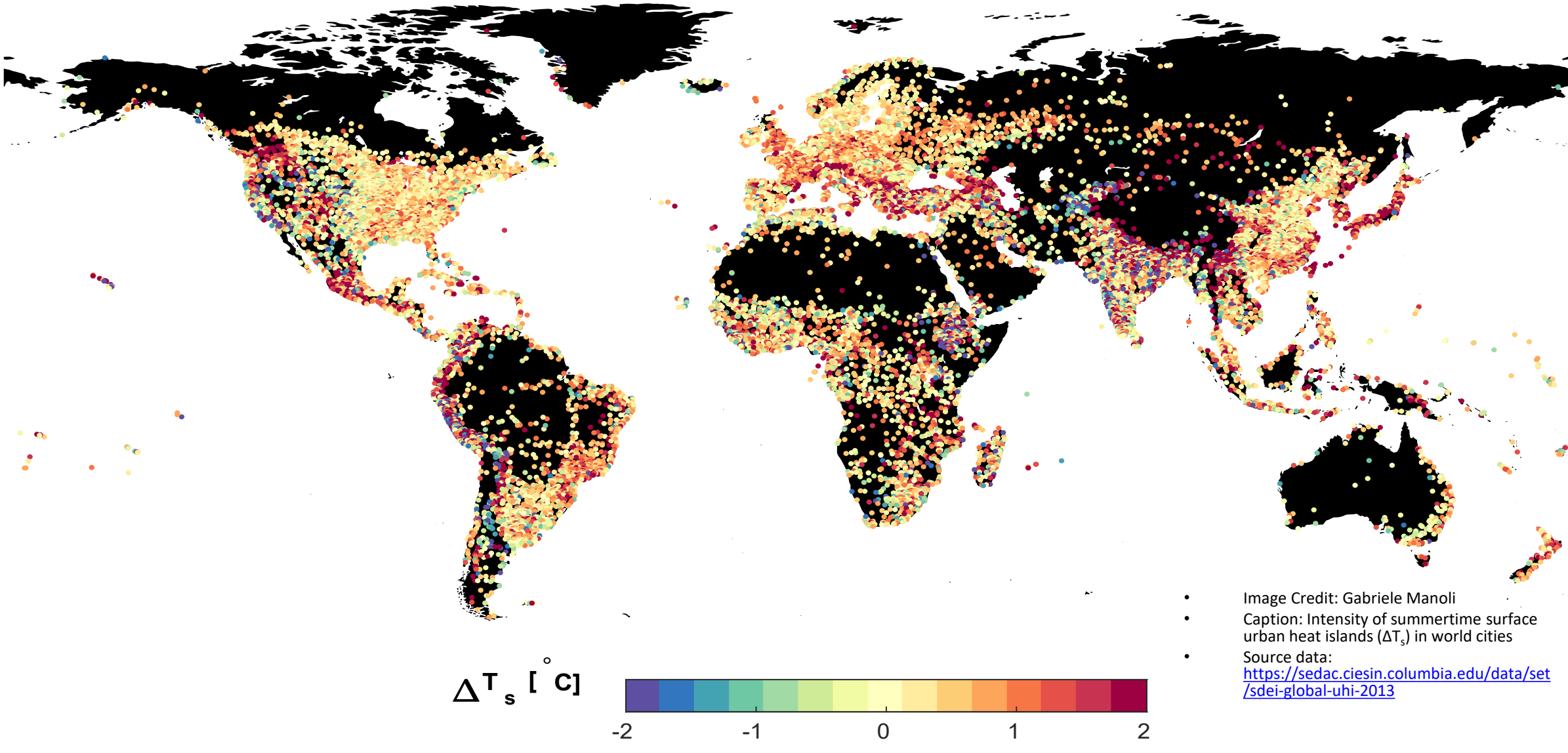
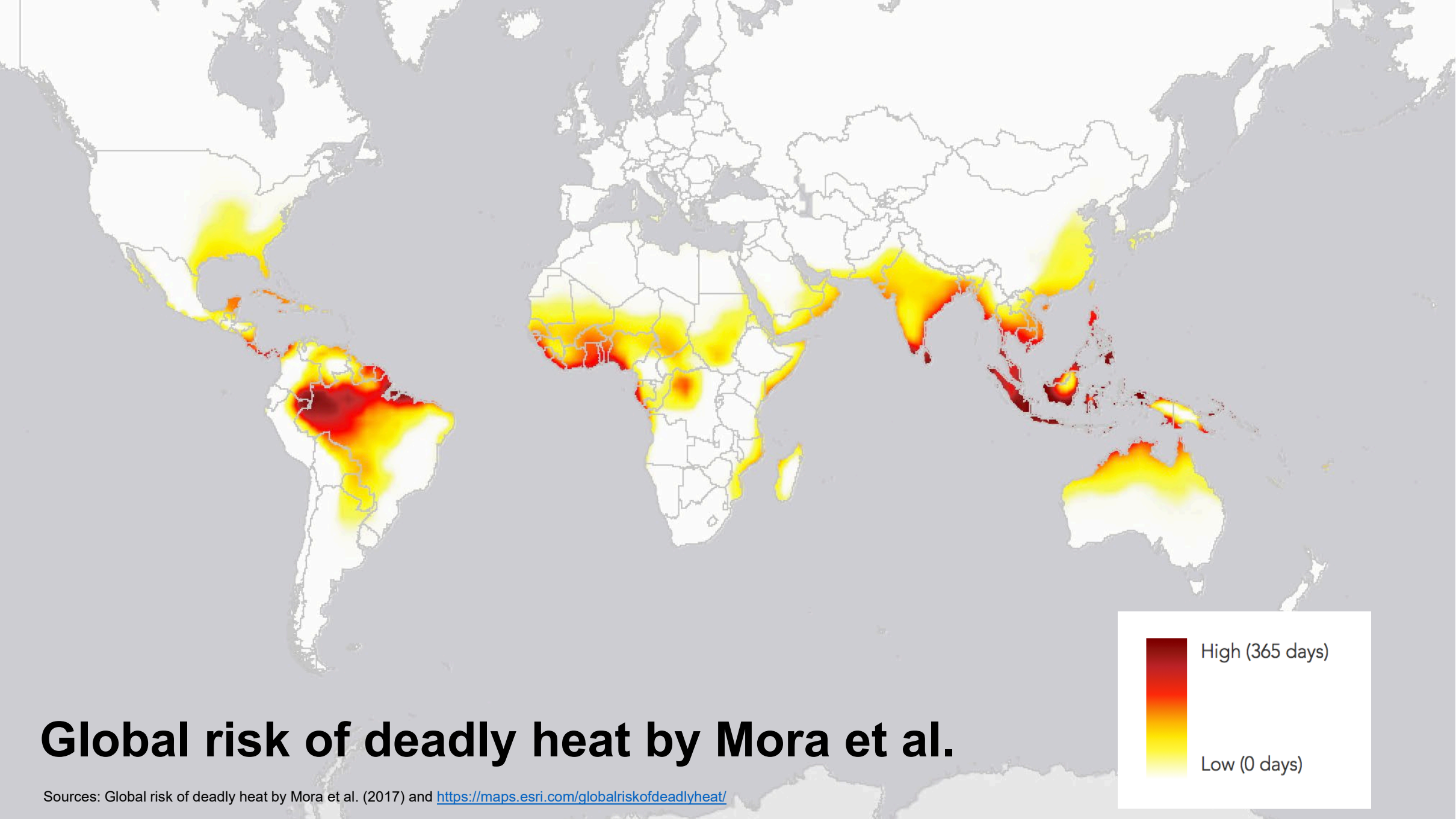
Cooling Singapore Digitale Zwillinge für die Satdtplanung

Prof. em. Dr. Gerhard Schmitt, ETH Zürich
Founding Director, Singapore-ETH Centre

1 The Existential Threat of Global Warming



- Image Credit: Gabriele Manoli
- Caption: Intensity of summertime surface urban heat islands (ΔT_s) in world cities
- Source data: https://sedac.ciesin.columbia.edu/data/set/sdei-global-uhi-2013



Global risk of deadly heat by Mora et al.

Sources: Global risk of deadly heat by Mora et al. (2017) and https://maps.esri.com/globalriskofdeadlyheat/

Cities

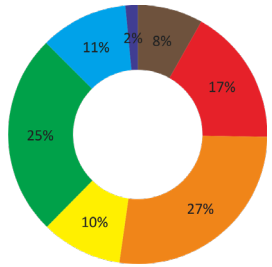
Causes and Victims of Climate Change

Digital Twin: Energy Switzerland

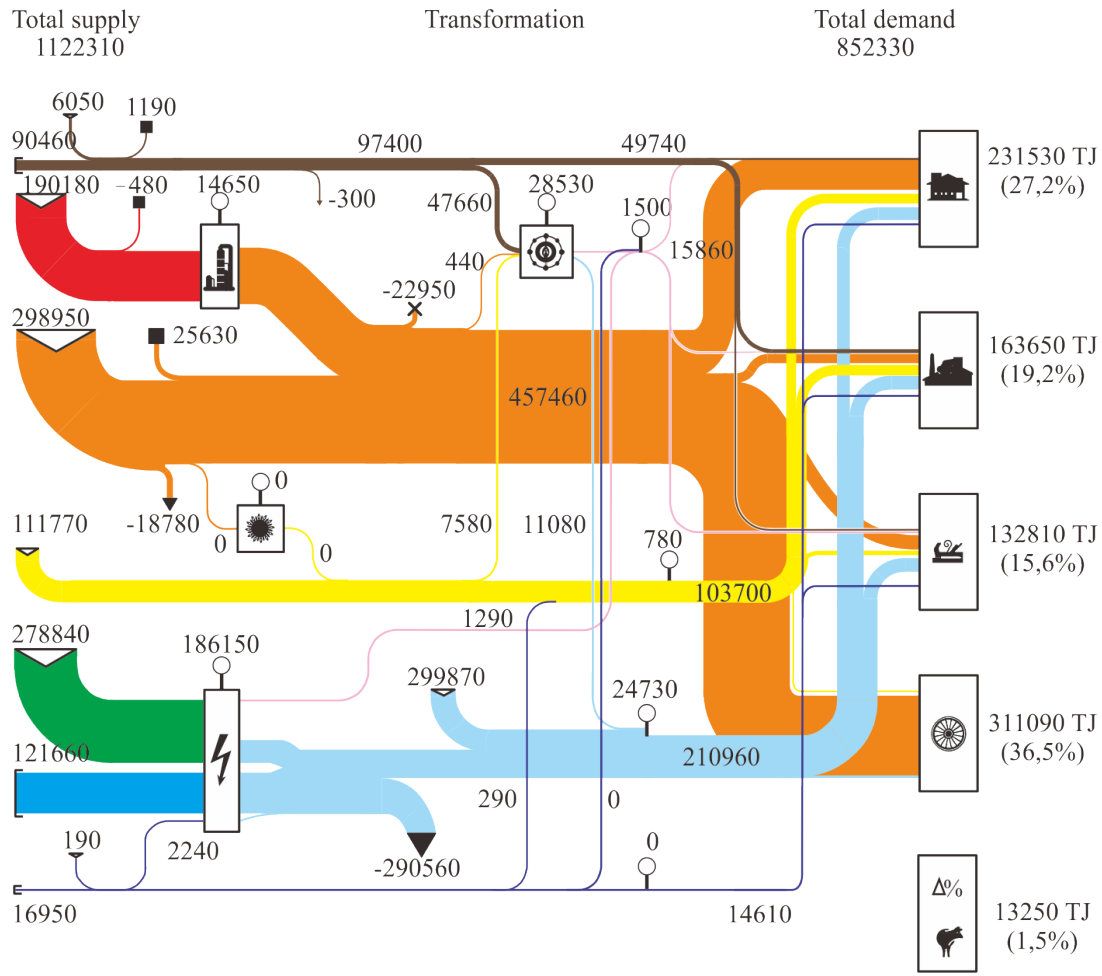
Dr. Matthias Berger, Singapore-ETH Centre, 2012.

Energy flows TJ for Switzerland (2011)

Total Primary Energy Supply (TPES)



Population	8’014’000
Energy demand	852’330 TJ
Area	41’285 km^2
Density	194/ km^2
GDP(PPP)	340 bil. US$



Wood/Coal/Waste
Crude oil
Petroleum
Natural gas
Nuclear fuel
Hydropower
New renewables
Electricity
District heat

Refineries
Hydro/Nuclear
Gasworks
Thermal
Production
Import
Export
Change in stocks
Losses
Non-energetic
Households
Industry
Services
Transportation
Difference

Image courtesy of Swiss Federal Office of Energy

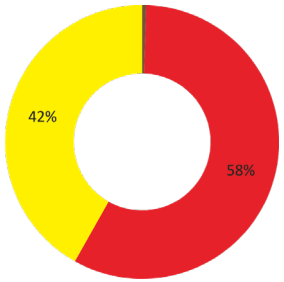

YORK
FedEx

Digital Twin: Energy Singapore

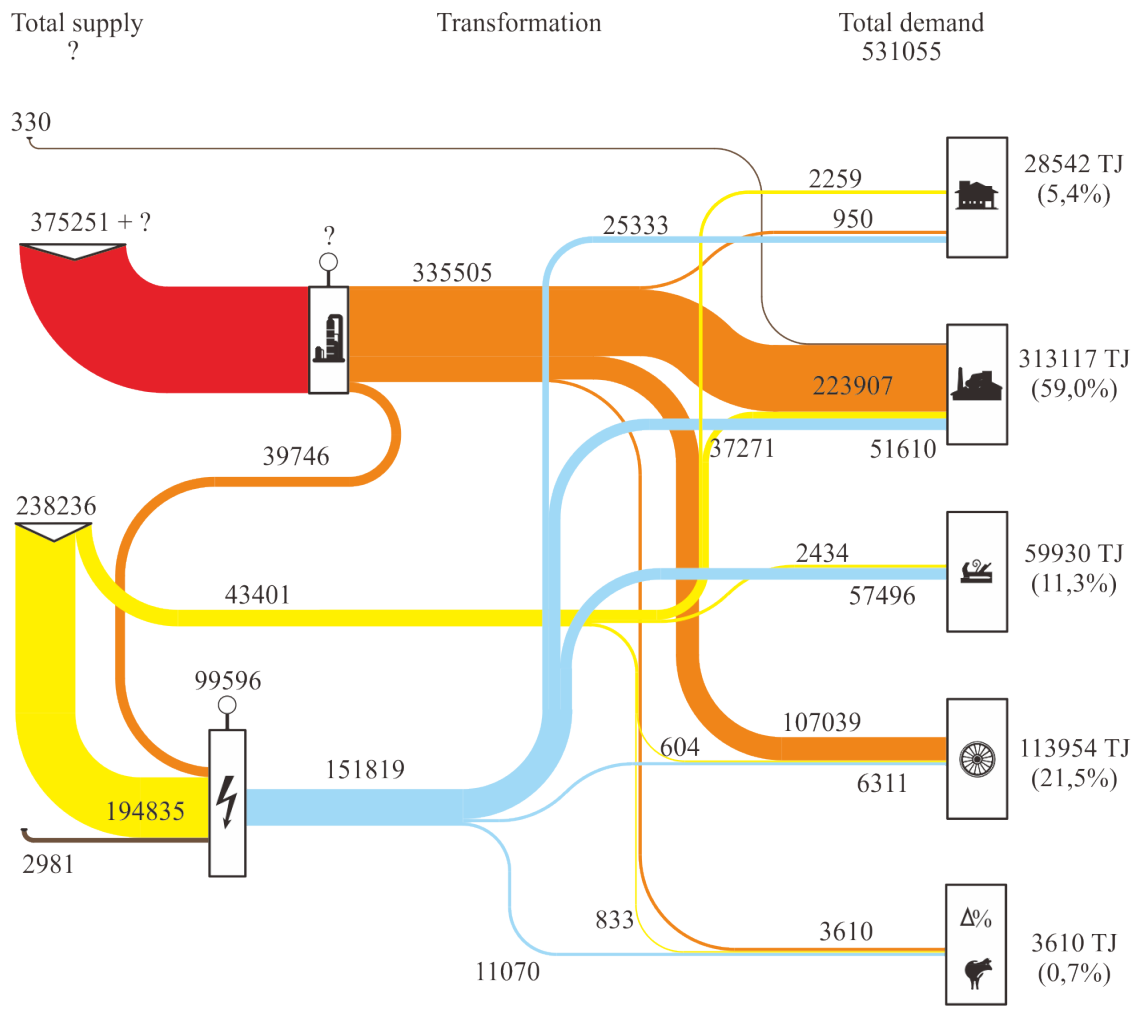
Dr. Matthias Berger, Singapore-ETH Centre, 2012.

Energy flows TJ for Singapore (2011)

Total Primary Energy Supply (TPES)

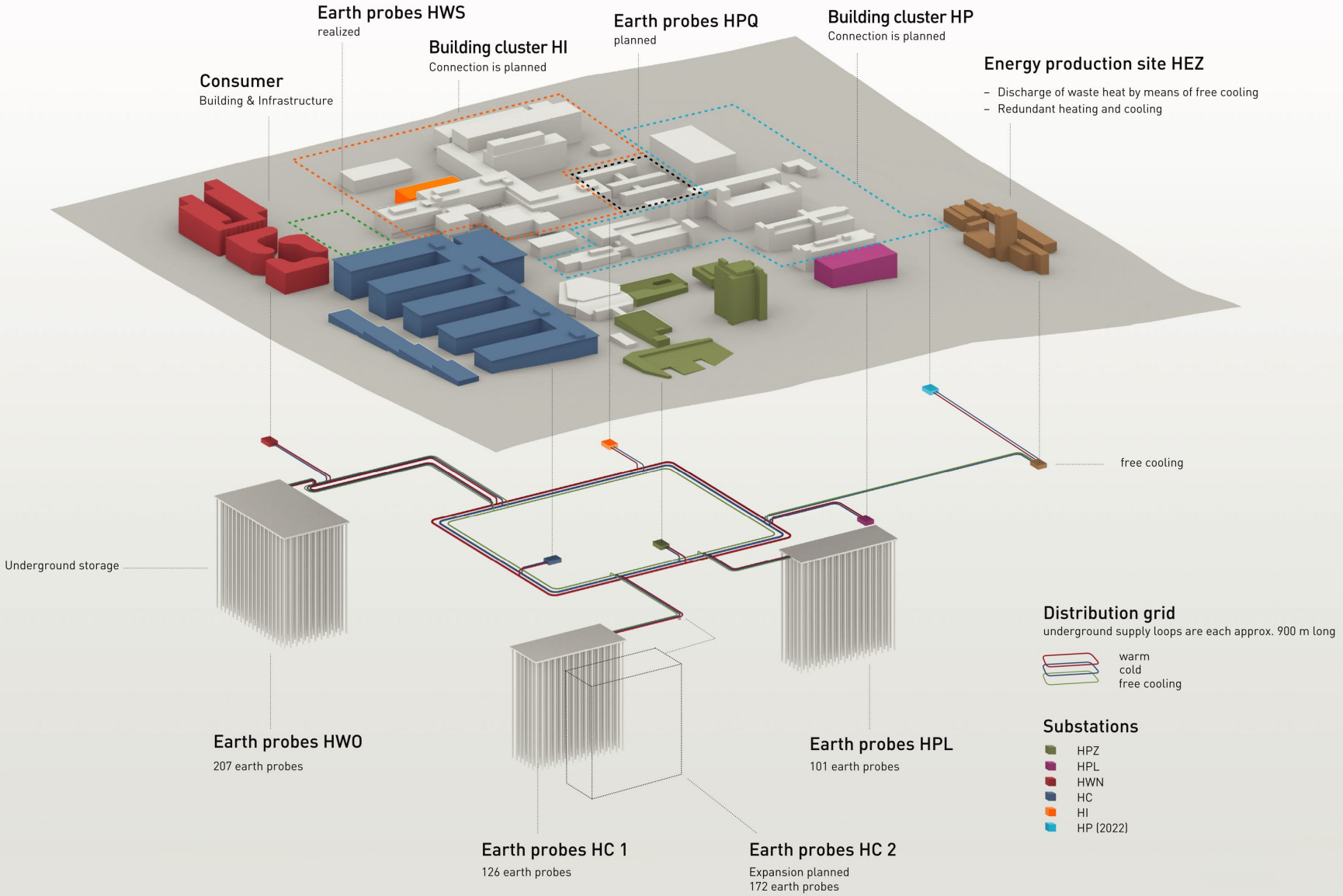


Population	5’312’400
Energy dem.	531’055 TJ
Area	712.4 km²
Density	7126/ km²
GDP(PPP)	315 bil. US$

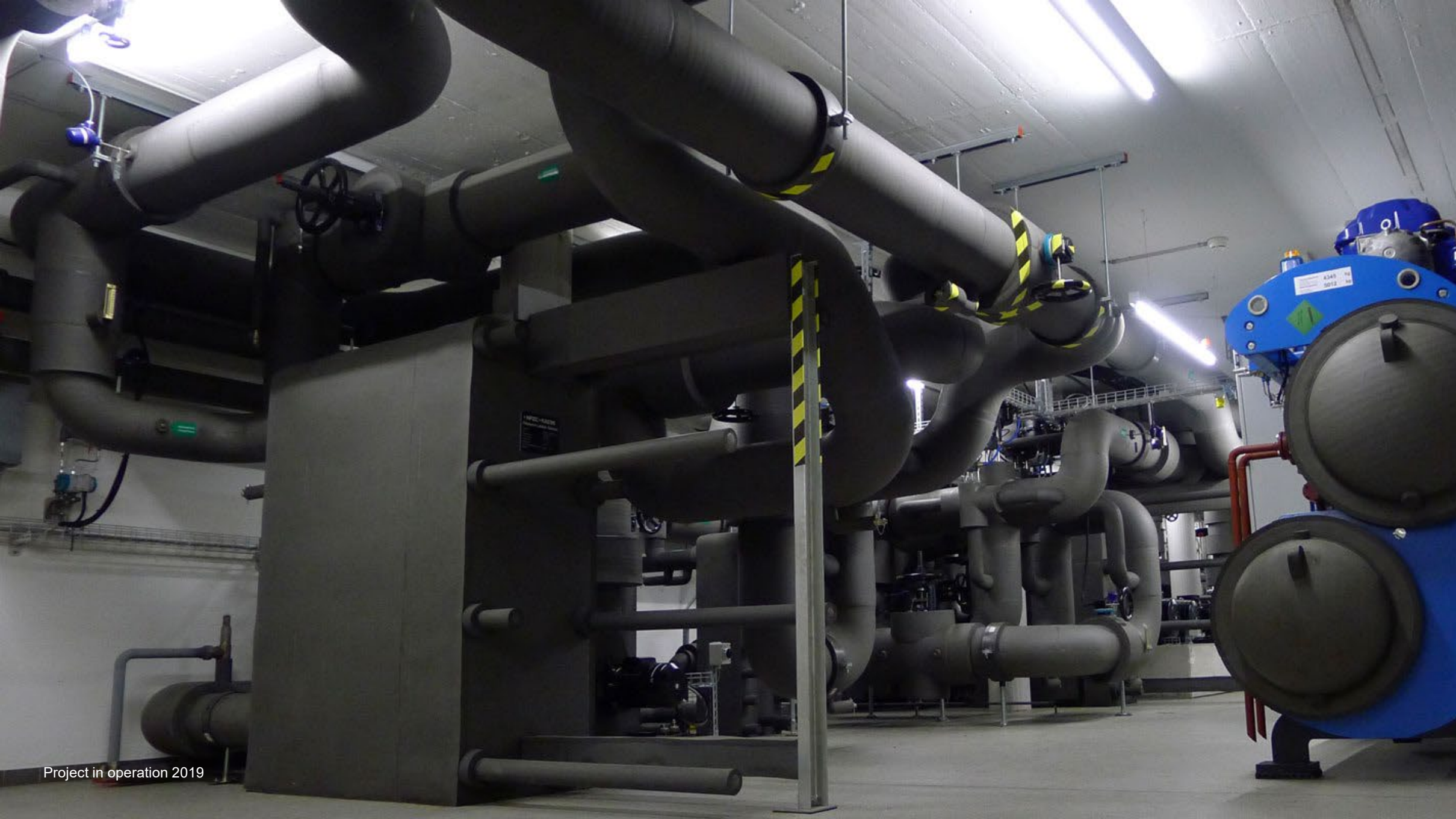


Beyond Sustainable Cities: Generative Cities

ETH Zurich, Campus Hönggerberg
Anergy Grid



Project in operation 2019



Project in operation 2019

Towards Sustainable

After 12 Years

Electricity	Production (photovoltaics)
Heating	Dynamic Earth Storage and Heat Pumps
CO_2	Massive Reduction (>50%)

House in the vineyard, Germany

Towards Generative

After 11 Months

12’400 kWh	Production (photovoltaics)
4’600 kWh	Consumption (household, floor-heating, floor-cooling, e-mobility

What do these examples have in common?

Designed using digital twins


Singapore-ETH Centre
CREATE Campus

- ETH Zurich's only major research centre outside Switzerland
- Part of National Research Foundation's Campus for Research Excellence and Technological Enterprise (CREATE)

ETH zürich
האוניברסיטה העברית בירושלים THE HEBREW UNIVERSITY OF JERUSALEM
Massachusetts Institute of Technology
NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE
NUS National University of Singapore
上海交通大學 SHANGHAI JIAO TONG UNIVERSITY
TECHNISCHE UNIVERSITÄT MÜNCHEN
Berkeley UNIVERSITY OF CALIFORNIA
UNIVERSITY OF CAMBRIDGE
ILLINOIS

CREATE Campus for Research Excellence And Technological Enterprise
ETH zürich
EPFL
NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE
NUS National University of Singapore
PAUL SCHERRER INSTITUT PSI
SMU SINGAPORE MANAGEMENT UNIVERSITY
SUTD

2

Thank you to the
Research Team, Partners,
UHI Workgroup,
Scientific Advisory Committee,
Steering Committee,
National Research Foundation,
and ETH Zürich

Dr Kristina Orehounig, EMPA & SEC
Current Lead-PI (SEC)

COOLING SINGAPORE

Future Urban Climate Design and Management

The COOLING SINGAPORE initiative is an integrated and holistic approach to address the URBAN HEAT CHALLENGE for Singapore and other cities around the world

Cooling Singapore in the News

Bloomberg Global News

LIVE

Bloomberg Global Financial News

Bloomberg Quicktake ✓ 1769 aktive Zuschauer

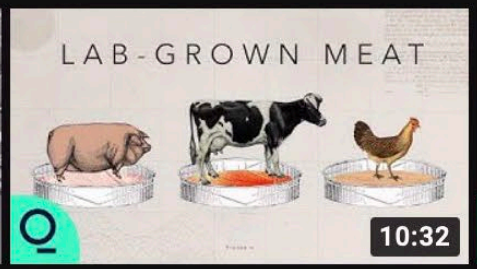
Bloomberg Global News brings you live coverage of the markets o
need to know across business, finance, technology, politics and m

New & Featured Original Series ▶ ALLE WIEDERGEBEN

Stay informed with the latest from our global team of video journalists.

How Singapore Uses Science to Stay Cool

Bloomberg Quicktake ✓
738.647 Aufrufe • vor 5 Tagen
Untertitel

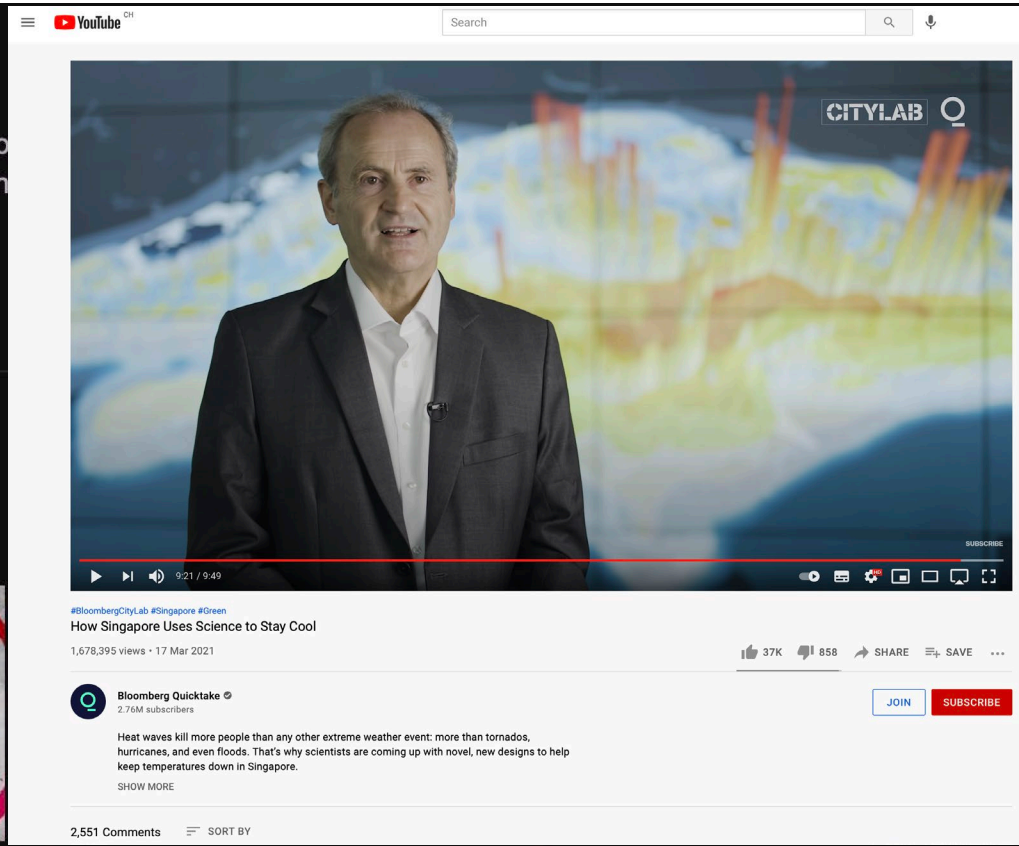


No Animals Were Harmed In The Making Of This Meat

Bloomberg Quicktake ✓
89.152 Aufrufe • vor 5 Tagen
Untertitel

Heroin's Hidden Ingredient, Courtesy of a U.S. Company

Bloomberg Quicktake ✓
226.861 Aufrufe • vor 6 Tagen
Untertitel



Life-Saving Car Technology No One Wants

Bloomberg Quicktake ✓
108.862 Aufrufe • vor 1 Woche
Untertitel

Untangling a Murder Conspiracy in Honduras

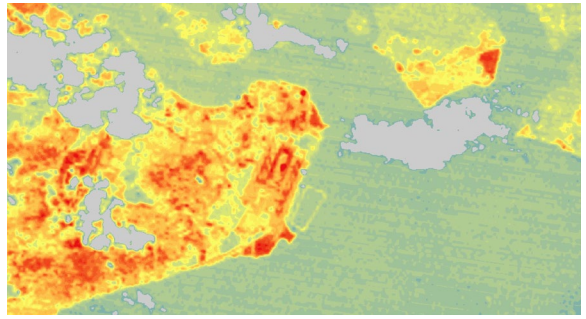
Bloomberg Quicktake ✓
58.476 Aufrufe • vor 1 Woche
Untertitel

3 SINGAPORE'S URBAN HEAT ISLAND

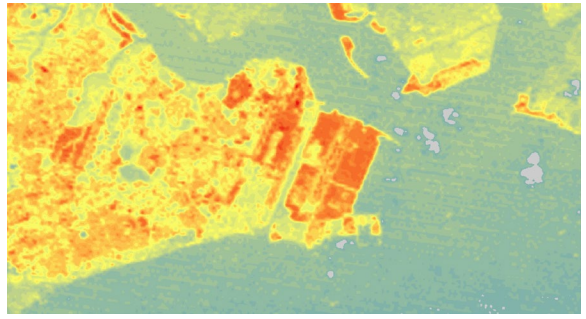

YORK
FedEx

AIRPORT

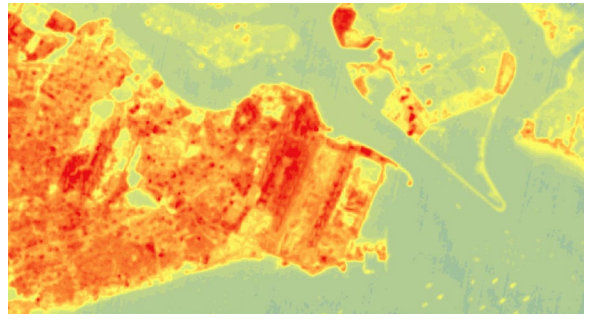
13 September 1989
10:42 am



25 December 2003
10:55 am



8 May 2018
11.16 am

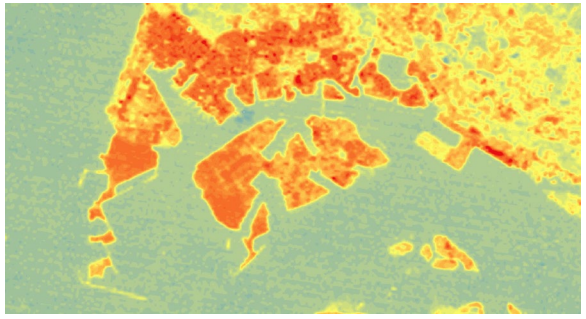


This is work in progress. The surface temperature map can be used as an initial indicator to understand the impact of the building mass.

JURONG

13 September 1989
10:42 am

25 December 2003
10:55 am



8 May 2018
11.16 am

This is work in progress. The surface temperature map can be used as an initial indicator to understand the impact of the building mass.

Passive and Active ANTHROPOGENIC HEAT

(Mostly Passive) ANTHROPOGENIC HEAT

CLIMATE RESPONSIVE DESIGN GUIDELINES


URBAN GEOMETRY
Sky view factor
Aspect ratio
Mean building/tree height
Building form
Variation between building heights
Wider streets
Avoid obstruction
Open spaces along sea shore
Building porosity
Street axes orientation
Well-ventilated sidewalks
Building arrangement
Open spaces at road junctions
Guide wind flows with urban elements
Passive cooling systems
Urban density by Local Climate Zones
Building Surface Fraction
Green Plot Ratio
Topography
VEGETATION
Green roofs
Vertical greeneries
Green walls/facades
Vegetation around buildings
Selective Planting
Green pavements
Infrastructure greenery
Macroscale urban greening
Local scale urban greening
Microscale urban greening
Green parking lots
Tree species
Urban farming
Transport corridors
WATER BODIES
Cool sinks
Blue and green spaces
Wetlands
Water catchment areas
Ponds on roofs/ground floor
Evaporative cooling
Fountains
SHADING
Building orientation
Shading on buildings
Permanent shading devices
Moveable shading devices
Smart shading devices
Shaded pedestrian spaces
Shaded bicycle lanes
ENERGY
Heat losses in buildings
Energy efficiency of air-conditioning systems
Energy efficiency of household appliances and office equipment
Energy efficiency of industries
Cooling load of buses
Indoor temperature setting
Sizing of the energy plants
Ventilation for heat exhaust of air-conditioning units
Window-to-wall ratio
District Cooling
Renewable energy sources
Heat recovery systems
Mixed used neighbourhoods
Buffer zones
Hybrid ventilation in outdoor spaces
TRANSPORT
Vehicle population
Public transport
Centralised routing system
Active mobility
Electric private vehicles
Electric public transport
Autonomous mobility
Infrastructure of buses/bus stops
Types of road materials
Material and colour of cars
MATERIALS AND SURFACES
Cool pavements
Permeable surfaces
Photocatalytic cool pavements
Cool roofs
Cool façades
Photocatalytic cool building envelope
Retro-reflective materials
Phase Change Materials
Desiccant systems
Water cooling façade system
Thermochromic/selective materials
Dynamic and active roofs
Dynamic and active façades or building components
Building envelop performance

(Mostly Active) ANTHROPOGENIC HEAT

ANTHROPOGENIC HEAT EMISSIONS

(left bottom) The Business Times (2017)
(left top) Cooling Singapore, Lina Meisen (2018)
(right top) The Straits Times (2019)

Energy consumption from buildings

HDB (i.e., public housing)
50 kWh/m^2 per year

Private housing (e.g., condos)
1.5x more than HDB

Commercial buildings
6x more than HDB

Source: Cooling Singapore (2019)

Energy used by road transportation

Lorries / vans
45%

Private cars
30%

Buses
15%

Taxis
8%

Motorcycle
2%

Source: Cooling Singapore (2019)

Analysis of the anthropogenic heat

Result #1

Yearly representation of AH sources of Singapore for 2016.

- The AH emissions of Singapore are generated by five key sources:
    - Industry (58.5%)
    - Power generation (15.3%)
    - Buildings (11.9%)
    - Road transportation (11.4%)
    - Human metabolism (2.8%)
    - *Excluding aviation and ship.*
- A **Sankey diagram** represents the emissions of Singapore for the year 2016.

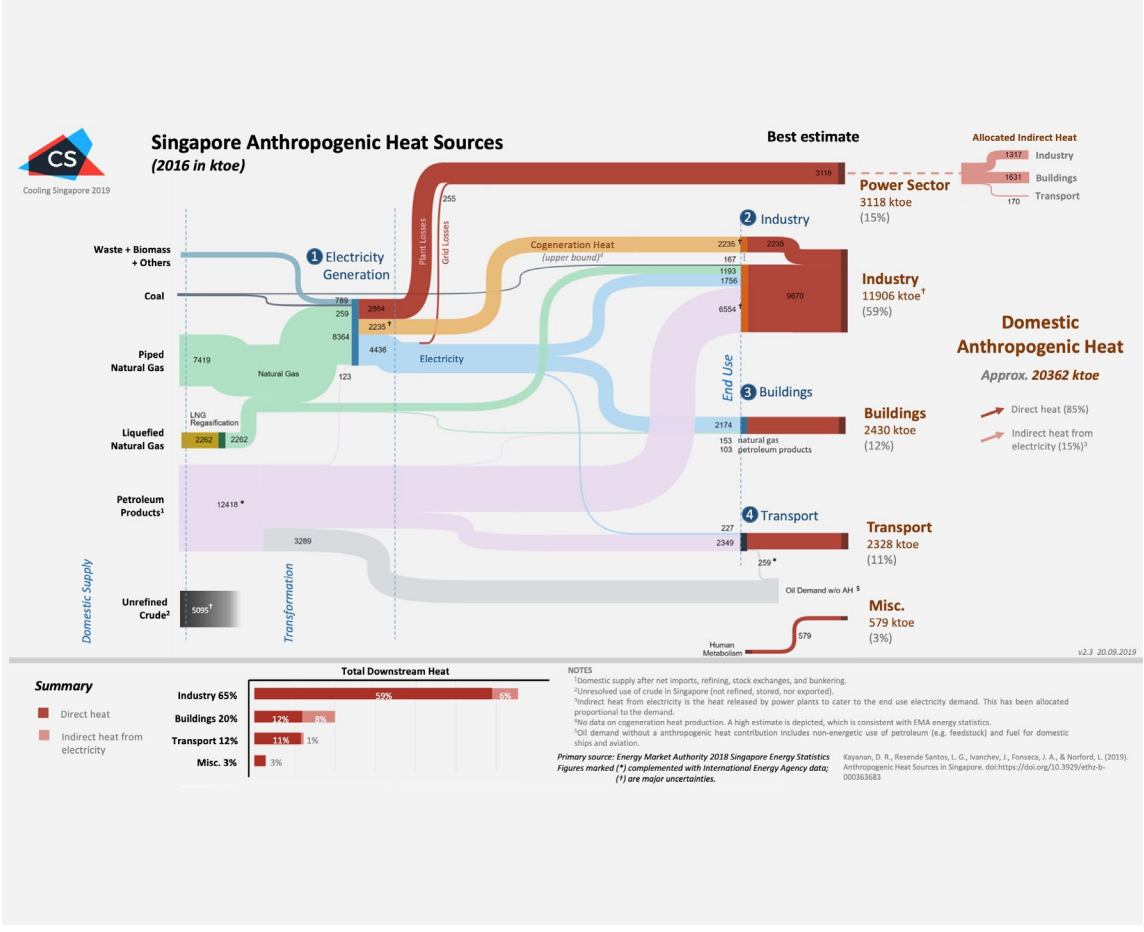


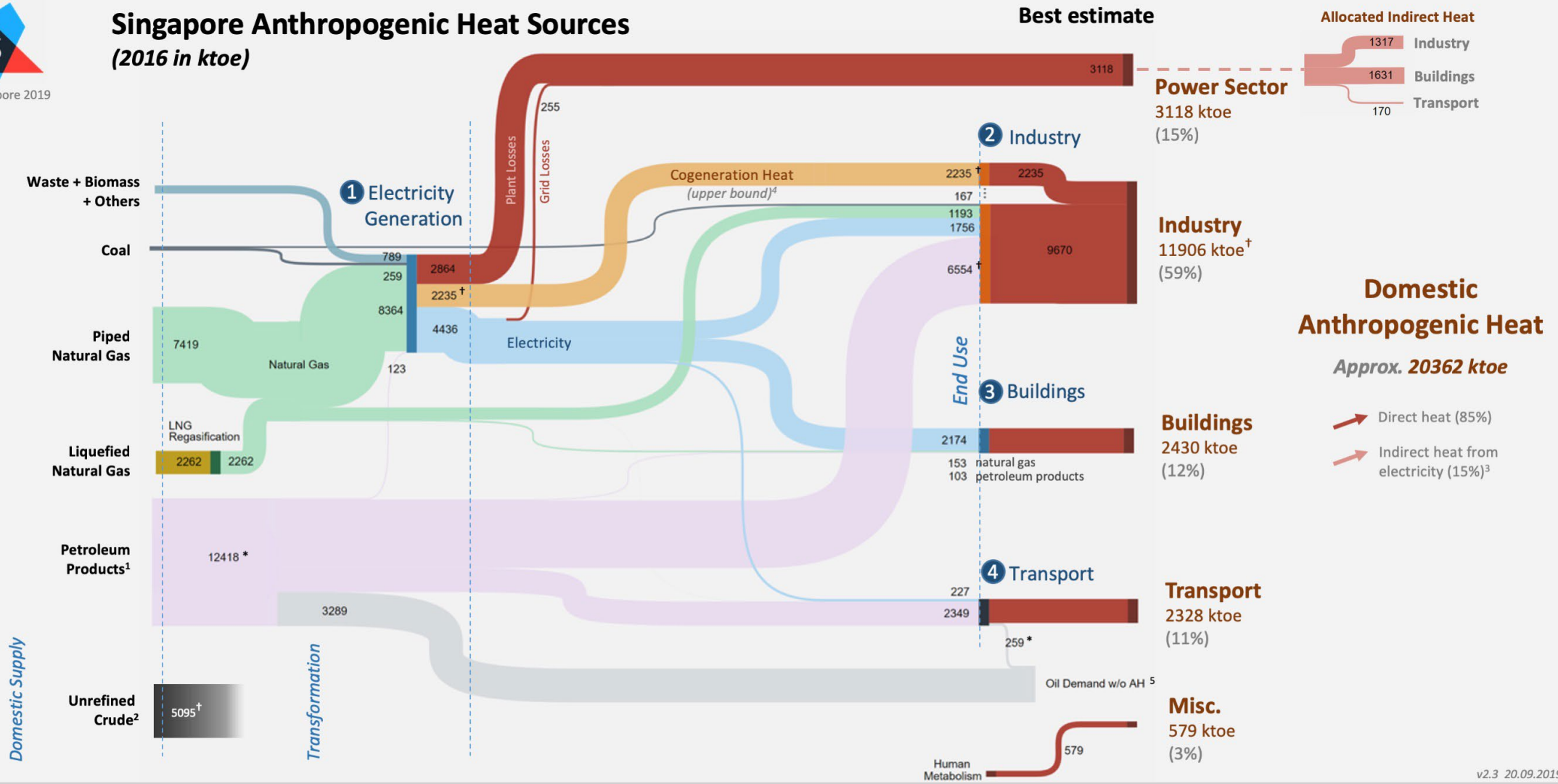
Image: Sankey Diagram | Cooling Singapore, 2019
Data: extracted from the public website of the Energy Market Authority of Singapore and the International Energy Agency.
Report: Kayanan, D. et al., 2019. https://doi.org/10.3929/ethz-b-000363683

COOLING SINGAPORE

Cooling Singapore 2019

Singapore Anthropogenic Heat Sources

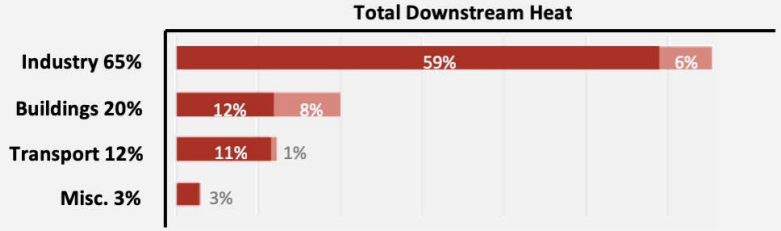
(2016 in ktoe)



Summary

- Direct heat
- Indirect heat from electricity

Total Downstream Heat



NOTES

[1]Domestic supply after net imports, refining, stock exchanges, and bunkering.
[2]Unresolved use of crude in Singapore (not refined, stored, nor exported).
[3]Indirect heat from electricity is the heat released by power plants to cater to the end use electricity demand. This has been allocated proportional to the demand.
[4]No data on cogeneration heat production. A high estimate is depicted, which is consistent with EMA energy statistics.
[5]Oil demand without a anthropogenic heat contribution includes non-energetic use of petroleum (e.g. feedstock) and fuel for domestic ships and aviation.

Primary source: Energy Market Authority 2018 Singapore Energy Statistics
Figures marked (*) complemented with International Energy Agency data;
(†) are major uncertainties.

Kayanan, D. R., Resende Santos, L. G., Ivanchev, J., Fonseca, J. A., & Norford, L. (2019). Anthropogenic Heat Sources in Singapore. doi:https://doi.org/10.3929/ethz-b-000363683

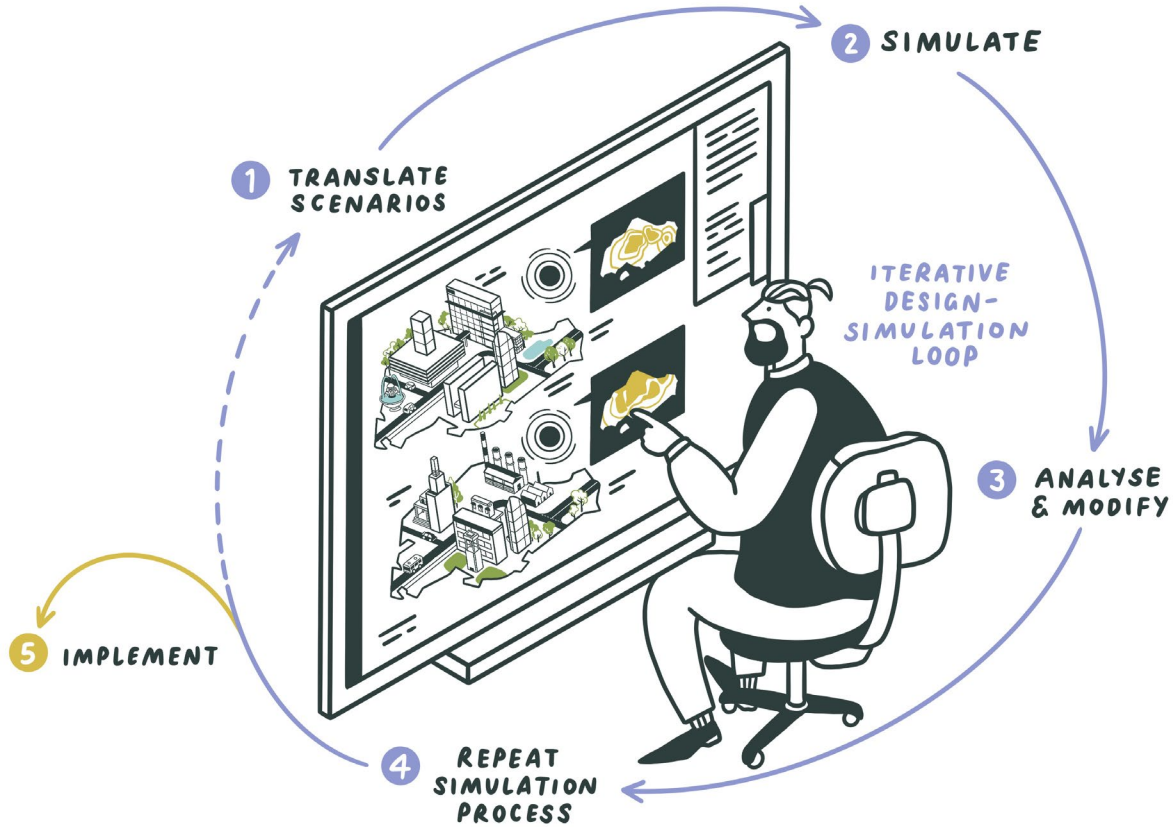
4 Digital Urban Climate Twin

DIGITAL URBAN CLIMATE TWIN
Urban Climate Design and Management

“Urban climate design and management refers to ability to understand the climate science, to modify and maintain the urban climate (temperature, humidity and air-flow) on different urban scales (e.g., island-wide and building-scale), and to comprehend the social science of risks and mitigation to set targets and desired conditions accordingly.”

Provide planners and decision makers with a tool (== Digital Urban Climate Twin) that allows them to experiment with what-if scenarios in order to make better-informed decisions.

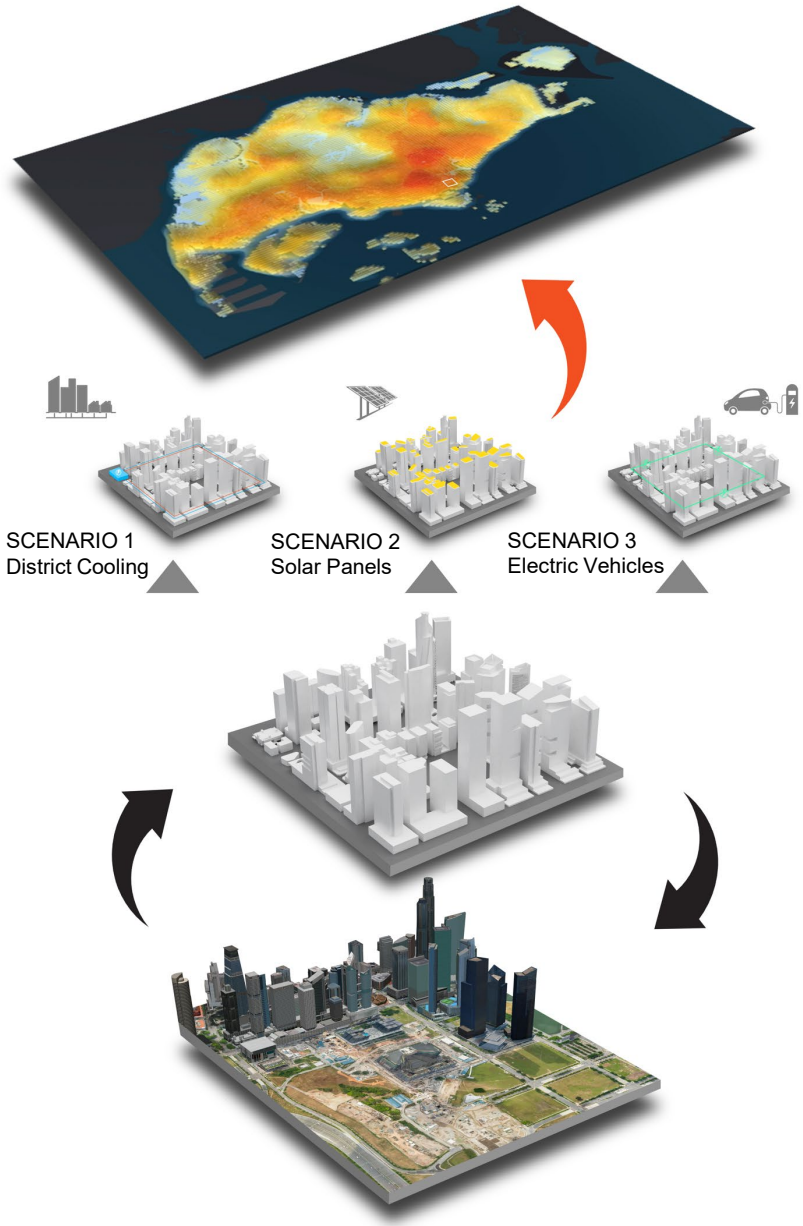
This will require a lot of computational power...



In reference to Dr. Heiko Aydt, Cooling Singapore

Source: H. Aydt (2020). Cooling Singapore – Towards Urban Climate Design and Management in Indicia 03, editors: S. Cairns and D. Tunas (forthcoming)

DIGITAL URBAN CLIMATE TWIN
What-if Scenario Analysis



MICRO- & MESOSCLE SIMULATION

WHAT IF SCENARIO

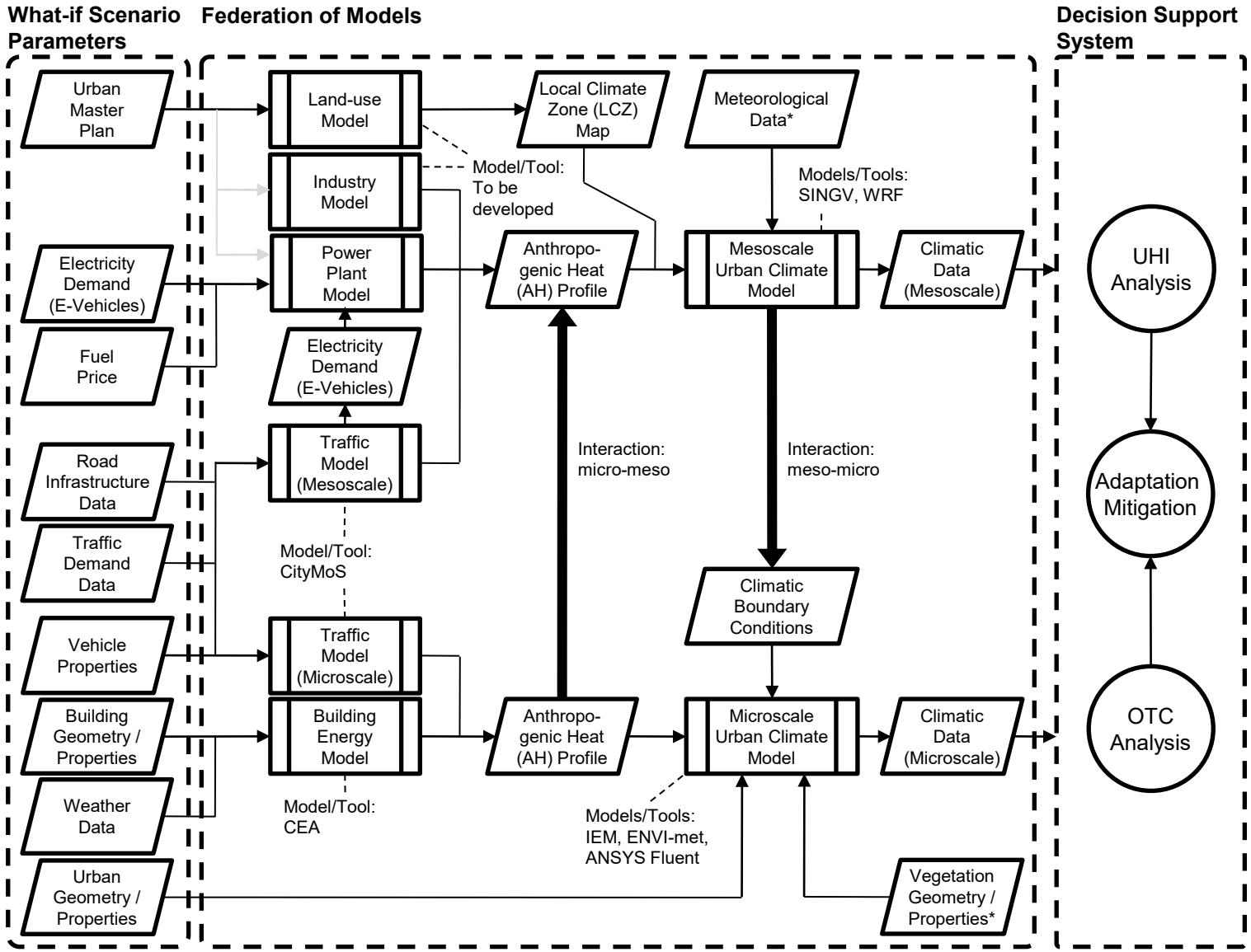
DIGITAL TWIN

REAL WORLD

In reference to Dr. Heiko Aydt, Cooling Singapore

Image: Lea Rüfenacht (January 2020)

DIGITAL URBAN CLIMATE TWIN
Principal Components

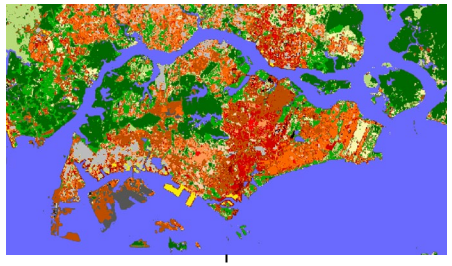


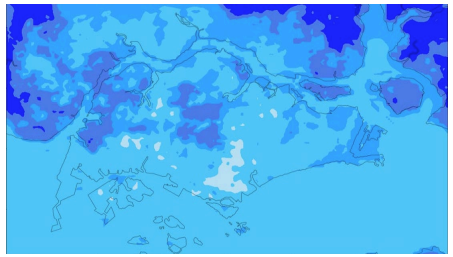
Data Flow | **Model/ Tool** | **Data Object** | User Interface (Apps)

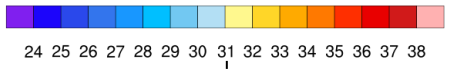
In reference to Dr. Heiko Aydt, Cooling Singapore

*) part of what-if scenario parameters but shown here for conciseness.

DEMONSTRATOR 1 – WORKFLOW AUTOMATION
Overview







LCZ Map (Urban)

WPS

WRF Package

WRF

Heatmap (T2, hourly)

2016-04-01 00:00:00

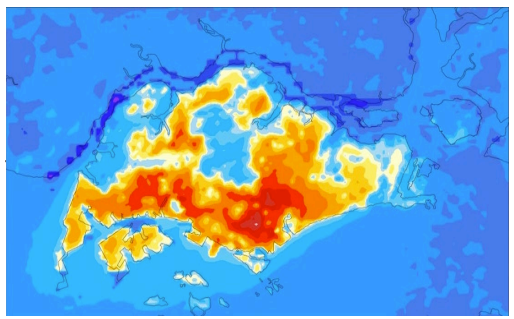
Date/Time (From)

2016-04-03 00:00:00

Date/Time (To)

UHI Calculation

Heatmap (UHI, hourly)



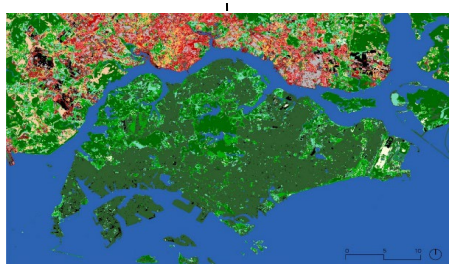
LCZ Map (AllGreen)

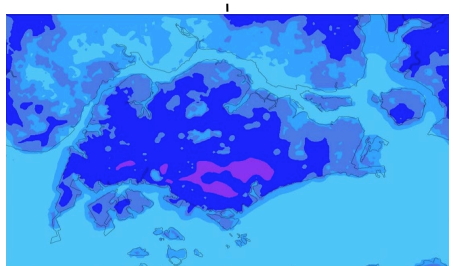
WPS

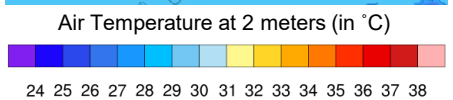
WRF Package

WRF

Heatmap (T2, hourly)



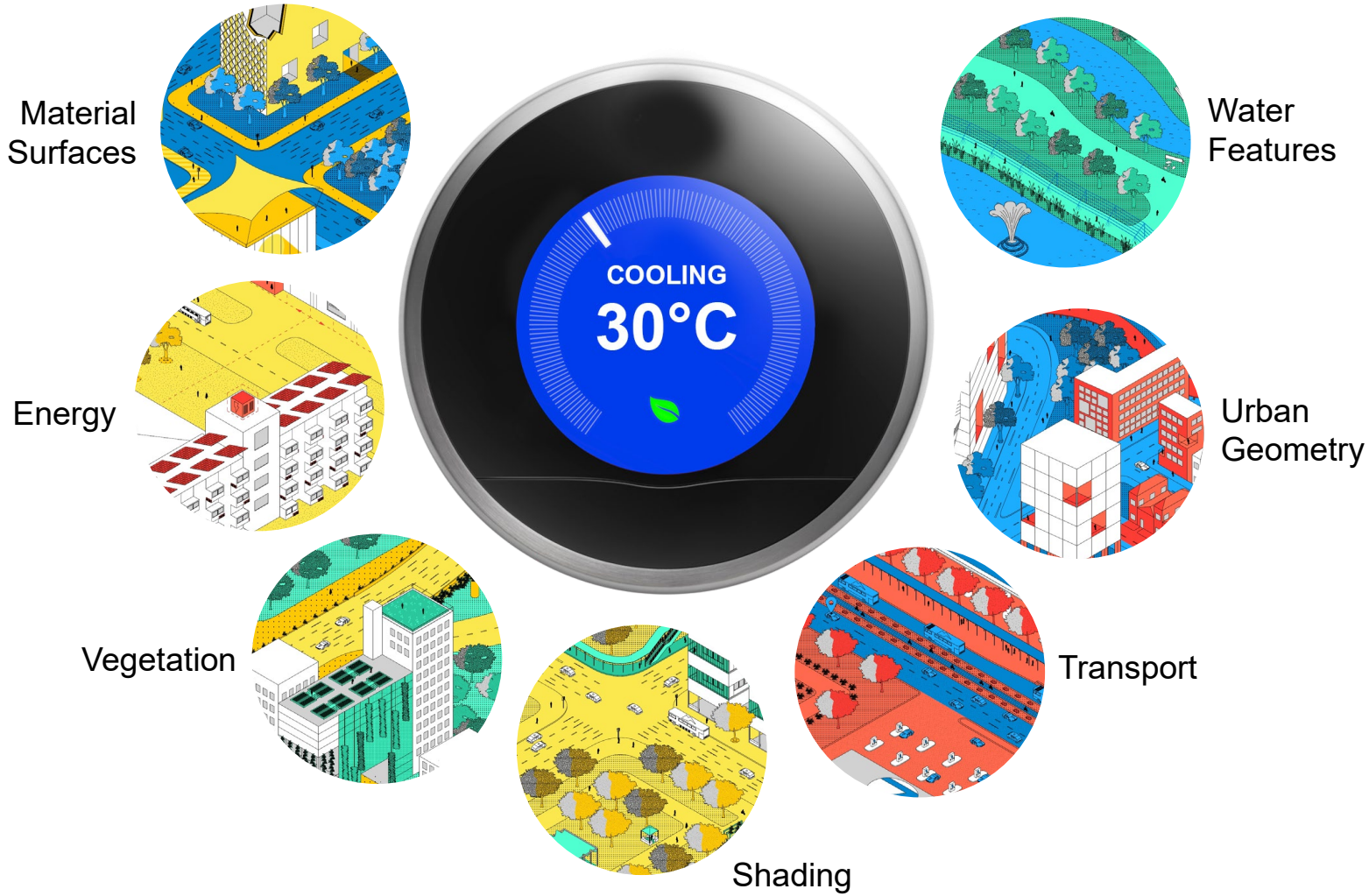




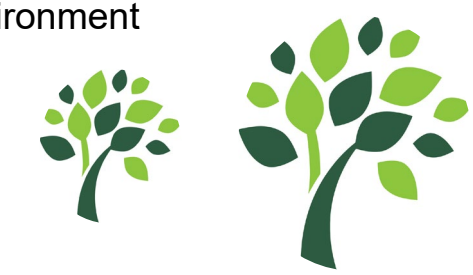
Images: Omer Mughal

URBAN CLIMATE DESIGN AND MANAGEMENT

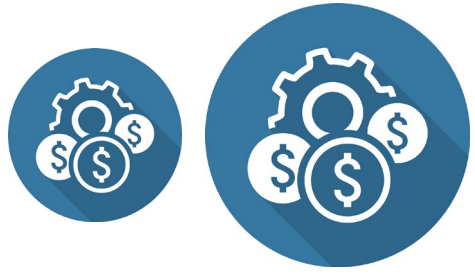
MITIGATION AND ADAPTATION



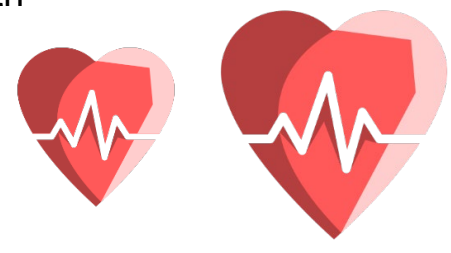
Environment



Economy



Health

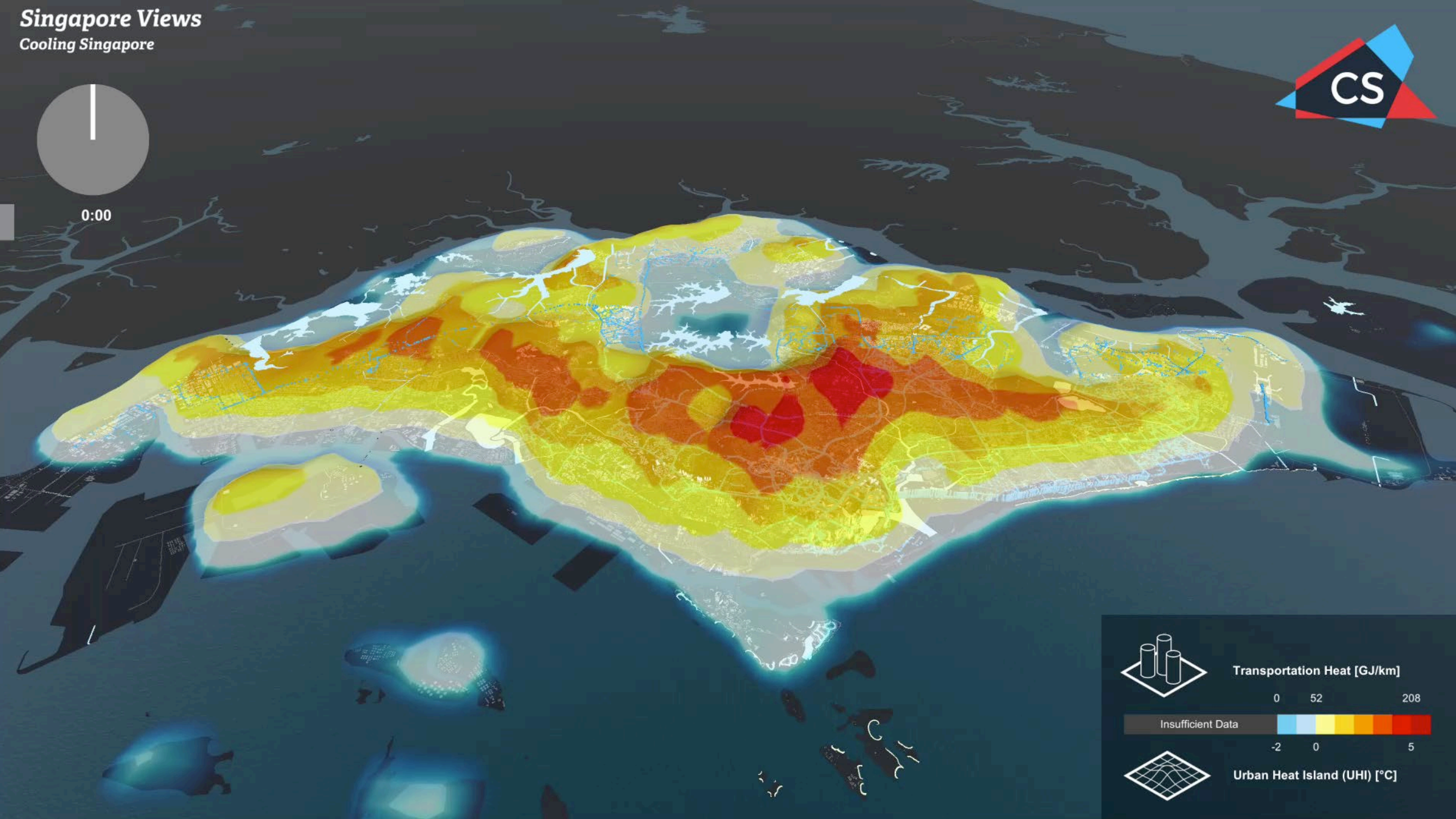


Costs

The temperature of 34 degree is based on MSS data where 30.0˚C is indicated as the highest monthly mean temperature[1] plus additional up to 4.6 degree (°C) temperature increase through to climate change[2]

1: Highest Monthly Mean Temperature (°C) / 1929-1941 and since 1948, average over all MSS Climate Station http://www.weather.gov.sg/climate-historical-extremes-temperature/

2: https://www.nccs.gov.sg/climate-change-and-singapore/national-circumstances/impact-of-climate-change-on-singapore


Singapore Views
Cooling Singapore
0:00
CS
Transportation Heat [GJ/km]
0
52
208
Insufficient Data
-2
0
5
Urban Heat Island (UHI) [°C]

Conclusion

From the Vision of Generative Future Cities Through Responsive Governance Towards Generative Enterprises:

Digital Twins as crucial enablers for moving towards decarbonized, cooler, quieter, healthier and more resilient cities


Thank you!