

An aerial view of a city block with a digital twin overlay. The buildings are represented as white 3D blocks. The ground is colored in a gradient from blue to red, indicating different energy or environmental zones. A central area is highlighted in blue and green, suggesting a park or water feature. The overall scene is a mix of urban architecture and digital data visualization.

RACE for 2030

RELIABLE
AFFORDABLE
CLEAN
ENERGY

**Digital Twin enabled
Sustainable Sunshine
Precinct Development**

Project context

The Digital Twin enabled Sustainable Sunshine Precinct Development project is co-funded by RACE for 2030, RMIT University, Department of Transport and Planning, and the Centre for New Energy Technologies (C4Net), with additional in-kind support from Monash University.

The Sunshine Precinct is a key urban area situated at a vital junction between Melbourne's city centre and the western growth areas, offering strong connections to regional hubs, major transport routes, and economic infrastructure (Victorian Department of Transport and Planning, 2021). Planned infrastructure upgrades through major government projects will further boost accessibility and development opportunities in the precinct.

As the precinct is expected to experience a significant increase in both population and employment density, it faces the risk of growing environmental pressures. Without a sustainable design framework, issues such as urban heat, water scarcity, high energy costs and inefficient land use could compromise the precinct's liveability. To ensure that growth is managed responsibly and the area remains resilient to future challenges, it is essential to embed environmental sustainability into the core of precinct planning. Figure 1 presents the key areas for growth and change identified for the Sunshine Precinct.





Project overview

The Victorian Department of Planning and Transport (DTP) provided RMIT with existing plans (referred to in this report as the Base Scenario and Updated Scenarios) based on the Sunshine Precinct Opportunity statement that foresees significant growth potential in the areas of Sunshine Station, Albion Precinct (or ‘Albion Quarter’) and Sunshine CBD (Town Centre). Within this analysis there was a strong focus on analysis of the Albion Precinct, which was undergoing a process of structure planning by the DTP.

This project explored opportunities to enhance precinct renewal, through the application of digital twin technology. Digital Twins enable integrated, data-driven modelling of critical urban infrastructure such as power and water, as well as outcomes like urban heat, wind patterns and embodied carbon. This can inform strategic planning decisions and ultimately opportunities to enhance urban resilience to climate change and other environmental challenges

Two high-density scenarios were tested in the research:

- A Base Scenario – buildings from 2 to 15 storeys with a median height of 8 storeys, limited use of podiums and relatively more public realm

- An Updated Scenario – buildings from 4 to 30 storeys with a median height of 14 storeys, widespread use of podiums, significantly more carparking, and relatively less public realm.

These scenarios are described in more detail in the Research Framework section of the full report, (RACEfor2030), Digital Twin enabled Sustainable Sunshine Precinct Development (2026) (‘the Full Report’). Within each of these scenarios there were various sub-scenarios modelled for different subject areas, to address specific research questions. The modelling of scenarios used 2019 CSIRO climate projections based on RCP4.5 and the 2024 Integrated Systems Plan (ISP) of the Australian Energy Market Operator.

When examining the impacts of specific urban design choices for the Sunshine Precinct, it should be recognised that factors such as aligning streets or buildings to a North-South or East-West direction reflect outcomes based on specific meteorological conditions more prevalent at this site and do not necessarily generalise to other locations in Victoria or beyond.

Detailed findings, background and analysis is provided for urban heat, water, embodied carbon and energy in the Full Report.

Urban heat

In a future, warmer climate, the management of urban heat emerges as a fundamental and overarching design objective. Urban heat directly influences energy demand, outdoor amenity and public health outcomes, and therefore has a critical bearing on the long-term liveability, resilience and viability of urban precincts.

This study demonstrates that effective heat mitigation cannot be achieved through single-variable interventions, but instead depends on the interaction between built form, vegetation, irrigation, surface materials and airflow. Key findings from the modelling indicate the following principles should inform effective urban heat mitigation:

Strategic irrigation of open spaces is the most effective driver of cooling at the precinct scale

Dispersed and linear irrigated open spaces function as primary cooling anchors, delivering substantial reductions in air temperature and thermal stress at the pedestrian level. Cooling effects were shown to propagate downwind for several hundred metres, provided that airflow pathways are maintained. This indicates that the spatial placement of irrigated landscapes relative to prevailing wind directions is more influential than uniform distribution. Targeted irrigated corridors and open spaces can therefore provide precinct-wide benefits without the need for irrigation everywhere.

The effectiveness of this approach was demonstrated most clearly in the Sunshine Energy Park sub-scenario and Updated Scenario. In the revised Energy Park design, median air temperature was reduced by 3.3°C, with maximum reductions of up to 10.9°C during extreme heat conditions through strategic use of irrigation. Thermal comfort improved substantially, eliminating extreme heat stress across much of the park. These benefits were strongly localised near irrigated surfaces but were amplified and extended through improved airflow, particularly closer to ground level where evapotranspiration is most effective.

Airflow is as critical as shading in determining heat outcomes

Across all scenarios, areas with restricted ventilation consistently exhibited higher air temperatures, even where shading was present. Dense or poorly arranged tree canopy and compact built forms were shown to obstruct airflow, creating hot pockets and limiting the spread of cooling benefits from irrigated areas. Conversely, maintaining ventilation corridors allowed cooled air to disperse more effectively, enhancing the impact of irrigation and shading, as well as enhancing passive cooling.

This finding was reinforced in the Updated Scenario (tree optimisation sub-scenarios) for the Albion Quarter, where active tree placement and selective canopy adjustment improved airflow. Although precinct-wide average temperature reductions were modest, localised cooling reached up to 8.4°C, with significant reductions in thermal stress in high-risk locations. These results confirm that airflow management is a prerequisite for translating local cooling interventions into broader precinct benefits.

Tree canopy should be optimised for spatial performance rather than uniform planting

The analysis shows increasing canopy coverage alone does not guarantee cooling. Trees are excellent at providing shade however their cooling performance varies depending on canopy density, shading context, local wind speeds and irrigation.

In areas with high solar exposure, it is critical that tree canopy is overlapping, to protect pedestrians and surfaces from direct and reflected solar radiation. In ventilation corridors, particularly close to irrigated areas, balance is needed between shading and allowing airflow. Street-scale analysis demonstrated that large trees can reduce air temperature when aligned with airflow, but may increase temperatures where they block ventilation, particularly in North-South streets. Small trees improve airflow but provide limited shading.

These trade-offs indicate tree canopy should be planned as a spatial system integrated with street geometry and wind behaviour, rather than delivered through uniform planting.

For the specific conditions of the Sunshine Precinct this means providing overlapping tree canopy on the southern side of East-West streets. Less dense planting may be feasible in North-South streets if these are well shaded by buildings and where there is limited airflow due to building configurations. Overlapping canopy is also required in streets otherwise unshaded by buildings due to adjacent open space or infrastructure, although breaks may be required at strategic points to enable airflow.



Water availability and evapotranspiration underpin vegetation cooling performance

Cooling from vegetation was strongly dependent on soil moisture and sustained evapotranspiration. Drought-resistant trees with limited soil moisture showed reduced cooling capacity and, in some cases, contributed to higher daytime temperatures during peak heat due to suppressed transpiration. Diurnal analysis confirmed that cooling benefits diminish during the hottest hours when trees close their stomata under water stress.

These findings highlight the importance of aligning vegetation selection, irrigation provision and realistic water management strategies. While irrigation imposes additional demand on water systems, its targeted application yields disproportionate cooling benefits, particularly when combined with airflow-aware design.

It is important to note this finding is focused particularly on very hot days. For most hot days (excluding more extreme conditions), drought-resistant trees play an important role in pedestrian shading and protecting surfaces from solar radiation, and these benefits potentially outweigh the risk of slightly higher temperature on extreme heat days.

Built form configuration significantly influences heat accumulation and dispersion

In the Updated Scenario, increased building heights and more uninterrupted built form on the north side of Ballarat Road resulted in higher air temperatures due to trapped airflow and reduced ventilation in East-West streets. Taller buildings also altered wind patterns, intensifying wind speeds in North-South corridors while limiting heat dissipation in East-West corridors. In contrast, areas with greater spacing between buildings and access to irrigated landscapes performed better thermally.

The analysis also indicates that low embodied carbon (i.e., mass timber) buildings have a limited influence on outdoor air temperature at the precinct scale, with variations of $\pm 0.2^{\circ}\text{C}$. However, they do affect the timing of heat release, with lower embodied carbon materials reducing daytime temperatures at the expense of slightly higher night-time temperatures. The implications of this dynamic in a multi-day heatwave are unknown as this was not modelled in the study. The complexity suggests that material selection should consider both carbon and thermal performance.

Heat risk is highly localised and should be addressed accordingly

Across all scenarios, the most meaningful improvements were observed in high-risk locations such as Sunshine Energy Park, compact street canyons and exposed paved spaces. Precinct-wide averages masked these outcomes and should not be relied upon as the primary indicator of success. Instead, heat mitigation strategies should focus on identifying, prioritising and treating hotspots through coordinated landscape, irrigation and built-form interventions.

Water

Rainfall in the Sunshine region, even if fully captured, remains at levels below expected demand for irrigation. However, water is critical to the survival of vegetation and can act to reduce temperatures through the latent heat of evaporation (directly from wet sources or transpired through plant stomata). Understanding the supply and demand balance and maximising co-benefits from its use is critical for efficient precinct development.

Given the overlap with urban heat and its mitigation through evapotranspiration, some outcomes for water are captured in the Urban Heat key findings. Additional research findings include:

The climate projections of lower rainfall, increased temperatures and drought, will create challenges to achieving greening outcomes

Average climate projections for 2050 point to an up to 13% decrease in annual rainfall and a 10% increase in evapotranspiration, creating a widening gap between available rainfall and tree water demand. In addition, lower rainfall and more frequent drought means that standard soil volumes for street trees are at risk of not providing sufficient water storage capacity to cover long dry periods over the summer. These dynamics create challenges for achieving greening objectives in the precinct, particularly on streets, and make provision of sufficient soil and water infrastructure critical.

Achieving overlapping tree canopy on streets requires investment in soil and water infrastructure beyond typical practices

To protect pedestrians and surfaces from solar radiation it is important that tree canopy is overlapping. Research in this study shows that investment in soil and water, frequently beyond typical practices, is needed to create this overlapping canopy.

In relation to streets, analysis found that 3 metre verges with structural soil, or 5 metre verges (no structural soil), created the potential for overlapping canopy. A 2 metre verge was insufficient, even when supplementary water was provided. Active and passive irrigation of street trees is also critical. Efficient passive irrigation is required as a baseline measure to create overlapping canopy. Even increasing soil volume from 3 metres to 5 metres, water remains a limiting factor, with overlapping canopy not achievable without passive irrigation for either verge width.

Supplementary active irrigation – potentially through low-cost drip irrigation systems – enhances this overlapping effect, enabling mature tree growth to be realised more quickly and providing security against drought conditions.

Where space is constrained, there is opportunity to focus the investment in overlapping canopy in areas with particularly high solar exposure in summer. These areas can be identified through shading analysis of a 3D built form model.



A 30% tree canopy target is unlikely to be met in the Sunshine Precinct without increasing the amount of public realm and/or increasing canopy provision on private land beyond current policy

Tree canopy was below 30% for both the Base and Updated Scenarios. In both scenarios increasing canopy cover on private land to 20% improved canopy percentages but did not reach the 30% target (25% for the Base Scenario and 22% for the Updated Scenario). This suggests that reaching this target would require more allocation of space to the public realm for greening, and/or additional private land canopy, such as above ground canopy on podiums (in addition to ground-level canopy).

Irrigation for cooling of open spaces requires investment in alternative water supplies

Irrigation of open space for cooling requires short bursts of intensive irrigation on days above 35 degrees. This equates to an annual water use of approximately 3.75ML per hectare in Sunshine, based on long term climate projections of 20 such days per annum.

The analysis showed that significant water could be captured from road runoff and building rooftops across the precinct, however there are competing uses for this water. Road runoff is required for passive irrigation of street trees. Regarding rooftop water, a significant volume can be captured, however, for high density residential buildings that water is likely to be fully utilised for the building and private gardens. Given that, water capture from low rise commercial and industrial buildings or other infrastructure, or other alternative sources may be required to avoid reliance on mains water for irrigation.

Embodied carbon

As precincts electrify and their supply becomes dominated by renewable energy, the embodied carbon in construction materials becomes a more significant contributor to precinct-level emissions. This is because the electricity grid is decarbonising more quickly than manufacturing processes for steel or concrete, which depend on direct burning of coal or gas. Concrete and steel account for the largest portions of the carbon footprint, highlighting the crucial role of material selection.

Key findings from the research were:

Material selection was able to reduce embodied carbon from between 14% to 46%

Material selection was seen to reduce embodied carbon by 14% when equivalent lower carbon materials (e.g., low carbon cement) were selected, highlighting the benefits achievable when carbon is prioritised during procurement.

More ambitious low-carbon material palettes such as light-weight and mass timber approaches, in combination reduced the embodied carbon of the precinct by 46%.

Concrete and steel were found to be the largest contributors to embodied carbon across most scenarios. Largely for this reason, the upper floor elements of buildings were found to be particularly important contributors to embodied carbon. Consistent with the literature, as buildings get taller, embodied carbon intensity typically increases. Furthermore, some forms of low-carbon construction approaches become difficult in taller buildings – such as light weight timber construction – which is uncommon in buildings above six storeys.

Carparking within buildings was found to contribute significantly to embodied carbon

The removal of carparking (within the building) from the Base Scenario was seen to reduce embodied carbon by 15%.

At the same time a tripling of carparking (between the Base Scenario and Updated Scenario) led to a 30% increase in embodied carbon.



The impact of basements on embodied carbon was relatively modest where carparking was retained elsewhere

Moving carparking from basements to the upper floors of buildings reduced embodied carbon by only 4%.

A study of the precinct carbon life cycle showed that reducing grid supplied electricity emissions currently has more impact potential than reducing embodied carbon, although this is projected to change over time as the grid decarbonises

At current grid emissions intensity, embodied carbon comprises between 7% and 12% of lifecycle emissions, depending on the extent of on-site renewable energy being used. Long term projections of electricity grid emissions intensity suggest the share of embodied carbon will increase to 53% of emissions over a 60-year lifecycle, if projections are realised. That is, we can expect the relative importance of reducing embodied carbon will increase over time.

Energy

Urban precinct design and energy infrastructure requirements are becoming more deeply connected as household electrification, PV, small scale/ community battery storage and electric vehicles become more pervasive. Demand for electricity is a function of the type of services being sought, primarily hot water and space heating or cooling but increasingly electric transport.. Heating and cooling loads are directly influenced by the built environment with material choices being particularly critical as well as meteorological processes that affect factors such as heat gain and local energy production.

Unique constraints on energy economic modelling resulted in the research focus being on exploring the relationship between built form and renewable energy outcomes, as well as high level, in-principle insight to inform planning processes and decisions. For example, we cannot reliably say what energy market wholesale conditions might look like in 2050, or customer uptake of variable pricing, therefore solar, battery and electric vehicle ('EV') charge management modelling focused on identifying issues to be managed within current local grid constraints, as opposed to the financial value of localised solutions to precinct stakeholders.

This was done by controlling distributed energy resources (DER units) and the energy management systems using a fuzzy-inference-system (FIS), which is a policy based control system that coordinates battery charge and discharge according to generation, load, and predicted load profile.

A follow up study could build on the modelling approach developed in the Full Report and focus on better quantifying the value gap between a standard roll out of DER at the precinct level, and a co-ordinated rollout that balances the objectives of stakeholders. This value gap is a function of both the deployment and management of DER assets, as well as the cost of delivering a comparable solution via grid supplied energy. For example, if the policy goal was for a precinct to be 100% supplied with renewable energy, on a 24x7 basis, the cost of delivering that outcome via centralised grid assets would need non-trivial work to quantify.

Key findings from this current research are:

Climate change and energy

Climate change is expected to both increase cooling loads and reduce heat loads, resulting in a net increase in energy demand

Increased temperatures in 2050 were projected to increase cooling loads in the Base Scenario by 50%, while reducing heating loads by 20%, with a net 2.58% increase in total thermal load.

Urban form

In a medium to high-density urban form, building thermal performance improvements depend more on urban morphology than the thermal design of individual buildings

The Updated Scenario (with a median height of 14 storeys and widespread use of podiums) had a thermal load 15.8% higher than a somewhat less intensive Base Scenario (with a median height of 8 storey buildings and limited use of podiums).

Modelling indicated that this change was not due to deficiencies in individual building envelope performance but rather the result of increased mutual shading of buildings combined with the heat retention effects of more condensed urban form. The results suggest that in dense urban environments, the dominant mechanism of building energy consumption shifts from building envelope control to urban morphology control. Urban morphology control in this instance refers to shading levels at the precinct scale and the extent of narrow deep urban canyons that exacerbate heat retention.

More intensive urban form concentrates energy demand spatially and increases reliance on energy from the grid. Within a high-density typology, there was a significant difference between an urban form of predominantly 8 to 10 storeys buildings with few podiums, which can achieve self-sufficiency of up to 45%, compared to 14 to 20 storeys with widespread use of podiums which has a maximum self-sufficiency of up to 30%.

The Base Scenario was able to achieve higher levels of energy autonomy under a wider range of operational strategies compared to the Updated Scenario.

While taller urban forms improve renewable generation intensity per unit land area through increased façade exposure, they also concentrate energy demand and operational loads. Where functional floor area increases faster than renewable collection surfaces, renewable generation is diluted when assessed per unit of usable space.

Overall the more intensive urban form creates a bigger gap between energy generation potential and energy demand. This results in lower self-sufficiency, reduced utilisation of on-site generation, and lower local energy autonomy compared with less compact urban forms. It also translates into higher relative costs of renewable energy deployment as the marginal benefit of investment is lower when the investment covers a smaller proportion of overall demand.

Changes in built form create materially different electricity network impacts, even with identical energy configurations

Network constraints emerged more readily in the Updated Scenario than the Base Scenario, under identical energy deployment assumptions. This was due to the greater transformer loading associated with serving larger buildings where both midday reverse power flows from building integrated photovoltaics and evening electric vehicle charging loads are concentrated. While there were options to meet demand within existing network constraints under both scenarios, there were fewer options under the Updated Scenario. This highlights the sensitivity of the network to spatial concentration effects at the building level.





Electric vehicles

EVs have the potential to be a major driver of infrastructure upgrades requirements

Across the urban forms of the Base and Updated Scenarios, EV uptake emerges as the dominant driver of infrastructure upgrades. In the Base Scenario, a sharp threshold is observed between 20% and 50% EV penetration, beyond which infrastructure upgrades become more necessary. At penetration levels above 50% (1 per 50% of dwellings) the probability of upgrade rapidly approaches 100%, indicating that existing network capacity can no longer accommodate the coincident charging demand. In the Updated Scenario, this threshold behaviour is preserved, but the baseline probability of upgrades is systematically higher at lower EV penetration levels, reflecting the higher demand intensity associated with the vertically intensified built form.

Managing evening demand, in particular EV charging demand, is critical to longer term network performance. Smart charging combined with solar generation and battery storage can improve energy utilisation by 13 to 15%

Given the potential stress of EV charging on network infrastructure, coordinating charging strategies (i.e. smart charges) are critical. This is likely to be most effective when combined with façade PV and medium-to-high battery storage capacity, which helps smooth the mismatch between supply and demand. Modelling indicated that the combination of smart charging, additional generation and storage could improve consumption profile stability (load factor) by approximately 13% to 15%.



Solar PV

There is complementarity between rooftop and façade PV, which can support local renewable generation usage

Evaluation of PV production across the precinct demonstrates a clear complementarity between rooftop and façade-integrated PV. Rooftop systems deliver strong summer peaks but significantly lower winter output. Façade-integrated PV produces less energy in absolute terms, but its relative contribution is higher during winter and shoulder seasons due to the advantages of vertical and east–west orientations under low solar elevation conditions. As such there are opportunities to exploit complementarities in renewable generation through combined rooftop and façade-integrated PV deployment, particularly if building integrated solar becomes cheaper over time.

Increasing northern façade PV is highly effective for improving energy autonomy but rapidly breaches infrastructure constraints

Increasing the proportion of north-facing façade PV leads to a strong increase in energy self-sufficiency. However beyond approximately 20% of the available north-facing façade PV coverage, infrastructure upgrades become both inevitable and economically significant.

East–west façade PV expands the feasible envelope with comparatively low network risk

Higher east–west façade coverage increases energy self-sufficiency proportionally with urban size, without systematically increasing network stress. This makes it an infrastructure-resilient pathway for increasing renewable penetration in dense urban contexts.

Spatial concentration of PV deployment across feeders can have significant network impacts

Scenarios with higher concentrations of building integrated photovoltaics on specific feeders exhibit increased exposure to reverse power flows and voltage constraints. This suggests that feeder aware deployment strategies, rather than uniform capacity expansion, may be important as photovoltaic penetration increases.



ELECTRIC SHOCK
Operate Carefully

Batteries

Medium-high battery use increases the potential to use localised DER and helps manage peak loads but does not eliminate network constraints

Scenarios with low battery capacity are more likely to approach transformer loading limits during evening peaks, whereas medium and high battery configurations consistently reduce peak loading through targeted discharge. This confirms that investment in batteries is important if the intent is to maximise local PV generation and use localised DER to meet evening demand. However, it does not eliminate network constraints if overall load volumes remain significantly higher. As such battery deployment must be carefully coordinated with generation scale and network capacity rather than pursued as a stand-alone optimisation lever, reinforcing the value of planning frameworks and processes that enable coordinated investment and management of battery assets.



Grid performance

The scope of the research focused on avoiding infrastructure upgrades and the research findings reflect this constraint. There may be broader benefits in upgrading infrastructure to encourage higher uptake of EVs and DER, which could be explored in future research.

The research found that achieving zero upgrades is not about aggressive electrification but rather maintaining loads below critical network thresholds. Financially viable outcomes depend less on maximizing individual technologies than on maintaining balance across façade orientation, storage scale, EV penetration, and infrastructure impacts.



Electricity demand could be met within the existing network constraints under both the Base and Updated Scenarios, under defined energy management scenarios. The range of scenarios was more restricted under the typology of the Updated Scenario

Under both scenarios, transformer constraints are localised rather than systemic, with overall network performance shaped by a small number of spatially clustered bottlenecks in higher density mixed residential and commercial areas. This pattern indicates that targeted, asset specific interventions would be sufficient to unlock additional hosting capacity, rather than requiring widespread network augmentation.

EV uptake and north-facing façade PV define the most restrictive feasibility boundaries

Across unfeasible scenarios, binding constraints were primarily associated with transformer thermal limits driven by evening EV charging demand, and local voltage rise occurring during midday periods of concentrated PV generation.

Beyond approximately 50% EV penetration and 20% north-facing façade PV coverage, infrastructure upgrades become both inevitable and economically significant.

Built form impacts network constraints

Under the Updated Scenario, the power system was able to operate safely but the feasibility envelope was notably narrower than in the Base Scenario. Compared with the Base Scenario, the Updated Scenario includes fewer but higher buildings, resulting in higher absolute levels of façade PV and battery capacity per building for the same percentage-based deployment assumptions. Consequently, binding constraints emerge more readily at specific assets, particularly at transformers serving larger buildings where both midday reverse power flows from building integrated photovoltaics and evening EV charging loads are concentrated.

For infrastructure planning, this implies the Updated Scenario would require stronger reliance on external energy supply or more off-site renewable sources to meet demand, while the Base Scenario offers a broader range of pathways toward improved generation-to-load balance and meeting more energy demand locally.

Infrastructure impacts are threshold-driven rather than incremental

Rapid EV uptake and uncoordinated or unoptimized PV deployment can trigger sharp feasibility transitions, beyond which infrastructure upgrades become unavoidable and escalate rapidly in cost.

Economic analysis

The below findings focus on analysis which seeks to minimise network upgrade costs. A broader analysis that compares the impacts of significant network upgrade costs has not been undertaken. The findings below should be considered with that caveat in mind.

Urban renewable systems are governed by trade-offs rather than a single optimum

The challenge of integrating planning decisions with energy asset deployment, is that energy autonomy (i.e., use of DER), private investor returns and infrastructure constraints are often in competitive tension. Further work is needed to better quantify the value gap between ‘business as usual’ energy asset deployment, and precinct optimisation. Increasing urban density will translate into higher electricity demand. This can be met through renewable energy from either the grid, or DER, or a combination of both. Built form design imposes constraints on how much renewable energy can be generated locally compared to demand. Further analysis is needed to determine whether there is value to be generated from meeting this energy demand through local generation, or whether, from an overall perspective of land economics, this demand is better met through grid-scale renewables.

This gap will then inform how much investment could or should be committed by policy makers, in pursuing innovations in the planning process (to adapt built form to facilitate precinct-scale energy management), or in precinct-scale energy supply models.


Urban form influences the economic viability of different energy deployment strategies

Vertically intensified urban form compresses the options available and lowers the ceiling of what can be simultaneously achieved across the objectives of energy autonomy, private sector returns and network capacity. While outcomes that balance these objectives are feasible under both scenarios, there are fewer balanced outcomes under the Updated Scenario, and those that are balanced have weaker performance in terms of energy autonomy and private sector returns than the Base Scenario.

Intensified urban form also amplifies the economic penalties associated with renewable energy-maximizing strategies and increases reliance on policy or financial support mechanisms. Renewable energy deployment was relatively more expensive and produced less energy autonomy under the Updated Scenario as compared to the Base Scenario.

There are comparatively fewer attractive private market investments under the Updated Scenario as compared to the Base Scenario.

These findings reinforce that urban form fundamentally conditions the effectiveness, cost, and scalability of renewable energy transitions locally, even when identical technologies and optimisation frameworks are applied. The Updated Scenario is a systematically more constrained urban configuration where there are fewer feasible options, and with a compressed upper envelope for both economic and energy performance.



Precinct-scale battery storage expands the economic envelope and simplifies the control optimisation problem, but not the infrastructure envelope

Precinct-scale battery energy storage systems (BESS) - for example a single large battery servicing an apartment block, as opposed to individual batteries for each apartment - tends to enhance economic performance in dense urban systems due to its lower capital cost per kWh, resulting in higher Internal Rate of Return and Net Present Value outcomes than household batteries. This advantage provides increasing flexibility to absorb additional capital costs as storage size increases. While utility BESS shifts many scenarios from financially unviable to investable, it does not remove the underlying infrastructure thresholds associated with high EV uptake or excessive north-facing façade PV deployment. In other words, utility BESS can make more scenarios economically viable but it may not fundamentally relax network-driven limits on renewable and electrification intensity especially at the higher end of renewable penetration and/or electrification.

Investment coordination is critical to value creation

With network constraints potentially being a key limit on EV uptake in the precinct, and the combination of solar PV, battery, EV and smart energy management an important source of value to precinct stakeholders, planning frameworks and processes that enable investment coordination are critical. For example, coordinated investment can help bring down the cost of battery deployment and EV charging infrastructure, while also simplifying the task of implementing control strategies that make best use of local energy assets within network constraints.

Recommendations

The key recommendations from the four workstreams are based on case studies, and include a degree of specificity to the Sunshine Precinct, particularly in terms of geometrical arrangement and use of local features.

While recommendations are presented by workstream, the greatest benefits are achieved when combining insights from across workstreams, as demonstrated in the connectivity analysis for the Sunshine Energy Park.

An overarching recommendation is to employ integrated digital planning tools to explore the potential for perverse outcomes or hidden benefits, arising from the interaction of urban design elements. This includes minimising unnecessary heat stress caused by hot air pockets, minimising embodied carbon in buildings, providing adequate water critical for the survival of local vegetation and the cooling effects on extreme heat days, and ensuring the value of local distributed energy resources is maximised with coordinated management.

Urban heat

Impacts of urban heat were examined through complex non-linear modelling of built form that considers factors such as reflectivity, heat gain, shading and air flow. Preferential outcomes are obtained when controls are put in place that maximise ventilation through the precinct and allow water to provide cooling through the latent heat of evaporation. Changes to building morphology can reduce the impact of reflected and radiated heat from man-made structures. Specific recommendations from the research suggest to:

Create a network of irrigated open spaces spread throughout the precinct that are placed strategically to take advantage of prevailing winds

Open space which has airflow to the south will spread more cool air (specifically in the weather conditions in the Sunshine Precinct). It is important to maintain some gaps in the vegetation in open spaces to enable airflow, provide irrigation to maintain soil moisture, and target daytime actions such as active watering in high temperatures, to provide cooling. Active irrigation for cooling specifically is required only in very hot conditions (e.g. 35°C plus, expected to occur approximately 20 days per year in 2050).

Plan for sufficient airflow in summer, and moderation of wind speeds in winter.

Building height, spacing and podium continuity should be considered as part of heat mitigation. In the Sunshine Precinct context:

- control wind through use of vegetation on North-West/North-East streets to prevent wind channelling.
- avoid long, continuous podium structures, to prevent wind channelling and improve airflow.
- increase setbacks between towers and buildings, and limit building heights to allow more airflow in summer and prevent hot pockets.
- avoid trees in the middle of streets where airflow is important.
- provide for airflow southwards in dead-ends and cul-de-sacs.

Plan tree canopy as a spatial system that considers locations where shading and ventilation is required

For the specific context of the Sunshine Precinct, the southern sides of East-West streets should be prioritised for shading with overlapping canopy, planting dense irrigated vegetation on the south side and low-density vegetation on the north-side (which is shaded by buildings). For North-South corridors that means balancing shading and ventilation. Shading from buildings can be utilised in summer, allowing somewhat less dense vegetation to enhance airflow. Soil and water infrastructure is required to support vegetation.

Irrigate vegetation and maintain soil moisture to support cooling

This will also support tree growth, as described in the Water section below.

Use climate-responsive material selection at the pedestrian scale

In highly sun-exposed locations, prioritise high-thermal-mass and low-reflectivity finishes where reflected radiation is likely to affect pedestrians or nearby surfaces. High-reflectivity materials remain appropriate where solar radiation can be reflected primarily toward the sky. These strategies should be applied selectively and, where needed, balanced with measures that support effective nighttime heat release and cooling.

Identify, prioritise and treat targeted hotspots through coordinated landscaping, irrigation and built form interventions, rather than focusing on precinct-scale averages

Micro-climate modelling, such as the Envi-met modelling used in the research, can be used to identify hotspots and test the impact of different interventions. This can enable more targeted interventions in specific locations rather than uniform rollout of initiatives that may have varying effectiveness in different locations.

Water

Specific recommendations for the use of water are highly correlated with urban heat which relies on adequate moisture for evapotranspiration. Specific additional recommendations suggest to:

Ensure adequate soil volume and active and passive irrigation to support overlapping tree canopy growth, particularly in priority areas for shading

Create 3 metre verges with structural soil or 5 metre verges with passive and active irrigation. Passive irrigation is critical to achieving overlapping canopy, while supplementary active irrigation is important to enable trees to meet maturity more quickly and to protect against drought conditions.

Provide efficient passive irrigation systems for street trees

Supply of additional water beyond rainfall is critical to achieving tree canopy in the precinct. There is a significant difference in outcomes between efficient and inefficient systems, so investment in a well-designed, efficient system is important.

Provide alternative water capture systems to provide water for active cooling of public open space

Aim for 3,7ML per hectare, per annum, above the amount already allocated to maintain a mid-range sports level. Water capture from low rise commercial and industrial buildings, or other infrastructure, could be good alternatives if other sources of water (e.g., residential building rooftops and road runoff) are already fully utilised.

Encourage capture of alternative water on private land

Water capture can support increased soil moisture in summer (for urban cooling purposes) and achievement of canopy targets on private land.

If a 30% canopy target is a priority, consider options to increase canopy cover across the precinct.

Options include increasing canopy cover on private land and allocation of additional public open space for greening.



Embodied carbon

The amount of embodied carbon was highly influenced by building morphology, carparking and precinct design approach. Specific recommendations suggest to:

Facilitate low-carbon building designs

Results show that substituting typical construction materials with low carbon equivalents can reduce embodied carbon by 14%. This could be improved to 46% if low-carbon (lightweight and mass timber) approach was adopted.

As embodied carbon becomes an increasing share of lifecycle emissions, encouraging material changes over the long term will be important to reducing built form emissions. This may entail some changes to built form, as research suggests that low embodied carbon buildings are easier to achieve when they are a lower height.

Reduce private carparking.

Carparking within buildings was found to contribute significantly to embodied carbon. By removing carparking (within the building) from the Base Scenario, embodied carbon was reduced by 15%. Moving carparking from basements to the upper floors of buildings had lesser impact, reducing embodied carbon by 4%. Public transport systems will be expected to reduce the embodied carbon of buildings by removing the need for private carparking space or by shifting such space to lower embodied carbon alternatives (such as remote carparking).

Use the Digital Twin to maximise the embodied carbon value of precinct designs while aiming for a net-zero carbon outcome.

Embodied carbon can be viewed as a cost to development that needs to be managed. It was clear that significant improvements in embodied carbon 'value' were achievable through various initiatives outlined above. None of the precinct designs achieved a 'net zero' carbon outcome over the life cycle, even when the carbon sequestration potential of mass-timber was included. The ability of mass-timber and other biogenic materials to store carbon presents a theoretical opportunity for a precinct to achieve a net-zero carbon outcome if this goal is prioritised.

Energy

Energy provision within an urban precinct requires a complex trade-off between the capacity required to meet current and future demand and the potential for over-building capacity leading to pressures from economic regulations and the public. This has become more challenging as the world shifts toward full electrification of end-use devices including EVs. Analysis in the Full Report considered the demand for energy services and local renewable supply and storage options within the constraints of the existing network. Urban heat recommendations highlight demand management opportunities through advanced microclimate management. Additional recommendations from the study suggest to:

For Distribution Network Service Providers (DNSPs)

- Implement spatially differentiated connection standards and incentives to encourage DER deployment on underutilised feeders.
- Require explicit evening discharge targets and standardised inverter volt-var and volt-watt settings for batteries and PV.
- Prioritise shared or utility-scale BESS where it delivers peak substitution, voltage control, and ramp-rate reduction.
- Use constraint classification frameworks to distinguish between scenarios requiring infrastructure augmentation and those addressable through operational or spatial measures.
- Coordinate EV smart charging programs to target load-factor improvement, not just peak avoidance.

For Planning Authorities

- Develop a strategic direction for energy management at the precinct scale that outlines the extent to which renewable energy and EV deployment is a priority, and how this can be addressed.
- Incentivise east-west façade-integrated PV through planning controls, design guidelines, or floor-space bonuses.
- Require shading, orientation, and energy performance analysis at early design stages for high-density developments to maximise passive heating and cooling and onsite renewable energy usage at a precinct scale.
- Support shared-service PV and battery business models (e.g. precinct energy services, community batteries).
- Understand potential EV loads based on proposed charging infrastructure and carparking capacity in new developments, and engage with DNSPs about the implications.
- Encourage smart charging infrastructure.
- Incorporate consideration of urban form in any localised renewable energy deployment strategy.

For Developers and Precinct Proponents

- Design buildings to maximise usable PV surfaces, particularly East-West façades in high-rise contexts.
- Treat rooftop and façade PV as integrated energy assets, not optional add-ons.
- Invest in smart EV charging infrastructure.
- Consider shared or utility-scale battery solutions to improve project economics and manage peak demand.
- Evaluate projects using integrated metrics (IRR/ NPV, self-consumption, network impacts) from early feasibility stages.



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