethought on the ability to withstand hail and intensive rain events, and recovery post storm. Specific resilience against extended dry periods and heat waves includes the forethought for the innovations to avoid mechanical/structural damage, and to have necessary access to water.	peaceful and inclusive societies for sustainable development, provide access to just for all and build effective, accountable and inclusive institutions at all level.	resilient infrastructure to support economic development and human well-being, with a focus on affordable and equitable access for all. **11.3** Enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management **11.B** Increase the number of cities and human settlements adopting and implementing integrated policies and plans towards adaptation to climate change, resilience to disasters, and develop and implement, in line with the Sendai Framework for Disaster Risk Reduction **13.1** Strengthen resilience and adaptive capacity to	have shared ownership.	**business entrants and exits:** Improvements in Darwin's liveability through cooling and greening leads to increased use of the city by people, and flows through to increased business investment. Investment in STEM, DLL and Smart Darwin leads to an increase in knowledge-based jobs and services.				

			climate-related hazards and natural disasters. **16.7** Ensure responsive, inclusive, participatory and representative decision-making at all levels.						

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