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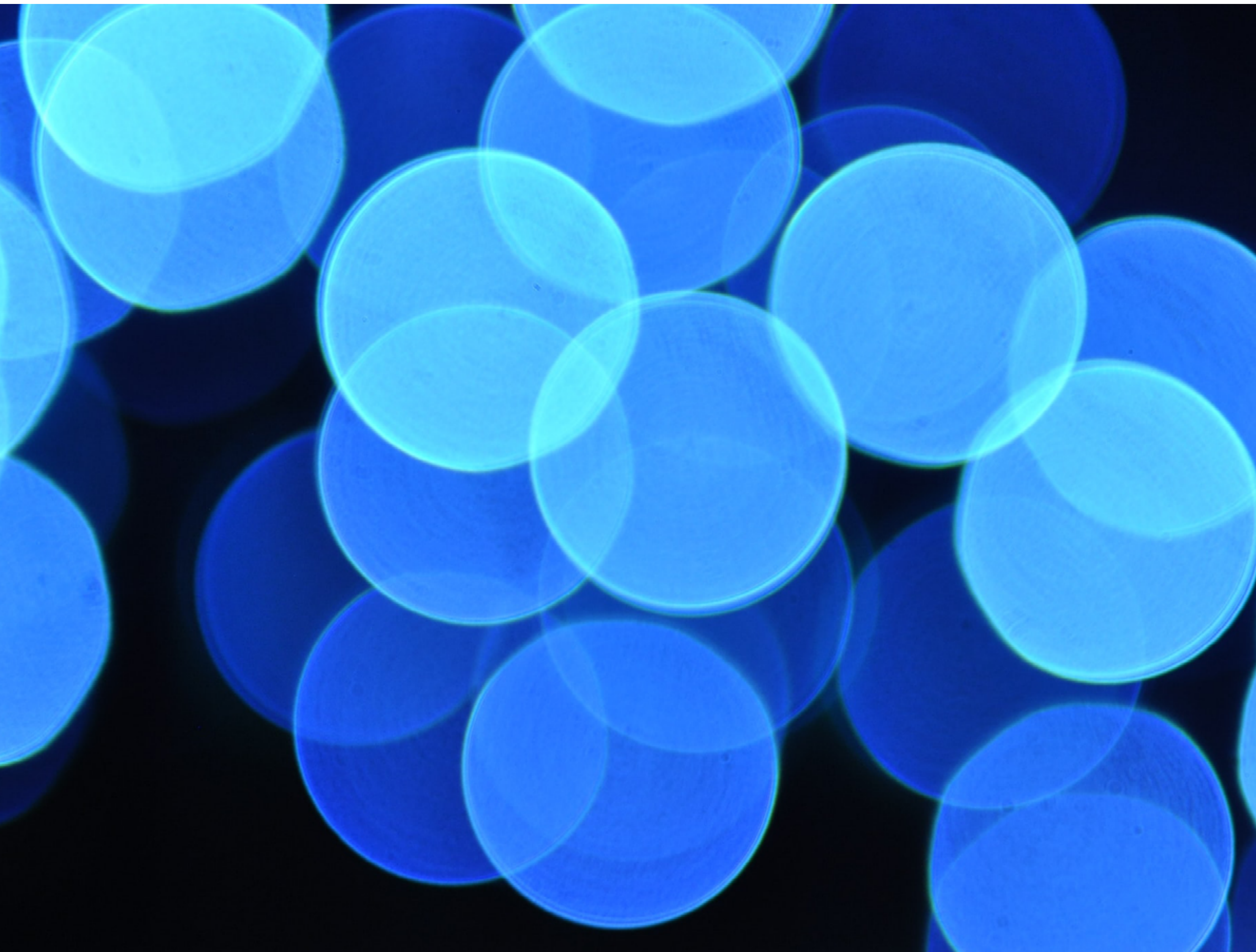
BEST PRACTICE DATA VISUALISATION GUIDELINES AND CASE STUDY



Data visualisation is a key component of climate change communication. Due to an increasing demand for evidence-based climate change visualisations, Monash Climate Change Communication Research Hub (MCCCRH) want to refine their data visualisation practices so that they are efficient, justified and motivate action in Australians. A literature review was conducted to determine guidelines based on existing visualisation practices that could be applied to the hub's design process. The review revealed three key aspects of data processing that should be considered in order to enhance a visualisation's success; perception, cognition and action. Findings from each of these categories are summarised as a series of actionable guidelines. These guidelines provide an accessible resource for MCCCRH to refer to when designing climate visualisations. The graphic's content should involve a single message that is positively framed, locally relevant and solution based. Linear charts are easier to interpret and the layout should be simple and consistent. Colour should be used sparingly to highlight the key message and colour associations should also be considered. Accessibility and implementation have also been outlined in the guidelines.

The Australian Conservation Foundation and MCCCRH proposed the guidelines be applied to a case-study of the Urban Heat Island (UHI) effect.

A local, solutions-based approach depicting the positive impacts of urban greening upon UHI was selected, to enhance public interest and actionability. Data was collected from the Melbourne Cooling and Greening Map, developed by the Victorian Government Department of Environment, Land, Water and Planning. Trees and shrubs were selected as the greenery variables as they are familiar to wide audiences and held strong correlations to decreasing UHI.

Graph design was an iterative process which involved consultation with Monash Art, Design and Architecture Faculty members. Graph type, colours, text, axes and other design features were considered; ensuring they aligned with the guidelines. Throughout this process, the trend line was the most significant feature as it carried the key message to users. The final graph has a bold green trend line, with slight teal tones to improve accessibility for those with colour blindness. Scatter points are a light grey to draw more attention to the trend. The title describes the graphical message to enhance comprehension for all audiences. Familiar icons are utilised to demonstrate the change of tree/ shrub coverage, improving comprehension. The resulting design is supported by the guidelines and is designed for a wide audience, with varied education, vision, cognition and backgrounds.

Context for this report

Data visualisations are crucial tools for communicating climate change to the public (Harold et al. 2016). They involve the visual representation of complex climate data to facilitate understanding of the effects of climate change, and are presented in a variety of formats; from digital media to televised broadcasts (Kirk 2016). Due to the multifaceted nature of climate concepts, it is often difficult to simplify a desired message into a visual form that is suitable for public understanding. Australia is home to a culturally diverse audience with varying backgrounds of scientific literacy. The relevance of visualisations to different sectors of the local populace is often not considered, especially when climate projections depict seemingly distant, catastrophic events at broad spatial resolutions (Aurambout 2013). In order to shift views on climate change and enhance climate progress, it is essential that data visualisations inspire action in a wider Australian audience. This can be achieved through well-designed data visualisations with simple messages, that are easily perceived and interpreted.

Monash Climate Change Communication Research Hub (MCCCRH) conducts social research and projects on climate change for media and policy infrastructure (Monash University 2020). They aim to convey data about climate change in the most digestible way, to motivate concern and action on climate change. They do this by generating climate graphs for online news publications, print media and televised broadcasts.

The hub is upscaling, due to an increasing demand for evidence-based climate change visualisations, hence, they wish to refine their data visualisation practices. In doing so, this project aims to enhance the hub's visualisations to ultimately encourage climate action in a wider Australian audience.

This report outlines a series of best practice guidelines that have been devised to enhance the visualisation output and the efficiency of the design process for the hub. These guidelines have been informed by a literature review on best practice for climate visualisations. The literature review is categorised into three key components involved in visual data processing; which are explained below under methodology. The key findings have been summarised in the guidelines; which provide an accessible resource for reference when creating climate visualisations.

The Australian Conservation Foundation, in collaboration with MCCCRH, proposed an opportunity to implement the guidelines for a current project that required a graph depicting the urban heat island effect and its impact on Australians. The second part of this report reveals the graph design and illustrates the justifications for the various design decisions that were made according to the guidelines.

How we approached the brief

In order to collate evidence-based best practice guidelines, a review of relevant literature was conducted. This involved gathering experimental results, outcomes of other literature reviews, opinions from experts in the field, and more. Informative sources included in the review were; peer-reviewed scientific papers, academic textbooks, news articles, and blog posts from reputable professionals. The review commenced with a broad literature search to discover the major themes of research on this topic. From this, the problem was categorised into three primary areas:

- Perception, which involves visual design elements
- Cognition, which outlines the processing of visual information and methods to enhance understanding
- Action, which considers the aspects of visualisations that motivate and affect behavioural change

Moreover, two adjacent research topics were identified - future research opportunities, and platform considerations. These sub-topics would aid in categorising information and composing the key guidelines.

Meanwhile, investigation into the urban heat island case-study began, allowing the implementation of the literature findings. For this, data associated with the provided topic of the Urban Heat Island Effect was explored and analysed. A relationship between greening in Melbourne and reduced urban heat island was selected, with two primary rationales: 1) ease of comprehension, and 2) a positive story for readers. Once the relevant data from Planning Victoria was plotted, design iterations were made, considering the perception, action and cognition framework, in collaboration with the MADA team. Each design iteration and justification were documented.

Finally, informed by the experience implementing the findings from the literature review, a list of best practice data visualisation guidelines was collated. These were written with practicality in mind, so that future visualisations created by the hub could refer to them easily.

Datavis Guidelines

Message

- Avoid purely catastrophic climate messaging
- Include messages centred around improving quality of life (e.g. health, security, finance, job growth, innovation)
- Keep visualisations local, to country, state, or local government area
- Messages that make reference to social trends may improve action through conformity

Layout

- Prefer the use of bar or line charts
- Keep it: simple, consistent, linear, logical

Language

- Simple sentences
- Dot points where appropriate
- Plain language with no idioms or figurative language

Colour

- Avoid yellow in background or non-focus aspects
- Adjacent colours should be high contrast or easy to distinguish from each other
- Avoid color combinations in fig. 1–2
- Avoid very bright and very dim colours
- Use varied intensity (brightness rather than hue) to indicate size of values. (i.e., use colours within a horizontal line in fig. 3–4)
- Use contrasting colours to signify and differentiate categories
- Consider color association and emotions evoked
  - High temperature: warm colours (eg. red)
  - Low temperature: blue colours (see fig. 3–4)
  - Traffic light system: Red = danger, amber = cautionary, green = safe

FIGURE 1. AVOID FOR TYPICAL VISION

FIGURE 2. AVOID FOR COLOUR BLINDNESS

FIGURE 3. WARM COLOURS

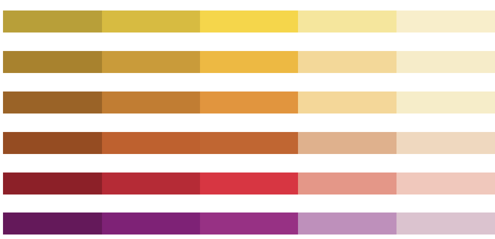
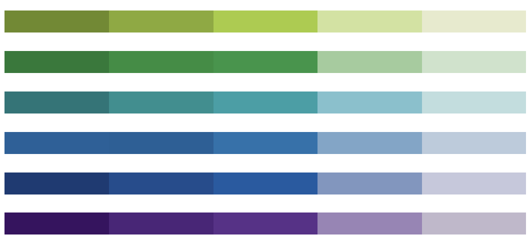


FIGURE 4. COOL COLOURS



General Principles and Goals

- Simplify: reduce number of variables and words
- Familiarity: use common or familiar graph type, use common colour coding
- Visual attraction:
  - Is the visual focus on the key message?
  - Tailor to the audience or concept:
    - Consider viewers' preconceived ideas, prior knowledge, cultural conventions, familiarities, possible biases
    - Do you need to include an explanation?
    - Get feedback from the target audience

Implementation

- Repeated exposure to the graph
- Longer viewing duration where possible
- Prominent timing
- Consider whether this graph is easily perceived and understood on a mobile phone screen

Disability

- If there is an audio aspect, include sign language, subtitles or transcript link
- Check how your visualisation is perceived in a colour blindness simulator, links in Appendix B.
- Communicate data in non-visual ways, for example by sound through data sonification.

Impact

- Test and iterate on graphs with community feedback & questionnaires
  - How attention grabbing is this graph?
  - Where is your attention primarily drawn?
  - What do you understand this graph to be showing?
  - Does this graph seem credible?
- Consider how you can add these to your visualisation
  - Emotional resonance
  - Practical value
  - Story-telling
  - Everyday triggers that remind a person of the graph

Comparative graphs

- Avoid legends if direct lables are possible
- Try to embed the legend into the chart title with color coding (see example five in https://datajournalism.com/read/longreads/the-unspoken-rules-of-visualisation?fbclid=IwAR2JpDhOU6SNhWjFzLuaaGTEJf3Itz17Q5T0JcscP8N3OjnYxzP9g3F5tiY)

Glossary

- *Hue:* Commonly referred to as colour, for example red, green and blue
- *Colour contrast:* Refers to how easily colours can be distinguished from each other
- *Intensity:* Commonly referred to as the brightness or shade

The Australian Conservation Foundation (ACF), in collaboration with MCCCRH, proposed an exciting opportunity to implement the findings of the literature review. The project required a graph depicting a climate change related phenomenon and its effect on Australians. The urban heat island effect was chosen by ACF, as it has been shown to influence multiple major Australian cities.

What is the urban heat island effect?

The urban heat island effect is the development of higher temperatures in cities compared to surrounding regional areas due to reduced vegetation, high densities of manmade materials (i.e concrete) and high anthropogenic heat production. Urban areas can experience air temperatures between 5-15°C greater than regional temperatures (Mohajerani 2017). Higher temperatures in urban areas can have a range of health, economic and environmental impacts; including heat stress, degraded ecosystems and air conditioning and infrastructural costs (Śarmā et al. 2019).

Data Selection

A series of Australian climate datasets were made available, from which variables that best represented the urban heat island effect were selected. Melbourne was chosen as the focal location, as there is a comprehensive, public dataset available, which contains urban heat temperatures and greening levels for local government areas (LGAs).

The importance of using locally relevant information was highlighted in the literature, as it enhances cognition and action, hence, urban heat values for Melbourne's LGAs in 2018 were used as the basis of the visualisation. Urban heat is the difference in heat between urban and non-urban areas.

The second variable is the amount of urban greenery corresponding to the level of heating for each LGA. More specifically, greenery levels have been separated into tree and shrub coverage, as the data demonstrated that these had the greatest impact upon urban heating, whilst also being easily understood by a wide audience. Shrubs have been defined as vegetation between 0.5-3 metres in height. Trees include vegetation greater than three metres in height.

Highlighting the fact that urban heat islands can be reduced by planting trees and shrubs frames the data in a positive light and provides a feasible solution to the problem. This is key, as a tangible, solution-based approach is more likely to result in reduced dissonance, effective cognition of the message, and action (Stoknes 2014).

Case Study: Graphs

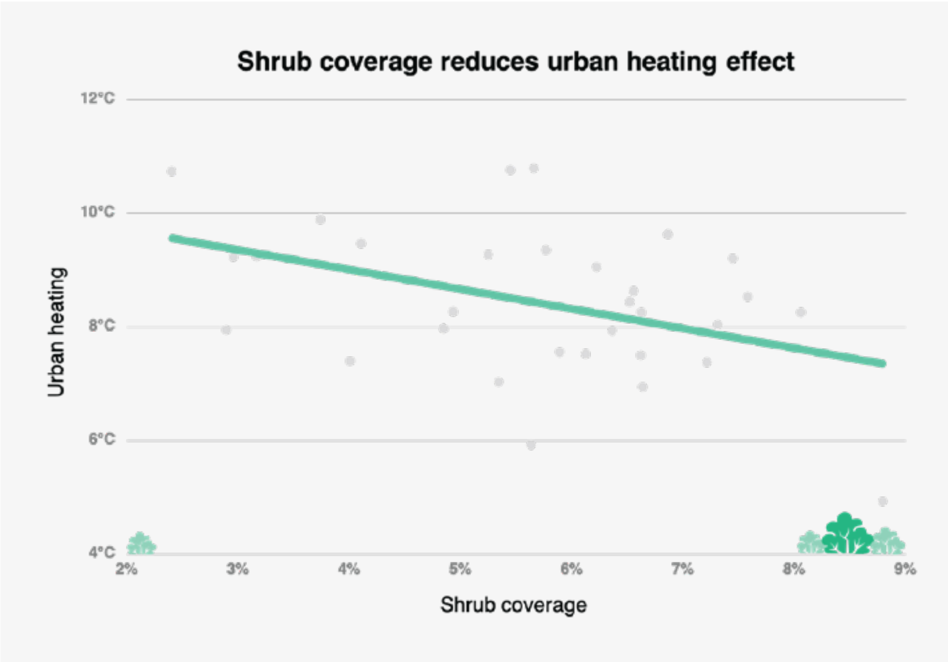


FIGURE 5. *Graph design depicting the effect of shrub coverage on urban heat (icons coloured)*

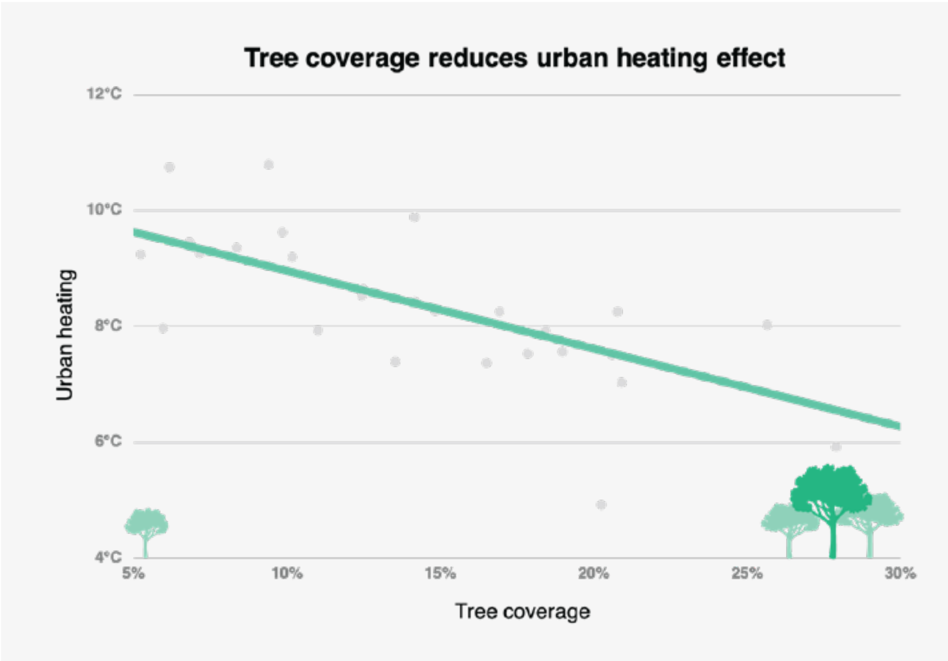


FIGURE 6. *Graph design depicting the effect of tree coverage on urban heat (icons coloured)*

Case Study: Graphs

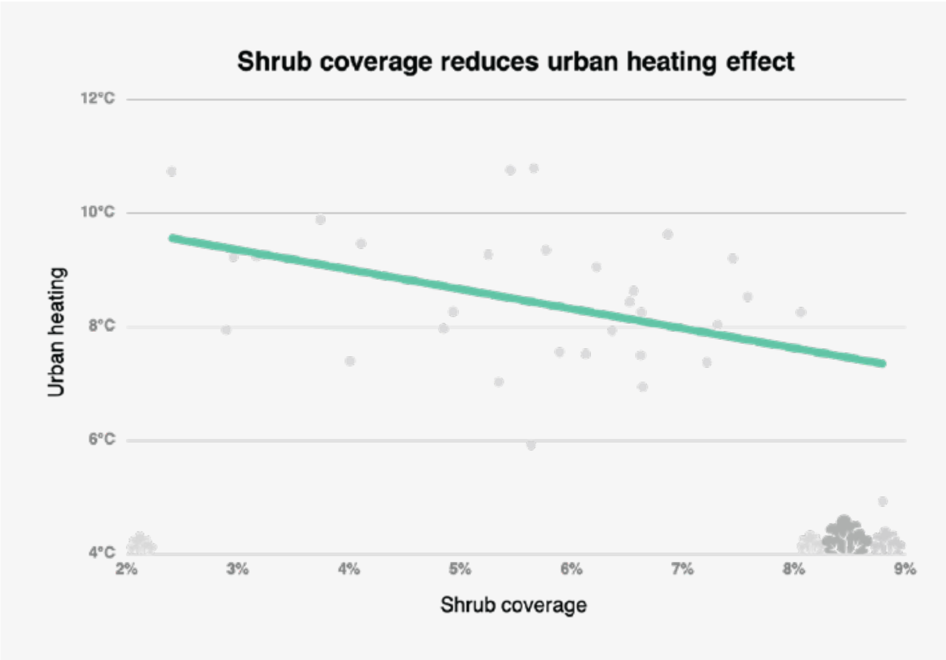


FIGURE 7. *Graph design depicting the effect of shrub coverage on urban heat (icons grayscale)*

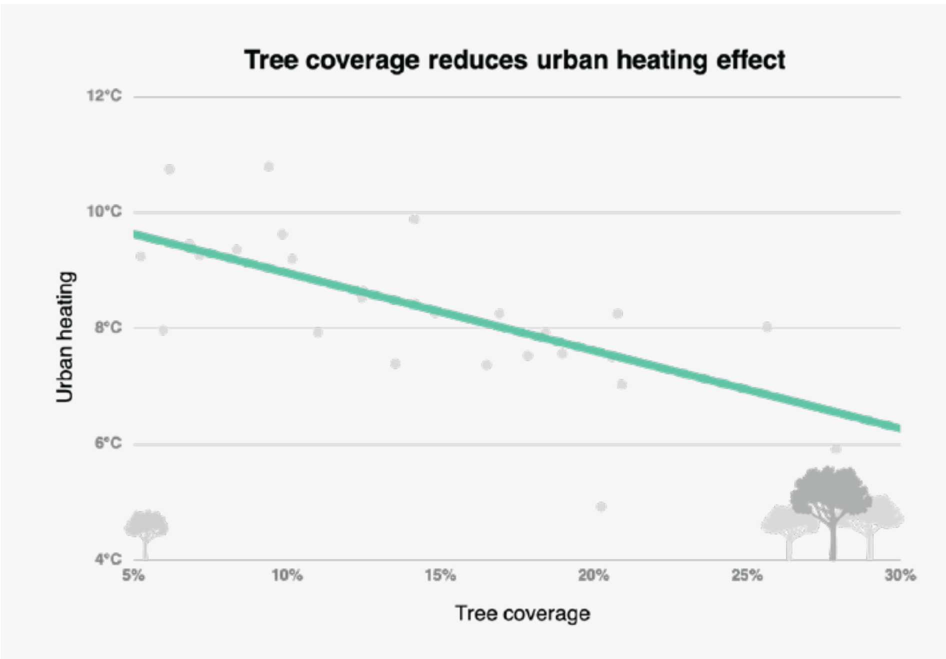


FIGURE 8. *Graph design depicting the effect of tree coverage on urban heat (icons grayscale)*

Case Study: Justifications

Graph Type

A simple scatterplot with a trend line was selected. Charts of this type are familiar to many audiences and hence easy to comprehend (Heer & Bostock 2010). Moreover, the overall pattern of greenery reducing heating was the desired message, hence lines between data-points were not used, drawing more attention to the trend line (Gillan et al. 1998; Kelleher & Wagener 2011). A thicker trend line and smaller scatter points are also used to improve salience of the trend line, directing visual attention (Harold et al. 2016). The graph is two-dimensional as it is simple and easy to interpret, a third dimension would only increase complexity (Kelleher & Wagener 2011). Maps are often used to communicate urban heat data; however, this can be quite complex and unfamiliar for many audiences, making the information difficult and slower to interpret (Gerst et al. 2020).

Trees and shrubs are displayed on separate graphs in order to reduce complexity and confusion (Haroz & Whitney 2012). Particularly as the range and spread of the data is very different for the two variables. However, they are displayed side-by-side for quicker comparison and interpretation (Bishop et al. 2013).

Design Process

The design process was iterative, evaluating the effectiveness of each graph with consideration to the audience, accessibility, education-levels and aesthetics (Atkins & McNeal 2018; Gerst et al. 2020; Grainger, Mao, & Buytaert 2016). A series of design iterations, alongside critiques and improvements are included in Appendix C.

Axes & Gridlines

The vertical axes ranges were minimised in order to emphasise the rates of change. They are the same for both shrub and tree graphs in order to allow for easier comparison (Kelleher & Wagener 2011). Vertical gridlines were removed as they improved simplicity and were not necessary for trend comprehension, as specific amounts of greenery weren't relevant to the key message. Increments on the axes were minimised to decrease clutter, and accompanied by their unit of measurement for faster interpretation and to simplify the axes titles.

Colour

A solid, white background was selected, as it allows for greater visual contrast between different graph aspects, and does not distract from the key message (IIPS Subcommittee 1993).

The trend line is the primary coloured item in the graph, as this carries the key message and humans perceive coloured features before size, shape, or other features (Gerst et al. 2020; Hegarty 2011). Green was the colour selected as it has familiar, cultural alignments with safety, environment and positive change (IIPS Subcommittee 1993; Peter & Keller 1993). These positive cultural connotations also help to counteract the subconscious connotations that a downward trend indicates negative or 'bad' change (Harold et al. 2016), however for some Chinese audiences green is perceived as negative change, whereas red is good, therefore it is important to consider the audience (Jiang et al. 2014).

A more turquoise-green was selected as it aligned with past MCCCRH/ ACF report palettes, whilst also improving visual perception for those with red-green colorblindness (Talley et al. 2011). The graph was tested against color blind simulators, finding the color choices retained their contrast.

A single, high contrast, simple colour palette was used for visual clarity (IIPS Subcommittee 1993) and to increase accessibility for those with autism, low vision or other cognitive differences (Pun 2016). Grey was used for all the scatter points as colour discrimination decreases with size of the object (IIPS Subcommittee 1993). Moreover, it draws more attention to the trend line if the scatter-points are not connected, nor coloured. Minimal colour usage also prevents interactions with neighbouring colours which can affect perception (Wong 2010).

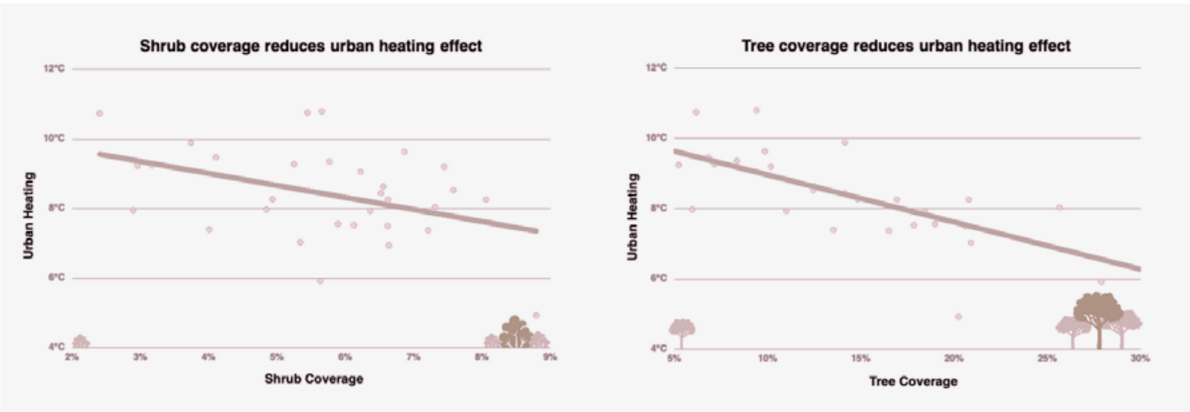


FIGURE 9. *Green-Blind/Deuteranopia Simulation*

Text

Text has been minimised to reduce complexity and clutter, as well as improve accessibility. The title 'Tree Coverage Reduces Urban Heating' states the relationship, telling the story for viewers, to improve direct message comprehension, as well as improving accessibility for those with visual impairments, as it can be read by text-to-speech features (Henry 2020; Harold et al. 2016). UHI (urban heat island) was not used as the label for the y-axis, as it is jargon and is not known by the audience (Harold et al. 2016; Cortesão et al. 2020). Instead, 'Urban Heating' was adopted. Ideally, this will be shown in context with an explanation of urban heating to those who are unfamiliar with the concept. Helvetica typeface was employed as it is aligned with Monash University branding, as well as simple and easy to read.

Iconography

Tree and shrub icons were used as they are familiar and can increase comprehension in smaller time frames by providing visual cues to connect the data to the physical world (GSA n.d.; Cortesão et al. 2020). These images support the text, which increases accessibility for those with dyslexia or other cognitive differences (Pun 2016). The amount and size of icons was reduced, and greyscale adopted to retain the salience of the trend line.

Platforms & Additional Features

A rollover effect can be added to each graph to reinforce that the data is locally relevant to the viewer (Figure 10). On applicable platforms, when the audience views the graph and moves their mouse over each data point or taps on the data point via a handheld device, detailed greening and heat values for Melbourne's LGAs will appear. This aligns with the concept that messaging perceived as remote and distant to the self arouses little concern and visceral response, as opposed to locally relevant data (Stoknes 2014). The rollover element and simplicity of the graph enhance viewing on various devices and platforms, which is important to consider when designing media content.

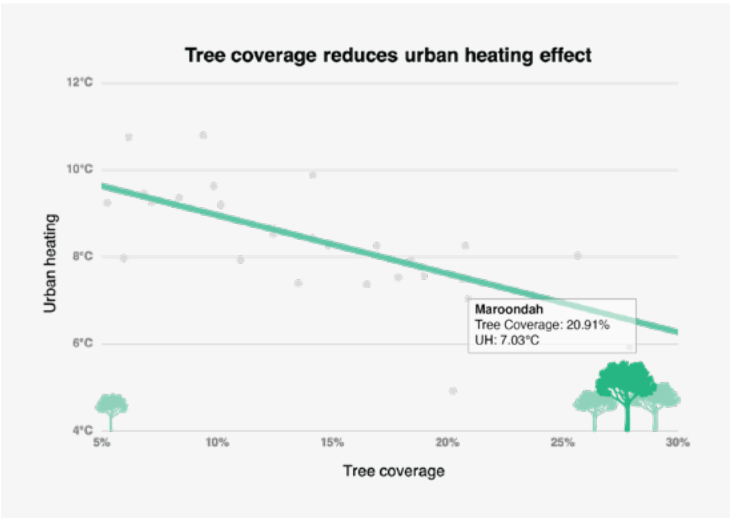


FIGURE 10. *Rollover example for the effect of trees on urban heat in Maroondah*

This report detailed the methodology of this project, guidelines for best-practice data visualisation (as informed by the literature review - please see Appendix A), and an in-depth description of design and content choices for the urban heat island case study. For more information on the iterations of the case study design, please see Appendix C. Overall, research pointed to simplification, and tactical choices to best direct the reader's attention.

These principles were employed in the case study, along with an experimental iconography approach. The latter was also directed by research findings that indicated iteration and novel ideas should be attempted and iterated upon with audience testing. The lessons from this project have broad applicability for a wide variety of communications, and form a useful reference guide for visual communicators such as those at MCCCRH.

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Appendix A: Literature Review Summary

This literature review covers aspects of perception, cognition and action in relation to data visualisations. Perception covers visual aspects of the design. Cognition outlines how readers process aspects of visualisations differently and how to enhance understanding. Action covers how aspects of visualisation can motivate and effect behavioural change. The review also explores communication platforms, and further research opportunities.

Perception

Perception is the first step in the audience's interaction with the data visualisation. In this context, it is defined as the identification and organisation of visual aspects. This section is based on general perception research and data visualisation perception research as there is much literature in this area. Important aspects of colour; including hue, intensity, brightness and, contrast or the ability to distinguish adjacent colours were emphasised as being important to perception. Considerations such as simple and consistent language and layout were highlighted to improve accessibility for those with and without various disabilities.

There is limited research on data visualisations for those with disabilities. Guidelines from government organisations including the Web Content Accessibility Guidelines (WCAG) were consulted. WCAG are considered to be global web accessibility standards and they include 3 increasing levels of accessibility: A, AA and AAA. The Australian government is required to adhere to level AA. The full WCAG guidelines are included in Appendix B.

FIGURE A1. *Light and Dark Blue*

FIGURE A2. *Yellow and Blue*

Colour

Colour is a key component in any visualisation and has a large impact on how individuals perceive a visualisation.

Hue: Hue, commonly referred to as colour, for example red, green and blue, should be considered. Yellow should only be used to highlight key points, as it draws attention and can be distracting when used in unimportant features (Light & Bartlein 2004).

Combination: Colour contrast refers to how easily colours can be distinguished from each other. Higher colour contrast is preferable as it aids the viewer in differentiating the various sections of a visual (Henry 2020). Contrast ratios can be calculated to assess whether colour combinations are at an effective standard; Appendix B includes further information on ratio calculations. The following combinations should be avoided as they are hard to distinguish for those with normal colour vision: red-black, blue-purple, light green-white and brown-green (Munzer 2014). Yellow-green and red-green are hard to distinguish for those who are colour blind (Munzner 2014).

Intensity: Another aspect of colour is intensity, commonly referred to as the brightness or shade. Variance in intensity is perceivable by normal and colour-deficient vision, so could be used to supplement change in hue (not perceived evenly; Light & Bartlein 2004). Furthermore, intensity is effective at indicating the magnitude of data values. For example, in figure A1, the lighter blue could signify a lower number and brighter blue a larger number. In figure A2, yellow could signify a smaller number, however it is more ambiguous and can be perceived differently for colour-deficient vision. Instead, the varied hues in figure A2 are useful for categorical data or where the size of value is not communicated through colour (Light & Bartlein 2004; Munzer 2014).

Disability

There are simple considerations that can be made to improve accessibility for those with disabilities and also benefit the general population's perception. Simple sentences with dot points and plain language without idioms or figures of speech, assist those with Autism Spectrum Disorder, Dyslexia, Intellectual Disability and Hearing Impairments (Pun 2016; Wu, Tanis & Szafir 2019). Simple and consistent layout will assist those with Autism Spectrum Disorder and Dyslexia and a linear and logical format will aid those with Visual and Hearing Impairments (Pun 2016). When displaying and explaining a visualisation in an animated format, it is preferable to include sign language, subtitles or a transcript link (Henry 2020). Non-visual ways of communicating data can also be beneficial for disability groups. Data sonification uses sound to communicate data and magnitude changes. This has been shown to improve statistical learning in general populations and is also useful for the visually impaired (Sawe 2020; Conway 2005).

Colour blindness: There are various design considerations that can be made to enhance the accessibility of visualisations for the colour blind (Brockmole & Goldstein 2017). Firstly, the key message should be communicated by non-colour dependent visual aspects to ensure that those who are colour blind can easily perceive the key message (Henry 2020; Muzner 2014). The visualisation can also be uploaded to a colour blindness simulator to ensure that key elements are distinguishable, see Appendix B for website links (Munzner 2014). Figure A3 simulates the colour spectrum for common types of colour blindness, more information can be found in the Appendix B.

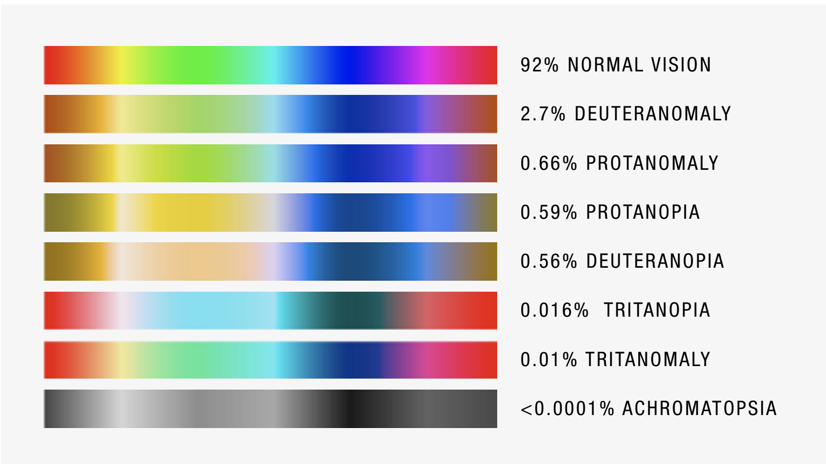


FIGURE A3. *Colour Simulation for various vision abilities*

Cognition

We define cognition in the project context as; the mental process involved with interpreting and comprehending visualisations. How an audience both consciously and subconsciously interprets information will affect the success of a visualisation. Therefore, cognition is an important aspect to consider when developing guidelines for best-practice data-visualization. Throughout the literature review there has been a significant number of papers with similar conclusions, hence improving confidence that the findings are accurate. The major influences upon visualisation cognition were found to be data simplicity, salience, familiarity, heuristics and biases. Simplifying the data presentation improves overall cognition for most audiences. Data simplification can decrease confusion which can be a result of overload or complexity (Haroz & Whitney 2012). Reducing the number of variables and words displayed in each graphic can reduce cluttering and hence, confusion (Harold et al. 2016; Haroz & Whitney 2012). Simplicity can also be achieved by using common or familiar graph types as well as ubiquitous colour coding (IIPS Subcommittee 1993).

Ensuring the most important aspect of the graph is salient should be a design priority. Typically an individual viewing a graph is initially and subconsciously drawn to the most prominent feature (Bostrom, Anselin, & Farris 2008), this is known as bottom-up visual processing (Harold et al. 2016). Therefore, the key message or trend should be visually attractive, as this will improve both memorability and comprehension even with short viewing times (Atkins & McNeal 2018; Haroz & Whitney 2012; Pandey et al. 2014). However, top-down processing is where heuristics and biases influence visual attention and interpretation (Harold et al. 2016). The preconceived ideas, prior knowledge and world view of the user affects their attitude toward the data presented and hence their interpretation of the message (Pandey et al. 2014). Therefore, when designing for an audience it is important to consider external factors which could affect how they decode the information.

Target audiences often have varying cultural conventions, familiarities and biases which will affect interpretation. For example, less experienced audiences tend to recognise general trends, whereas more experienced individuals can identify specific patterns in data (Atkins & McNeal 2018). Therefore, tailoring a concept or design for the audience is important, yet even well designed visualisation cannot compensate for lack of user knowledge (Hegarty 2011). Hence, additional information and explanation can be provided to alleviate knowledge gaps (Bishop, Pettit, Sheth, & Sharma 2013). Ultimately, identifying and involving the target audience during visualisation iteration stages is crucial to safeguarding the desired message is communicated and comprehended through the design (Bishop et al. 2013; Gerst et al. 2020; Grainger, Mao, & Buytaert 2016).

Colour use is often optimised for quick cognition when cultural conventions are used (Hegarty 2011). These include higher temperatures being associated with warmer colours such as red, and lower being associated with blue colours, this is useful for climate mapping (Schneider & Nocke 2018). However, another common association is the traffic light system of red, amber and green for dangerous, cautionary and safe environments (IIPS Subcommittee 1993). These conflicting subconscious messages can lead to the 'burning world' perception of climate map projections (Schneider 2016). This can lead to feelings of helplessness and disaster, ultimately leaving the audience discouraged (Schneider & Nocke 2018). Hence, it is important to consider the different emotions that colours can elicit and how this may affect the response to the visualisation message. Ultimately, the message interpretation is affected by many factors, both within the visualisation design, as well as within the audience themselves. Decreasing the complexity of design and having the key message as prominent as possible is recommended, to reduce confusion and improve overall cognition, regardless of the audience's background.

Action

Once a visualisation has been effectively perceived and has undergone adequate cognitive processing, the audience should ideally implement a behavioural change. Due to the increasing urgency for climate action, climate change visualisations need to go beyond temporary engagement. The audience should take the key message of a graph and use it to motivate climate positive actions. Due to limited resources on actionable climate visualisations, this section was based on general visualisations and psychological studies on climate inaction.

Barriers to Climate Action

There are various barriers to climate action that should be considered when designing actionable visualisations.

The audience may be ignorant of climate change due to the use of complicated empirical evidence in visualisations (Swenson-Lengyel 2018). Ignorance can result in dissonance and can deter people from action. To remedy this, the level of scientific literacy of the target audience should be considered when creating climate visualisations. Graphs can be made applicable to a wider audience by portraying simple trends. These trends should be based on climate indicators that don't require an extensive scientific background to understand.

Theoretical denial is fuelled by misinformation via industry, social media, politics and anti-intellectual trends (Swenson-Lengyel 2018). Misinformation can lead to a lack of confidence in science and prevent action.

To inhibit misinformation and ensure that the visualisation won't be misinterpreted by the media or the public, the visualisation should be made simple by following the design techniques outlined under 'Perception' and 'Cognition.' In addition to this, correspondence with the media outlet should occur, to ensure that the graph is being used in an appropriate context.

External structural constraints can also limit action (e.g. inefficient public transport prevents action) (Swenson-Lengyel 2018). To overcome this, the visualisation should highlight a solution that can be easily implemented by a wide audience (e.g. planting trees).

Content

The way in which a visual's content is framed influences concern and action. It has been identified that the media's portrayal of tragic and apocalyptic imagery associated with climate change inspires immediate engagement, but fails to have a lasting effect on audiences. It instead stimulates fear, guilt, anger, despair and helplessness (Stoknes 2014; Stoknes 2015). To remedy this, positive data sets that are centred around improving the quality of life should be implemented. This could involve the depiction of climate change in terms of insurance, health, security or opportunities for innovation and job growth (Priest, 2016).

Dissonance can be further reduced in some audiences by using past data sets that don't project into the future (Swenson-Lengyel 2018). Future projections can be dismissed as they aren't based on reality and may be perceived as catastrophizing the future. This can again result in paralysis and a failure to act.

Threats that are perceived as remote and distant, such as increasing global temperatures, tend to arouse less concern and visceral response (Stoknes 2014; Stoknes 2015). A visualisation's content should be salient to local users where possible, to increase the likelihood of an active response.

Humans are inherently social beings and we subconsciously base our choices on the behaviours of those around us (Berger 1984). The decision to act on climate change could therefore be influenced by visualisations based on social trends (e.g. the number of people that have switched to renewable energy and the effect of this on climate change).

Implementation

The exposure, duration and timing of a visual can also influence action. Engagement should begin long before an issue emerges in public debate. A visualisation should also undergo repeated exposure in various formats using an array of platforms; to reinforce the message and reach a wider range of public segments (NAOS 2017).

Future Research

The efficacy of visualisations could be further enhanced through research into data gaps that were identified through the literature search. Findings from future research could result in the refinement of the above recommendations to better suit the needs of MCCCRH.

Some data gaps include; the perception of visualisations by those with disabilities (see 'Perception'), the effects of climate literacy on graph comprehension, effects of supplementary text on graph cognition and the influence of worldview on view time (Atkins 2016). In order to increase the likelihood of climate action, research into the use of socio-economic data in conjunction with biophysical data to produce positive climate models could also occur (Sheppard 2011).

Animation of visualisations was described as an area requiring further research. Whilst the animation of a graphic can enhance comprehension by breaking down a complex process, scientists and designers need to consider cognitive principles and whether they should provide user control over playback and animation speed (Harold 2016; Stoknes 2014).

Research into opinion leadership and credibility in regards to climate issues and the role that media plays in this, would also help to inform best data visualisation practice (Priest, 2016).

Appendix B: Colour Perception

Color Blindness Information

Currently, the understanding of colour visual perception combines trichromatic theory and opponent processes theory. Trichromatic theory states that three cell types are responsible for detecting various colours, red, green and blue, and the combination results in colour perception. Complimentary to this, three additional cell types, are activated to simultaneously increase one colour and decrease another, for example blue and yellow, in opponent processes theory. Colour blindness results from a loss of one or more types of pigment cell. Monochromatism is where people can only see shades of black and white. It is a rare condition caused by very few or a complete lack of colour pigment cells. Dichromatism is where people are missing one of the colour pigment cell types and it results in seeing colours in a different way and not being able to distinguish some colours (Brockmole & Goldstein 2017).

Color Blindness Simulator

For images:

http://colororacle.org/

https://www.color-blindness.com/coblis-color-blindness-simulator/

https://pilestone.com/pages/color-blindness-simulator-1

For webpages:

https://www.toptal.com/designers/colorfilter

Color Contrast

Colour contrast is how easily colours are discriminated from each other. It can be quantified by colour contrast ratios; calculated by dividing the relative luminance (brightness) of colours. The following sites automatically calculate it and provide further information:

Contrast Generator:

https://contrast-ratio.com/https://webaim.org/resources/contrastchecker/

https://contrastchecker.com/Further Contrast Information

https://www.w3.org/TR/WCAG20/#contrast-ratiodef

https://medium.muz.li/the-science-of-color-contrast-an-expert-designers-guide-33e84c41d156

Context	Level AA	Level AAA
Text	4:5:1	7:1
Large Text	3:1	4:5:1
Logos	None	None
Non Text: Images and Graphics	3:1	–

FIGURE B1. *Outlines the colour contrast ratio guidelines from Web Content Accessibility Guidelines with increasing accessibility from level AA to level AAA (Henry 2020).*

Appendix C: Graph Iteration Process

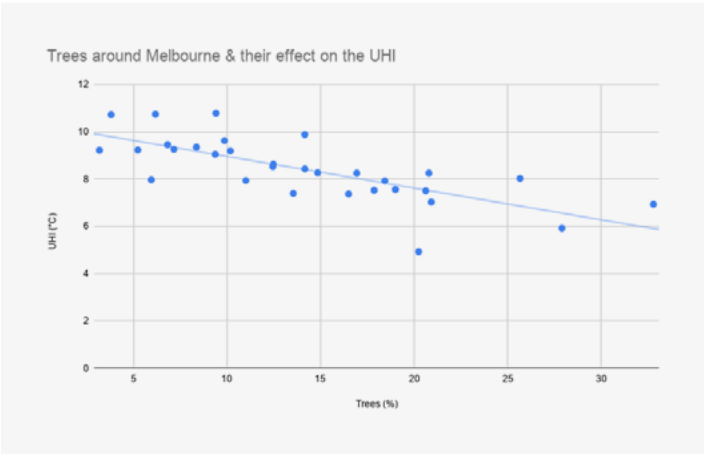
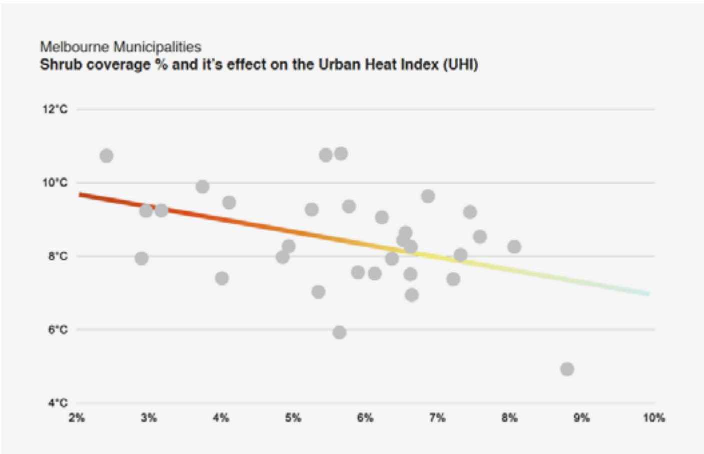
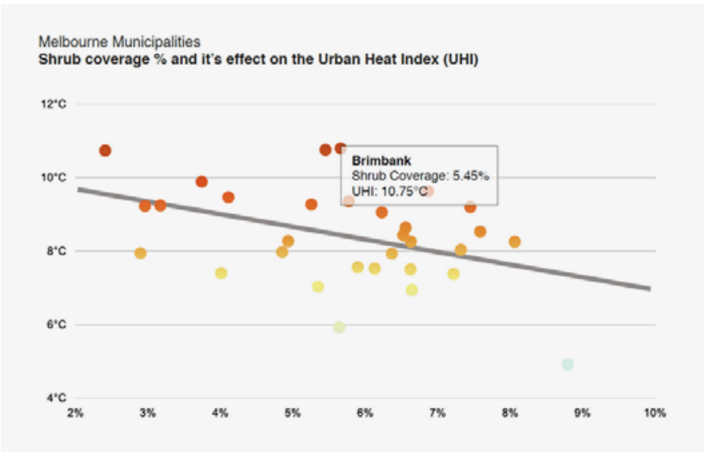


FIGURE C1: AUTO GENERATED PLOT

- Line graph selected as a simple, understandable and familiar graph for wide audiences
- Remove solid x-axis line
- Remove vertical grid-lines
- Make trend line bolder/ thicker
- Make scatter points grey
- Minimise vertical axis to accentuate gradient
- Place unit values on axis markers
- Explore gradient effect on trendline





FIGURES C2 & C3: GRADIENT & ROLLOVER

- Gradient concept rejected as it increased complexity
- Rollover effect was a useful integration
- Grey scatter points most effective
- Reduce size of scatter points
- Axes titles should be included to enhance readability
- Helvetica font aligns with Monash branding

Appendix C: Graph Iteration Process

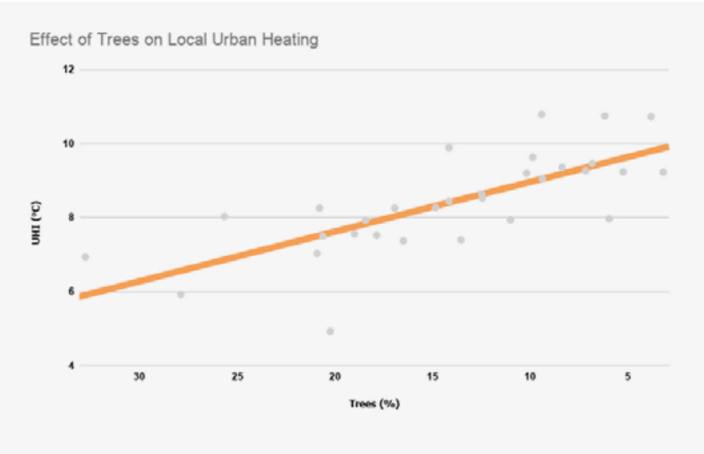


FIGURE C4: REVERSE X-AXIS ORANGE

- Orange used to demonstrate heating without catastrophising
- Reverse axis could be confusing
- Smaller grey scatter points effective

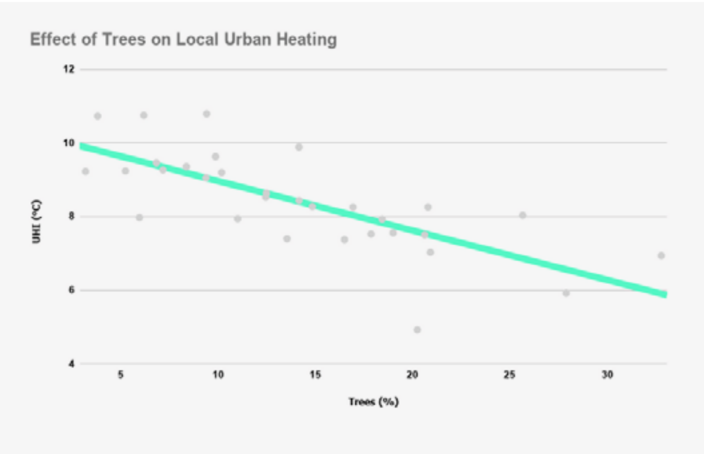
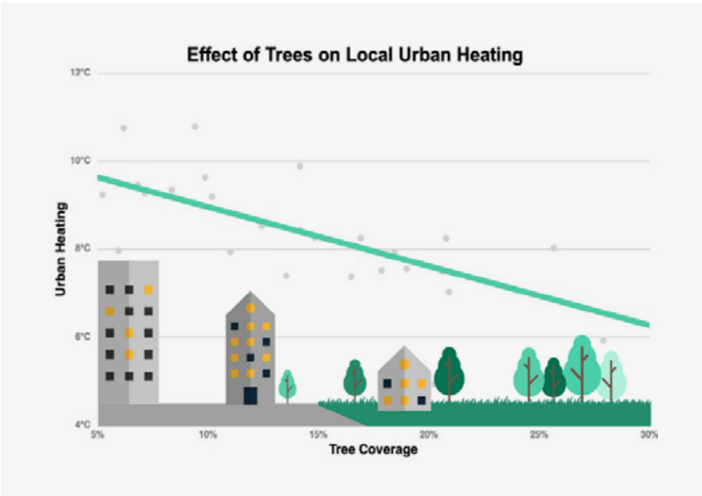
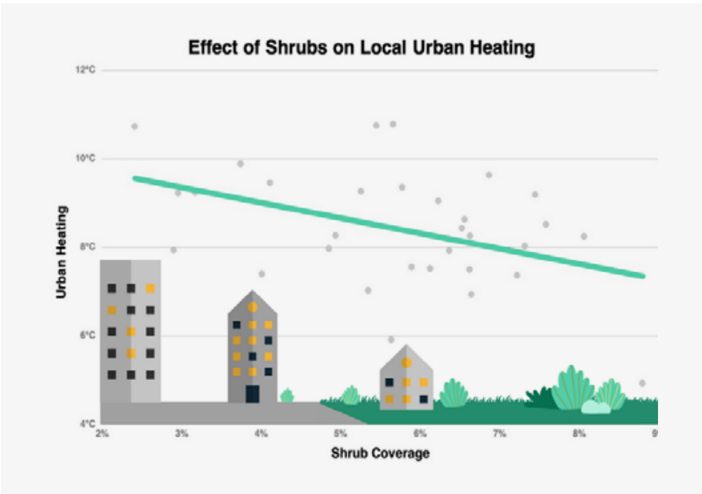


FIGURE C5: SIMPLE, BRIGHT GREEN TREND

- Similar colouring to ACF colour palette
- Trend perhaps too bright
- Green colour has positive and environmental connotations
- Emphasises solution-based approach
- UHI is jargon; audience may not understand

Appendix C: Graph Iteration Process





FIGURES C6 & C7: CITYSCAPE TRANSITION ICONS

- Yellow windows may distract
- Too many icons distracting from trend
- Depiction not aligned with data, low SES rather than city had less greenery

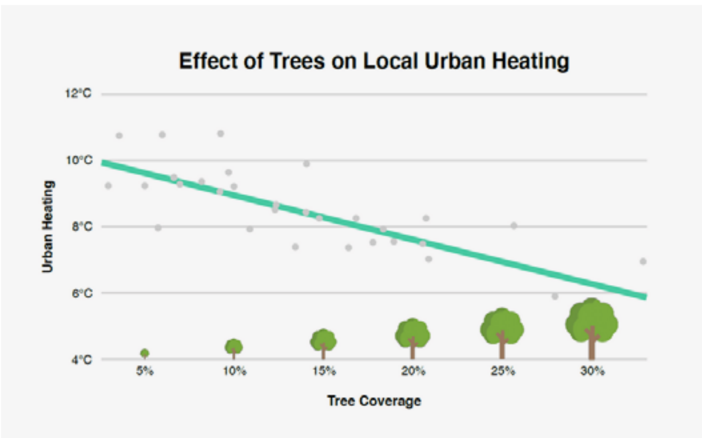


FIGURE C8: DARKER TREND, SIMPLE ICONS

- Simpler icons improve interpretation
- Too cluttered and distracting from trend

Appendix C: Graph Iteration Process

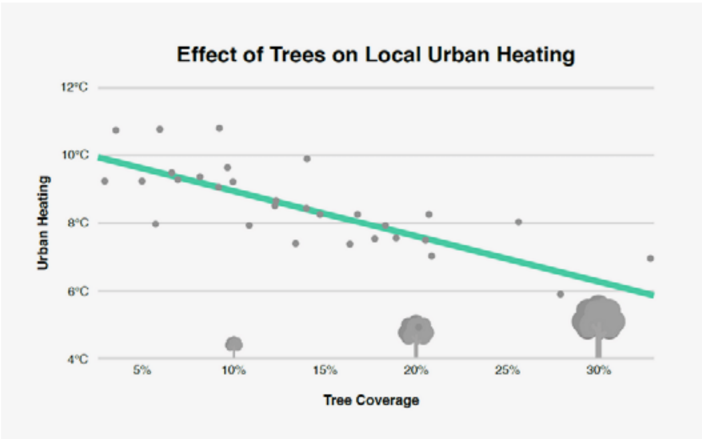
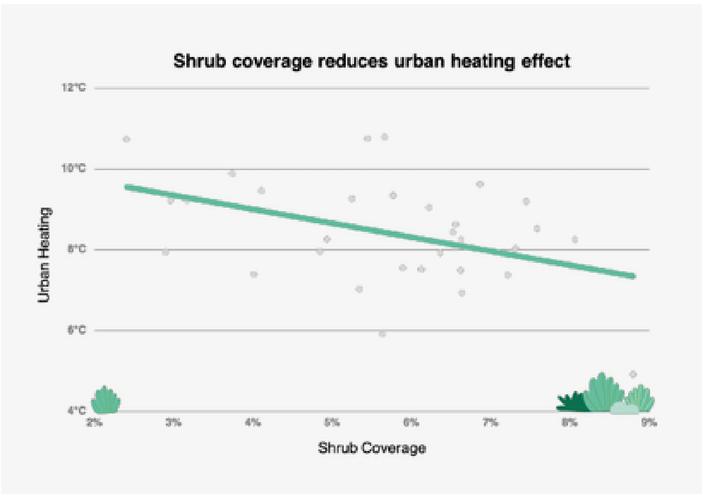
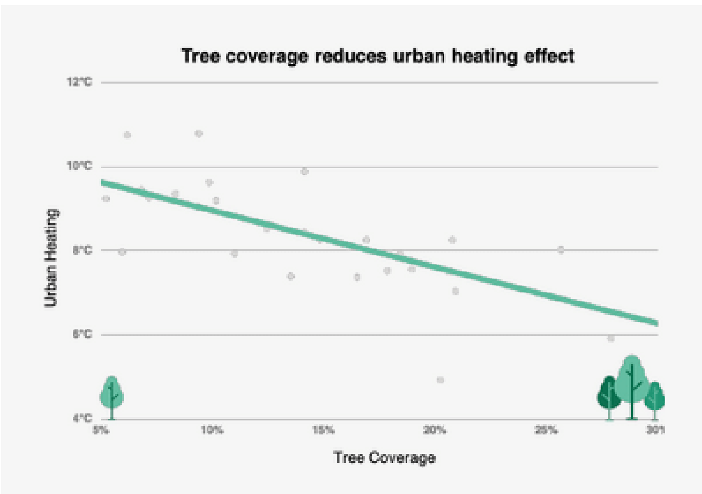


FIGURE C9: FEWER & GREY ICONS

- Improved salience of trendline
- Size of tree may generate confusion of coverage vs tree-size
- Grey too dark, potentially distracting

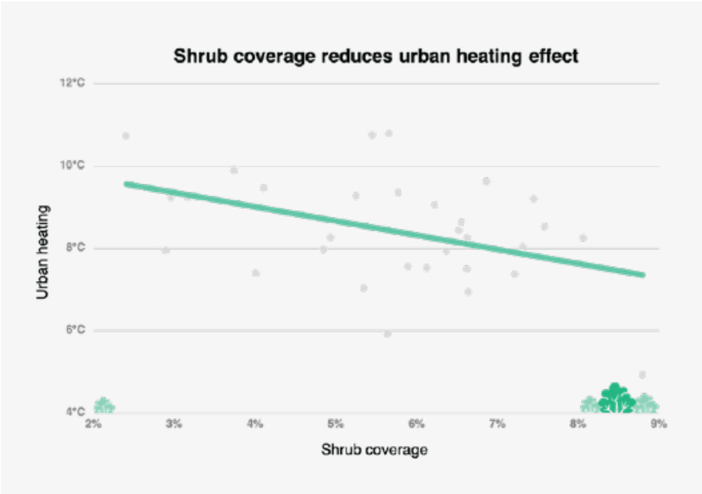


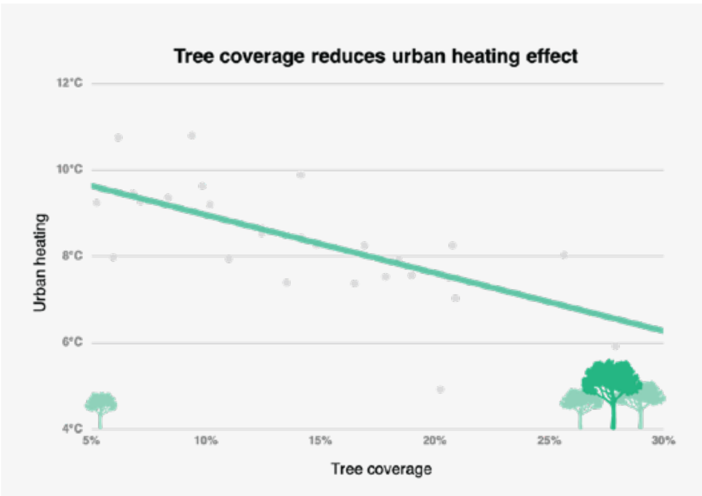


FIGURES C10 & C11:
GROUPED ICONS & TABLOID TITLE

- Single item of greenery vs grouping is more accurate depiction of coverage
- Fewer icons improves trend salience
- Stating the message in the heading improves accessibility
- Bolder heading than axes titles is effectiveIcons may need to be more realistic for faster interpretation

Appendix C: Graph Iteration Process





FIGURES C12 & C13: MORE REALISTIC ICONS

- These icons may allow for faster interpretation because they are more familiar

Cover image
Daniel Falcao
https://unsplash.com/photos/xRwraanRKPQ