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Powering the City: **Integrating Renewable Energy at Scale**

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Zurich Hub

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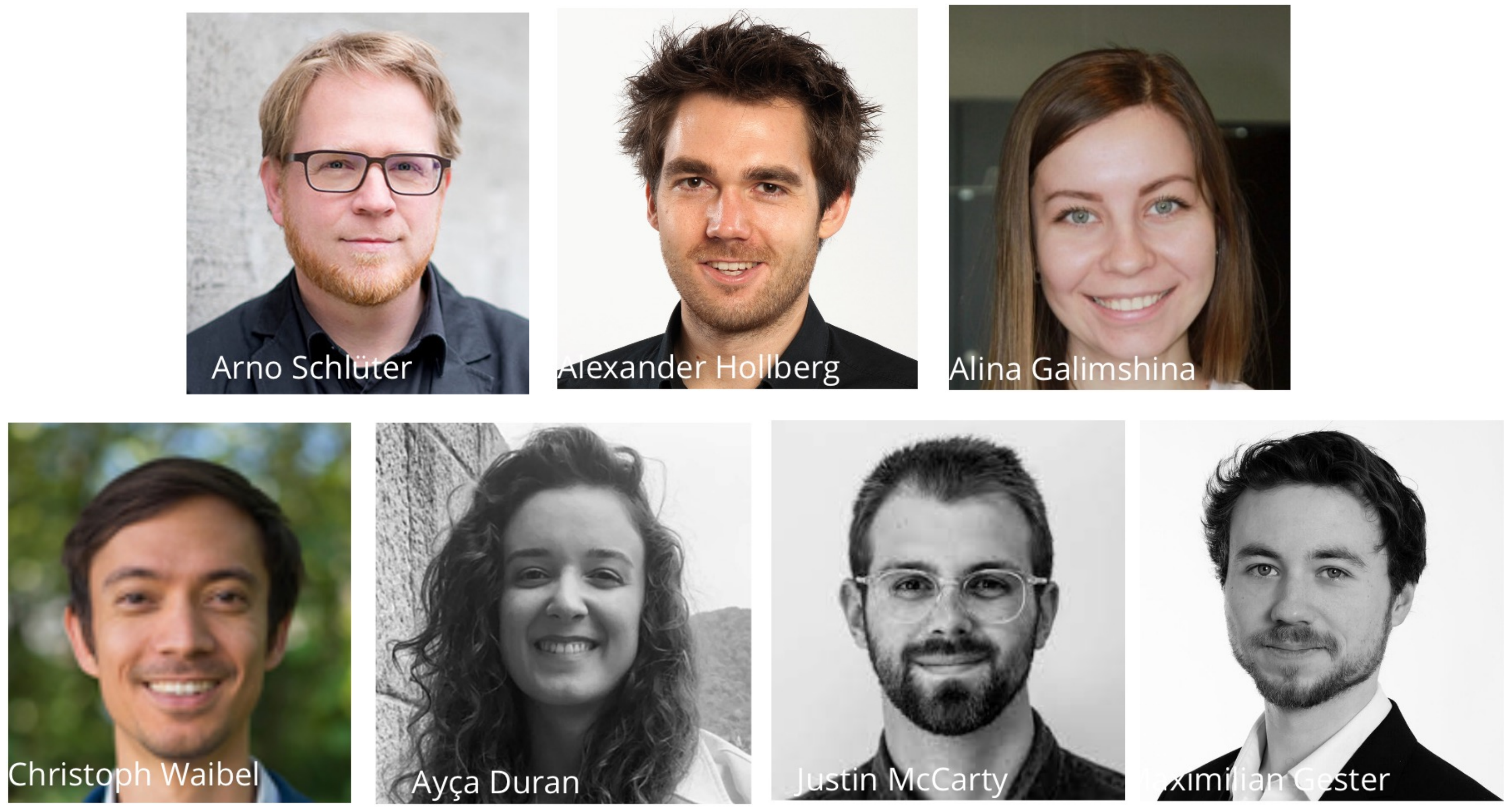
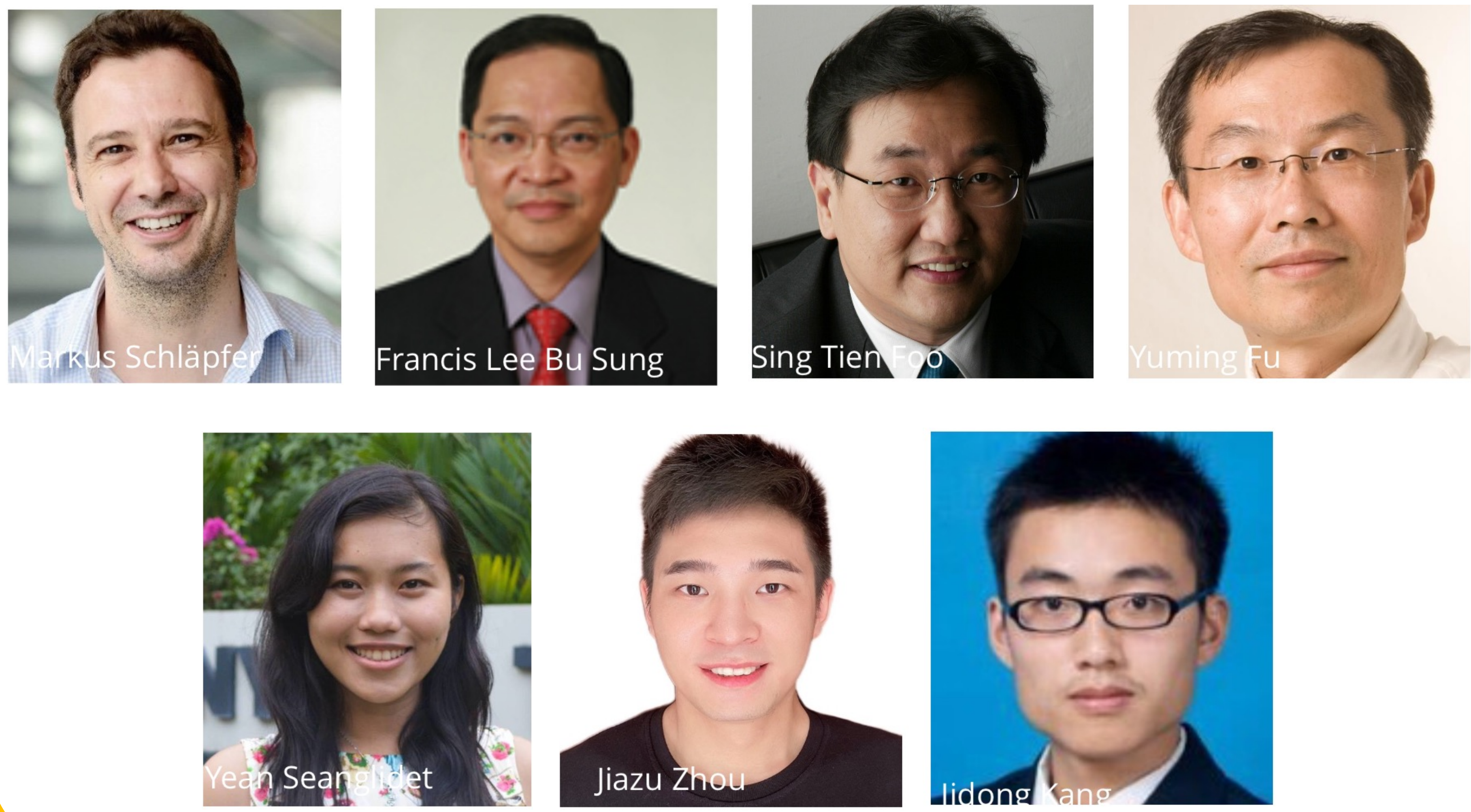
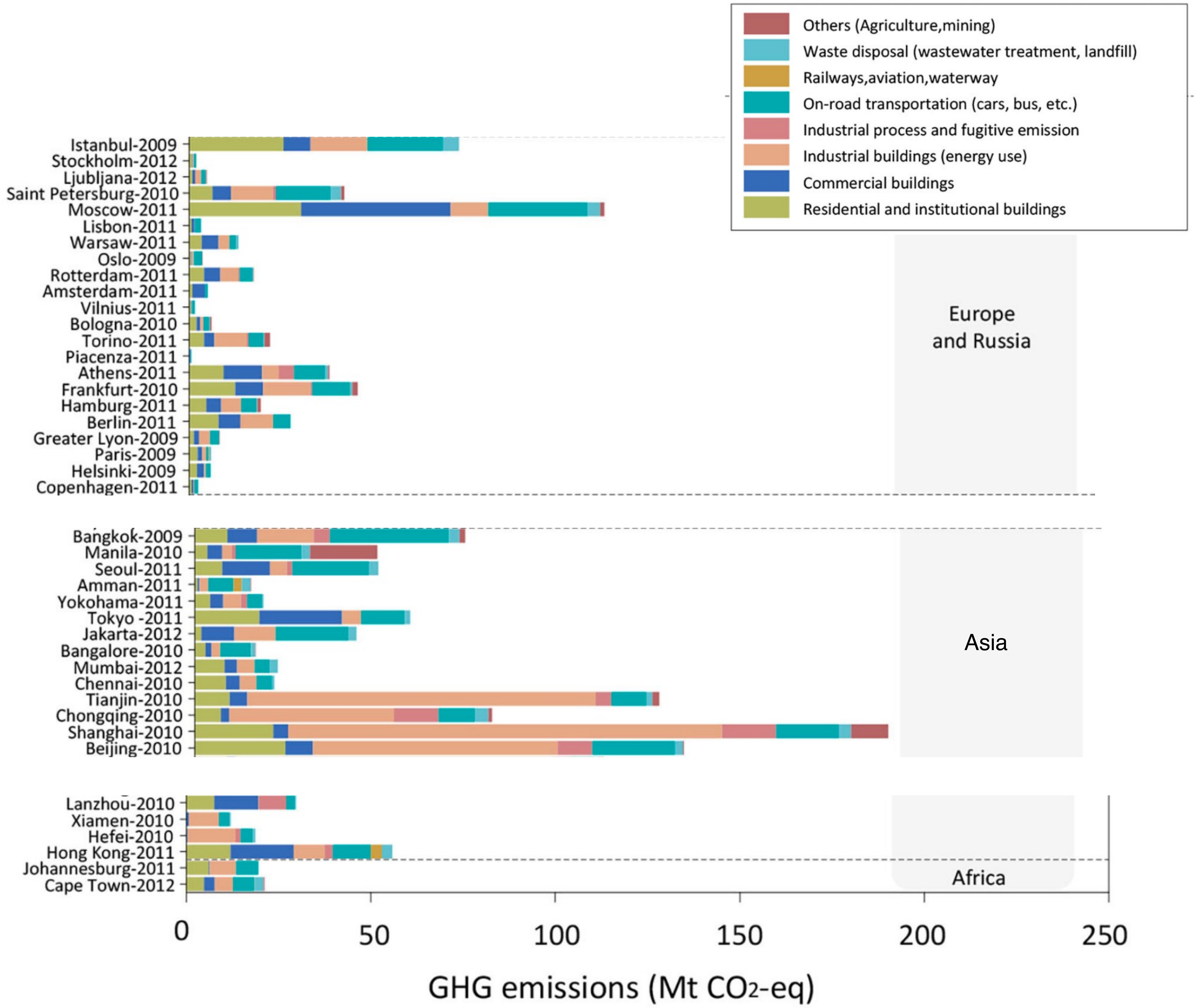


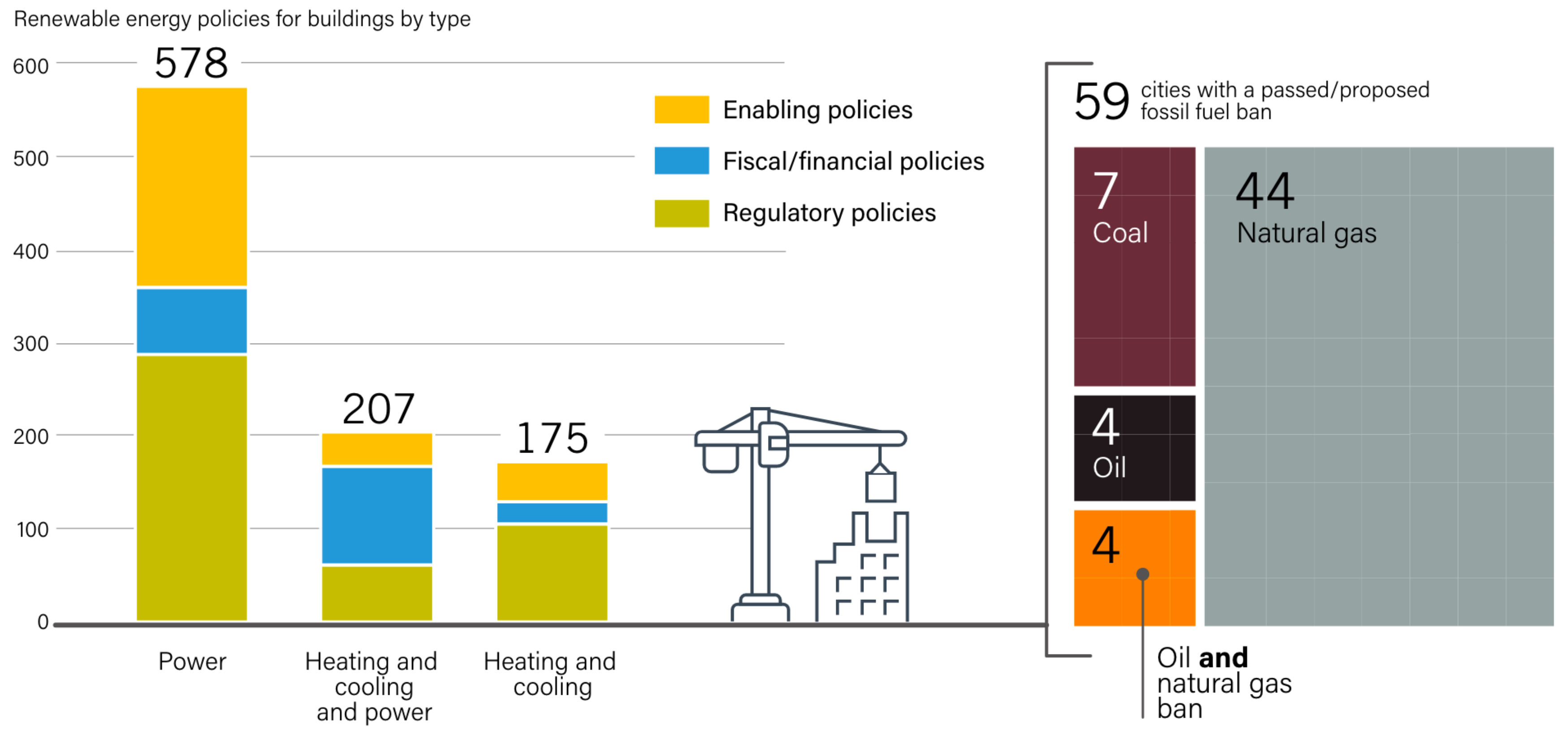
Singapore Hub

NUS National University of Singapore
NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE
COLUMBIA UNIVERSITY



Top 100 Urban Areas account for 18% of Global GHG





*" By the end of 2021, over 920 municipal governments had implemented direct regulatory policies, financial and fiscal incentives, and indirect support policies aimed at **decarbonising buildings through renewable power** and/or renewable heating"*

REN21. 'RENEWABLES 2022 GLOBAL STATUS REPORT'. Accessed 20 September 2023

Wei, Ting, Junliang Wu, and Shaoqing Chen. 'Keeping Track of Greenhouse Gas Emission Reduction Progress and Targets in 167 Cities Worldwide'. *Frontiers in Sustainable Cities* 3 (2021).

Definition of Building Integrated Photovoltaics (BIPV)

*A BIPV module is a **PV module and a construction product** together, designed to be a component of the building.*

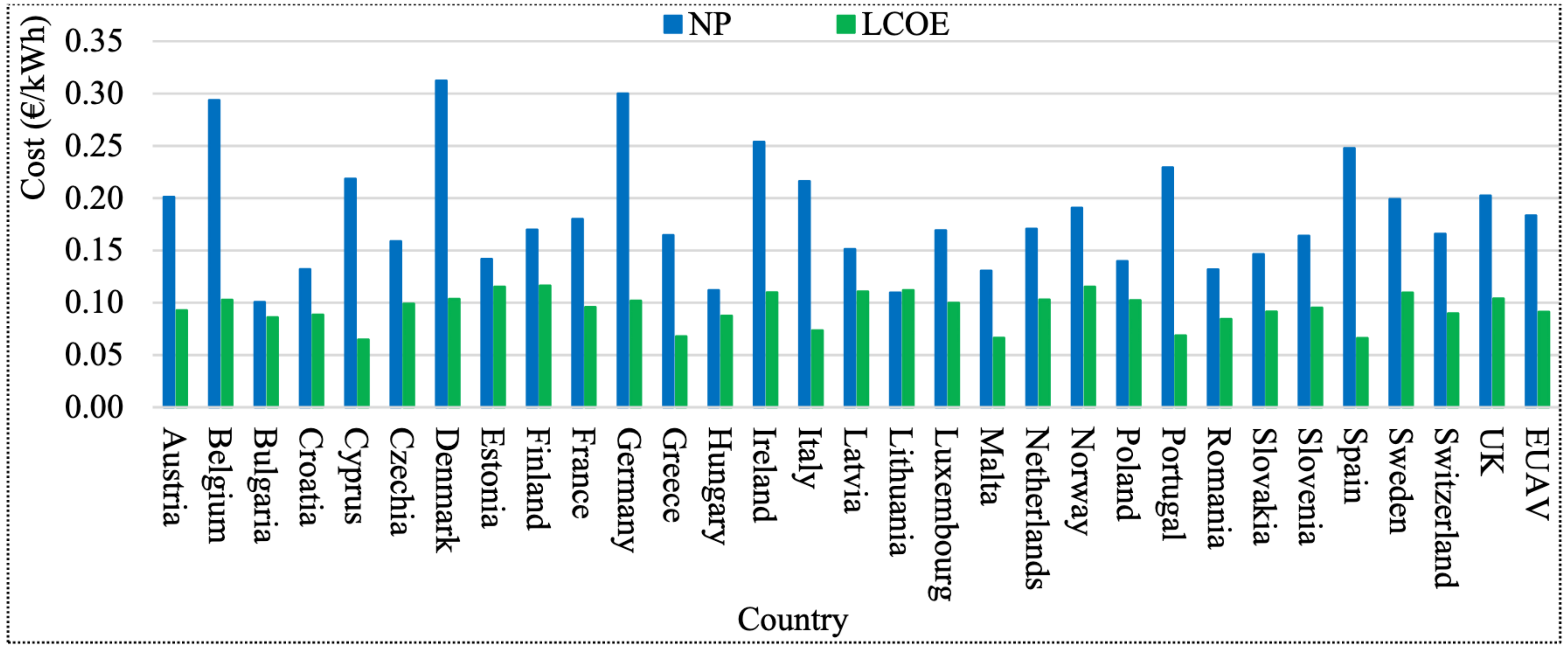
A BIPV product is the smallest (electrically and mechanically) non-divisible photovoltaic unit in a BIPV system which retains building-related functionality.

*If the BIPV product is **dismounted, it would have to be replaced by an appropriate construction product**.*

Source; IEA-PVPS Task 15

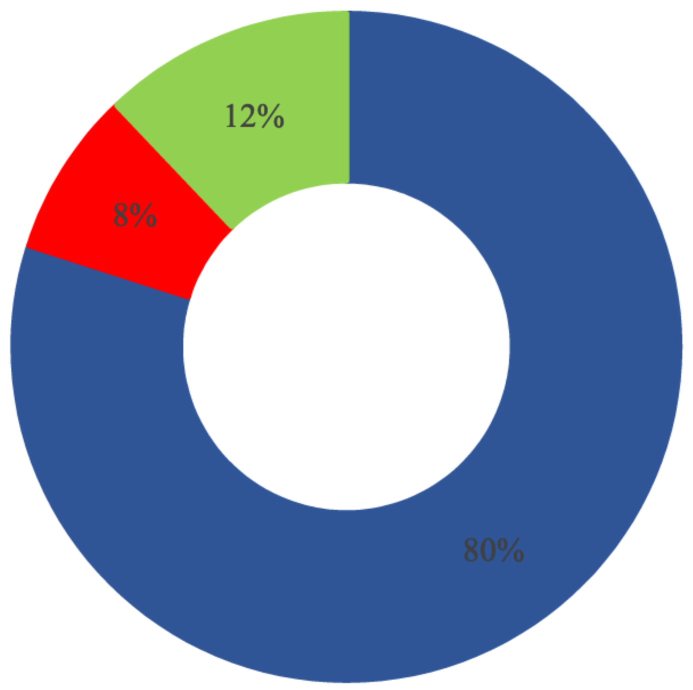
Source: https://scherrer.biz

BIPV in Europe: Cheaper Energy than the Grid

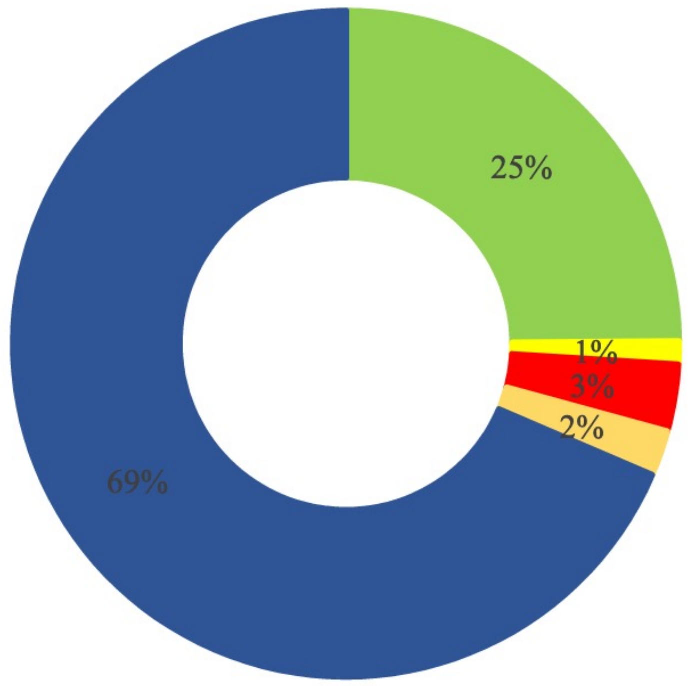


LCOE vs. Netwok Price factoring in savings by replacing building envelope materials

a. BIPV system cost break down



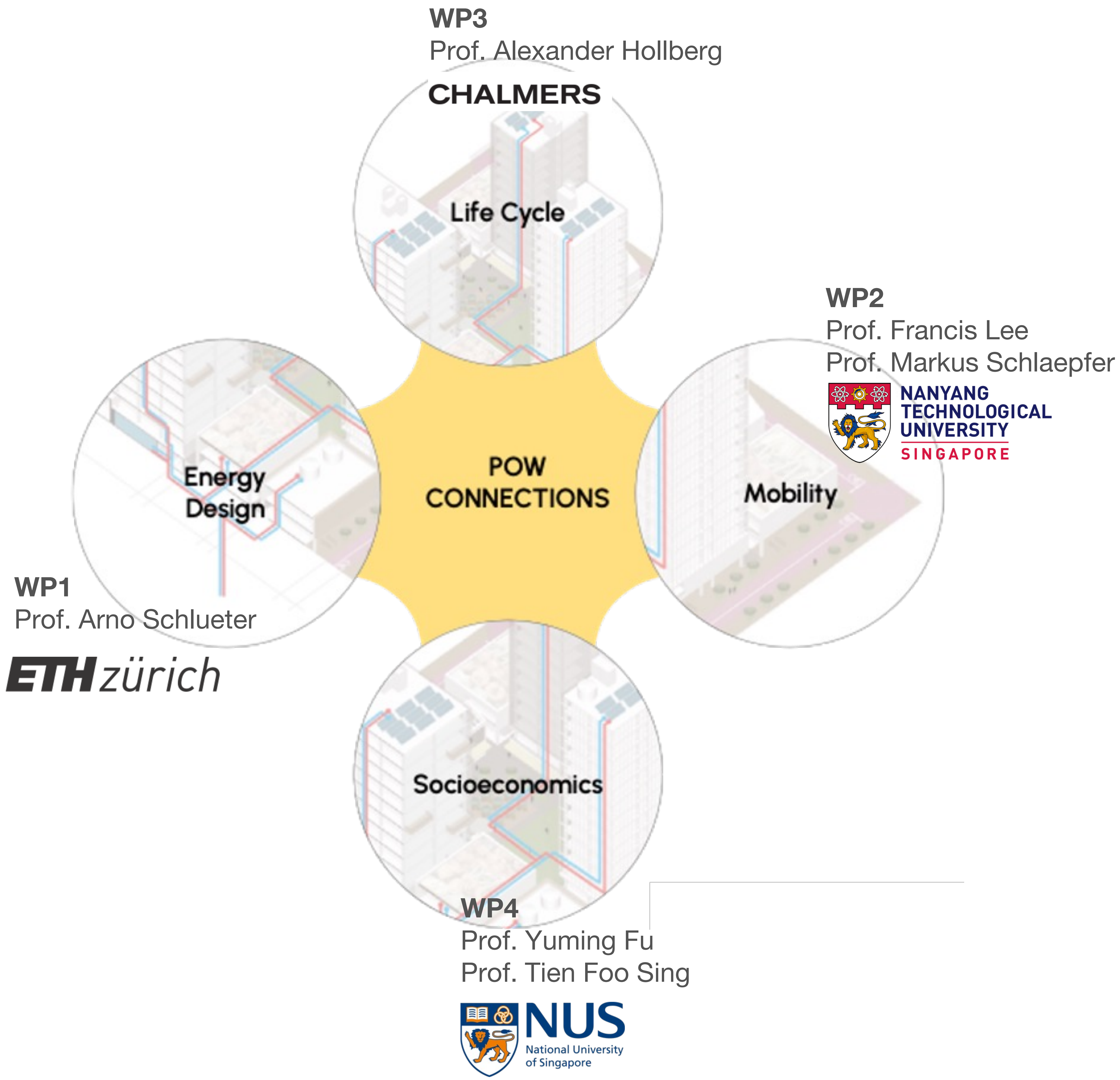
b. BIPV system income break down



Gholami, H., & Nils Rɯstvik, H. (2021). Levelised Cost of Electricity (LCOE) of Building Integrated Photovoltaics (BIPV) in Europe, Rational Feed-In Tariffs and Subsidies. *Energies*, *14*(9), Article 9

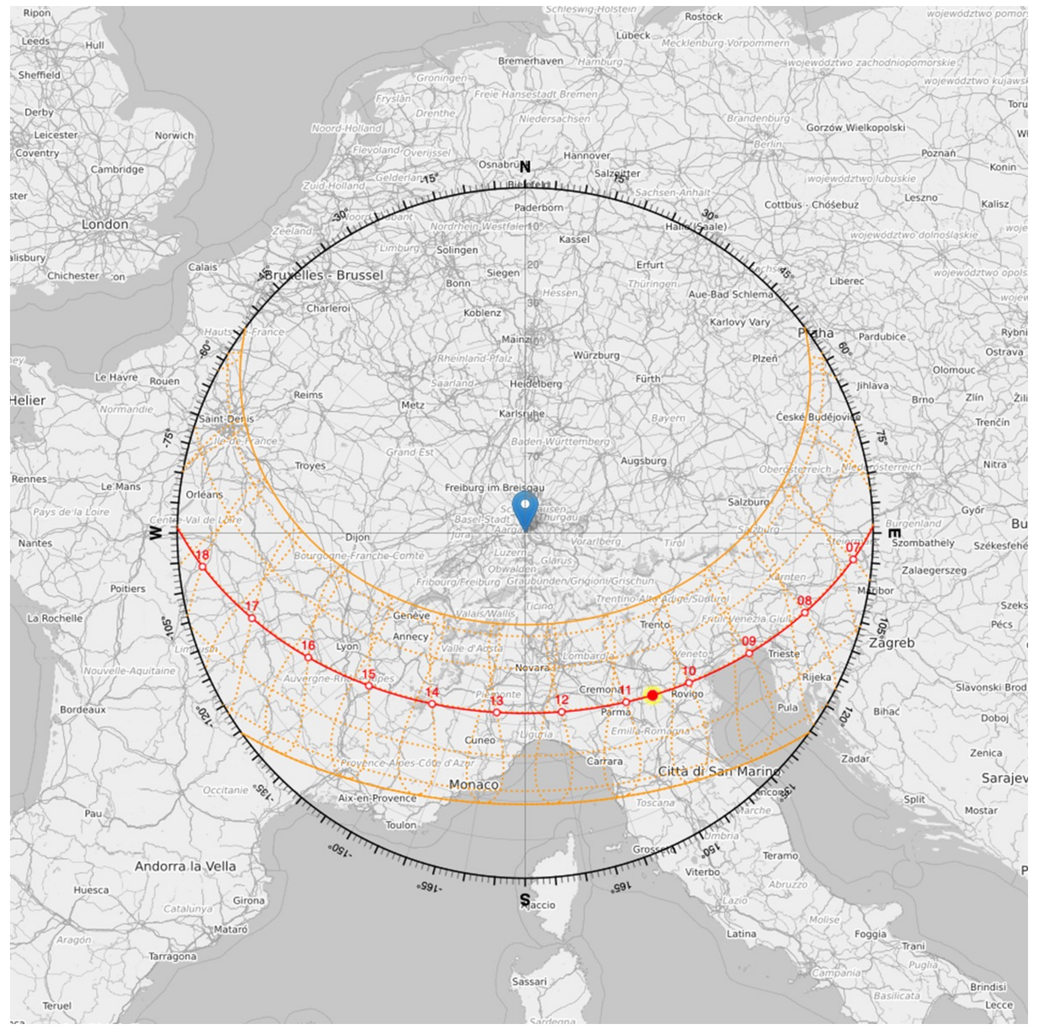
FCL G POW Research Questions

- How can **solar yield be estimated realistically in urban contexts?**
- What are urban and system parameters that influence the **lifecycle** carbon footprint of BIPV?
- **Where and when** to place BIPV in a city, consindering economics, encvironment and boundary conditions?
- How can the utilization of solar electricity be maximized by **sector coupling with electric vehicles as movable energy storage**
- What are **localized BIPV solutions** systems that fit to the context and balance embodied vs. operational GHG emissions?
- What are next generation **toolsets** to integrate BIPV in urban design and decission-making?



Case studies: Zurich and Singapore

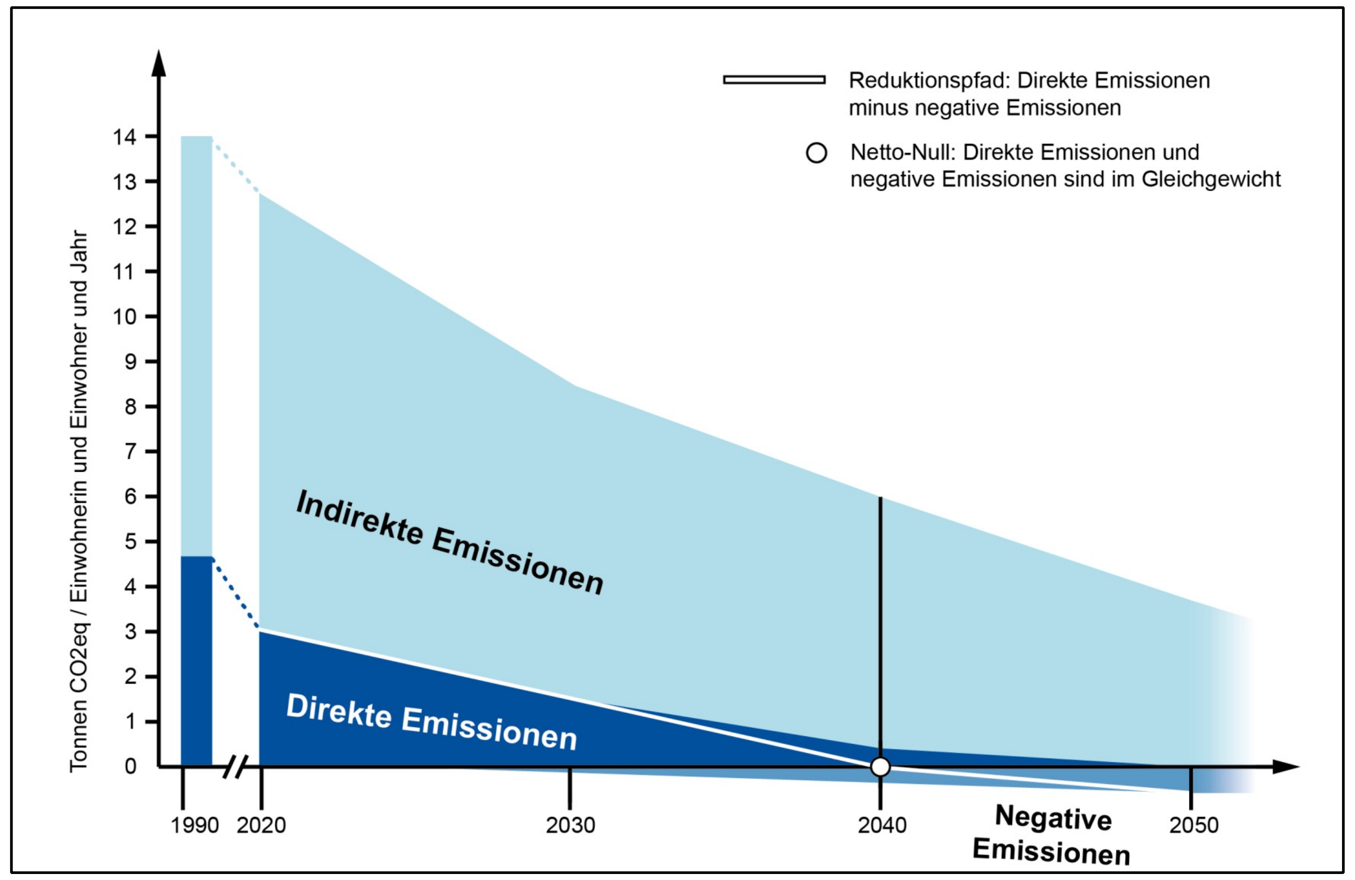
Zurich



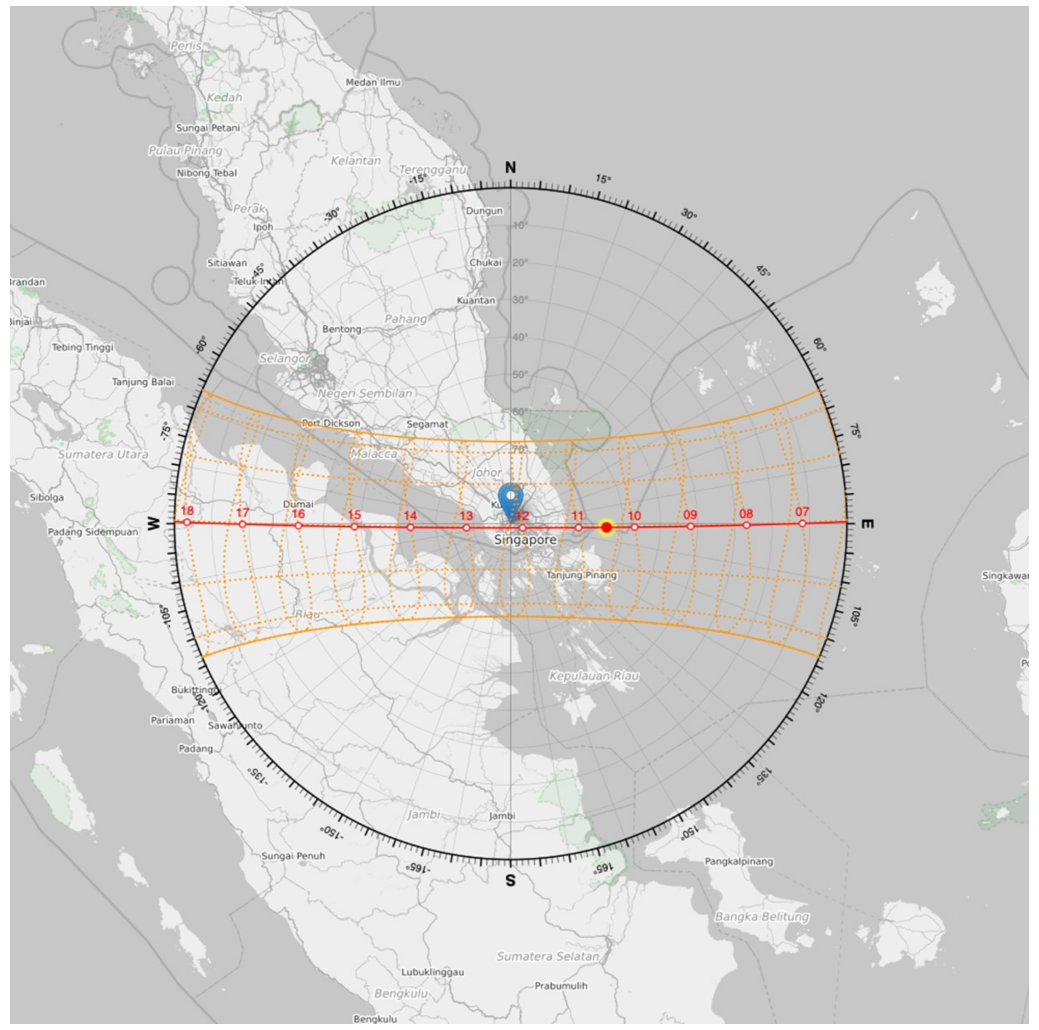
‘..climate neutral by 2040’

Approx. 45% of Swiss electricity demand could be generated on buildings

Source: Meteotest, 2017



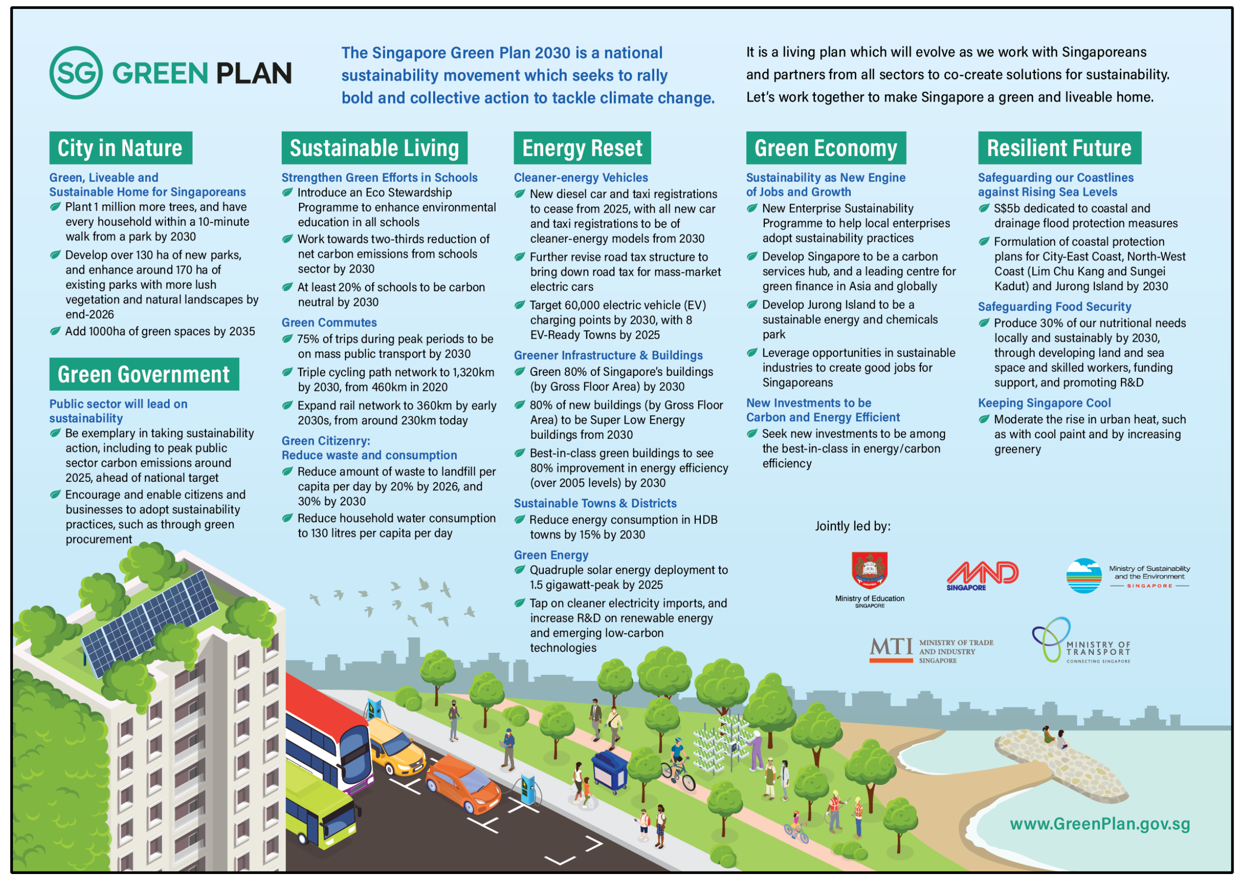
Singapore



‘..quadruple solar energy deployment’

‘Accelerated scenario would lead to 22% and 43% solar contribution to electric power demand ‘

Source: SERIS Solar PV Roadmap 2020

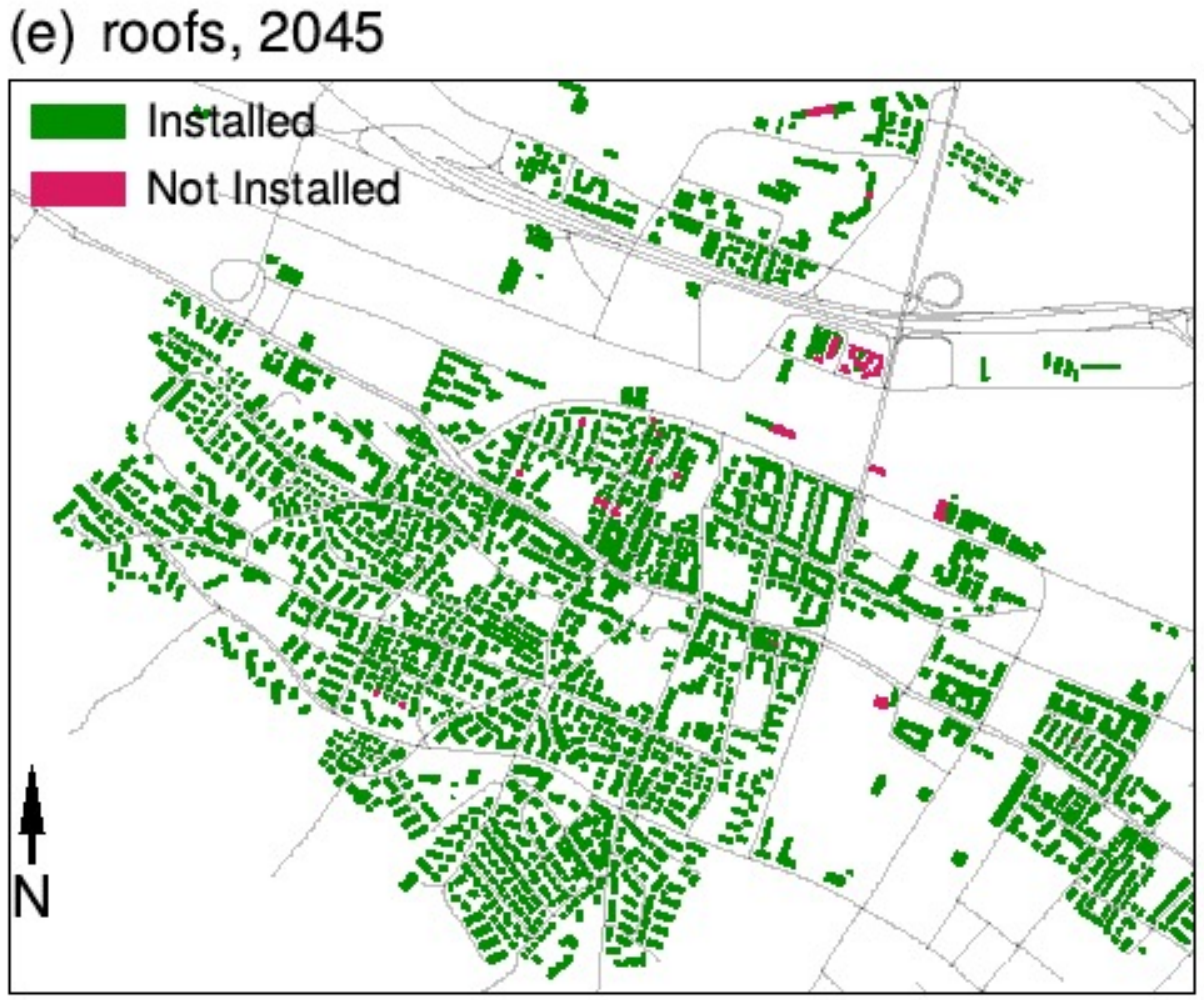


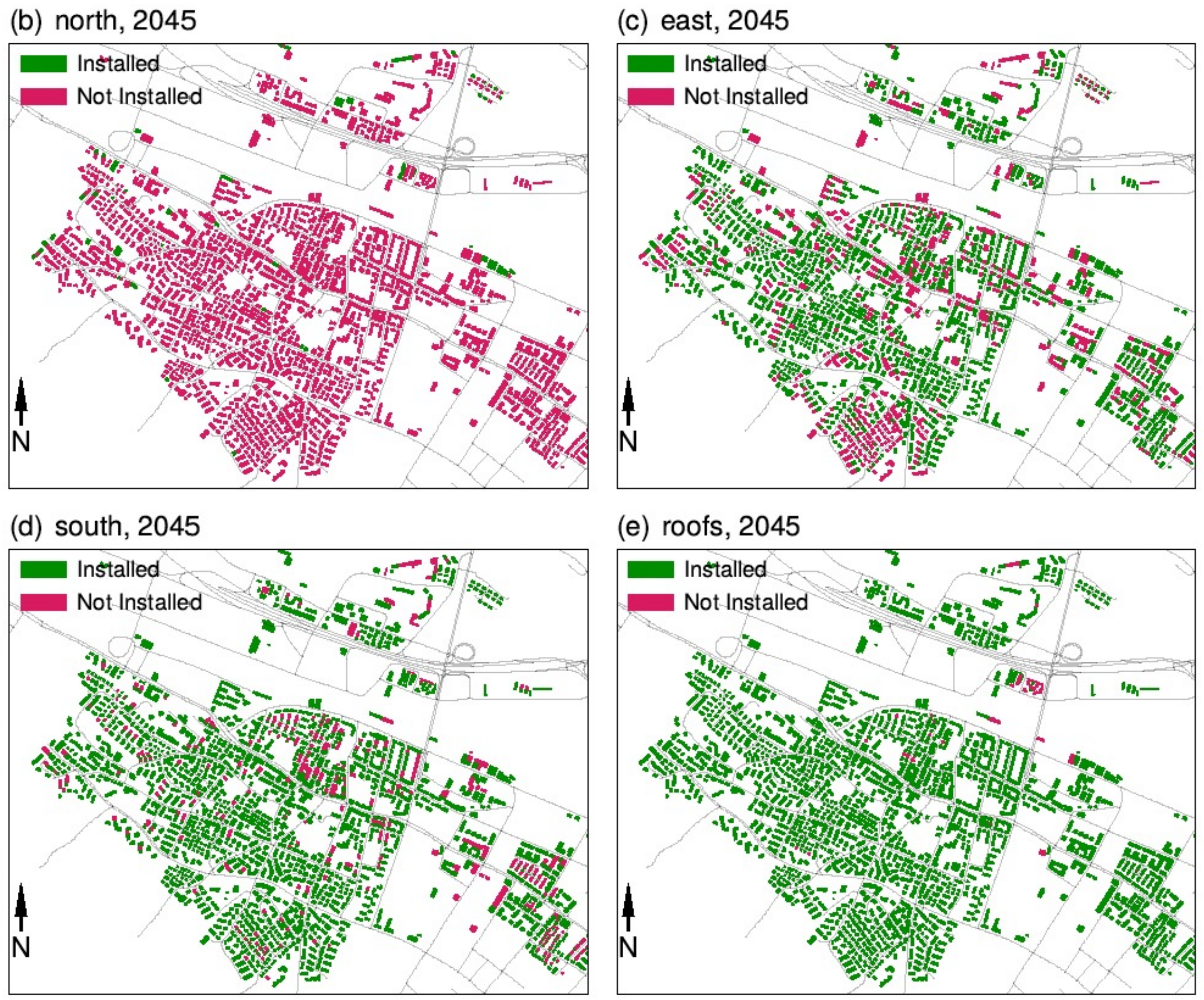
Key Results

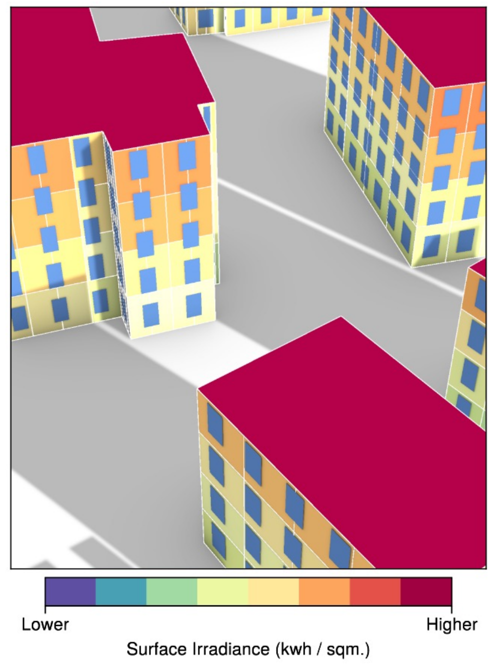
Powering the City through Renewable Energy

Urban PV: Optimal Deployment over Space and Time

WP1: Justin McCarty, Christoph Waibel, Arno Schlueter







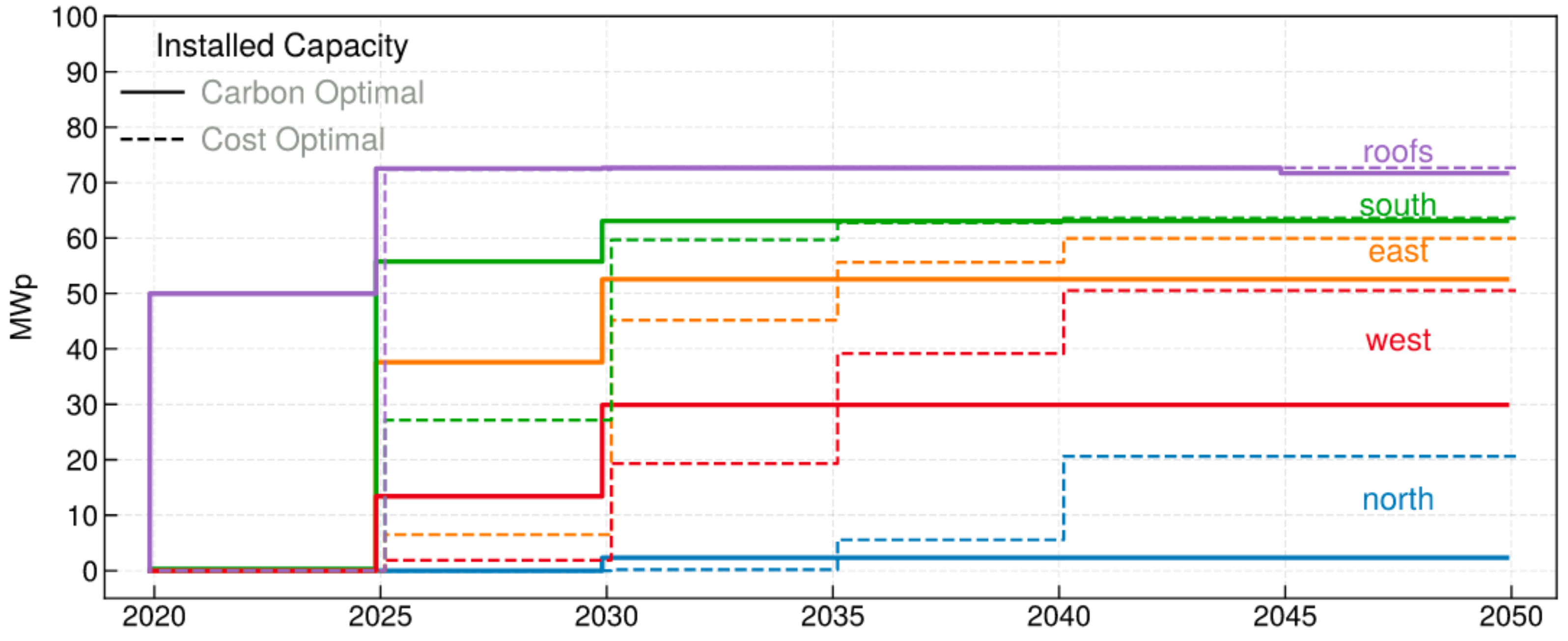


Figure 5: The deployment timeline for the carbon optimal and cost optimal solutions, subset by surface direction/type.

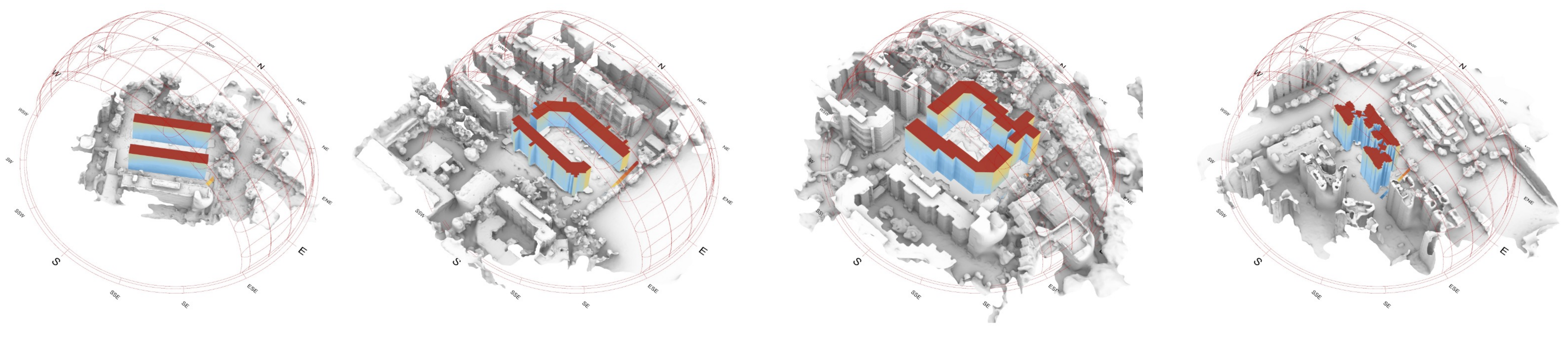
Key takeaways:

- Fast uptake even on non-optimally irradiated surfaces for ecologically optimal solution
- Learning curve for cost-optimal, slower uptake but higher total share in 2050

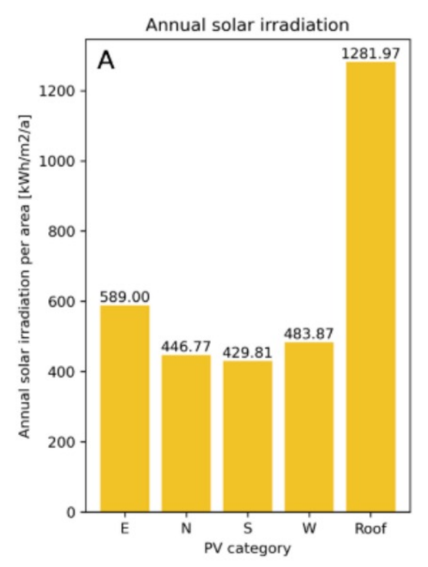
McCarty, J., Waibel, C., Schlueter, A.: Multi-Period Optimisation of District-Scale Building Integrated Photovoltaic Deployment, SBE 2023 Thessaloniki

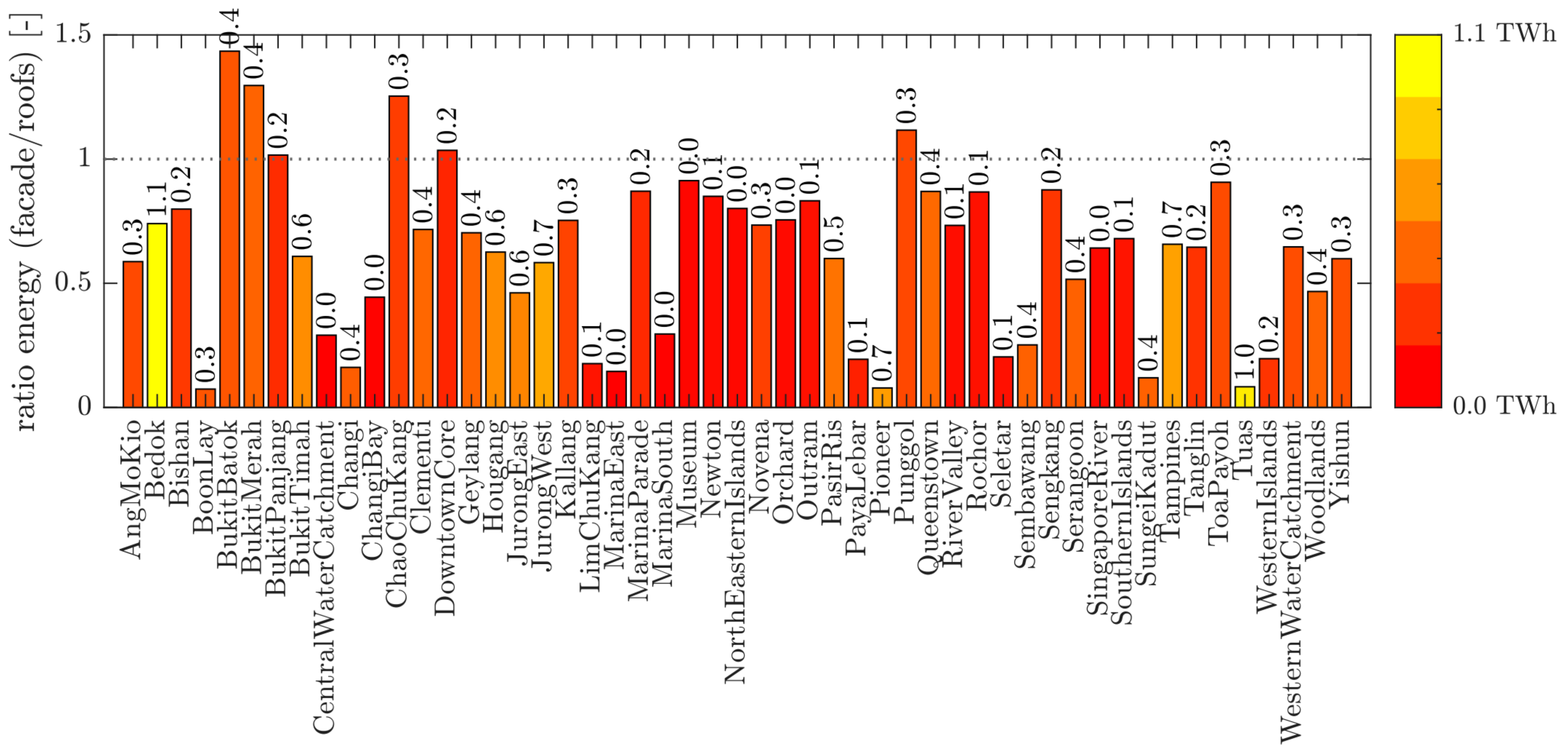
Solar Potential at HDB in Singapore

WP1: Max Gester, Christoph Waibel, Arno Schlueter



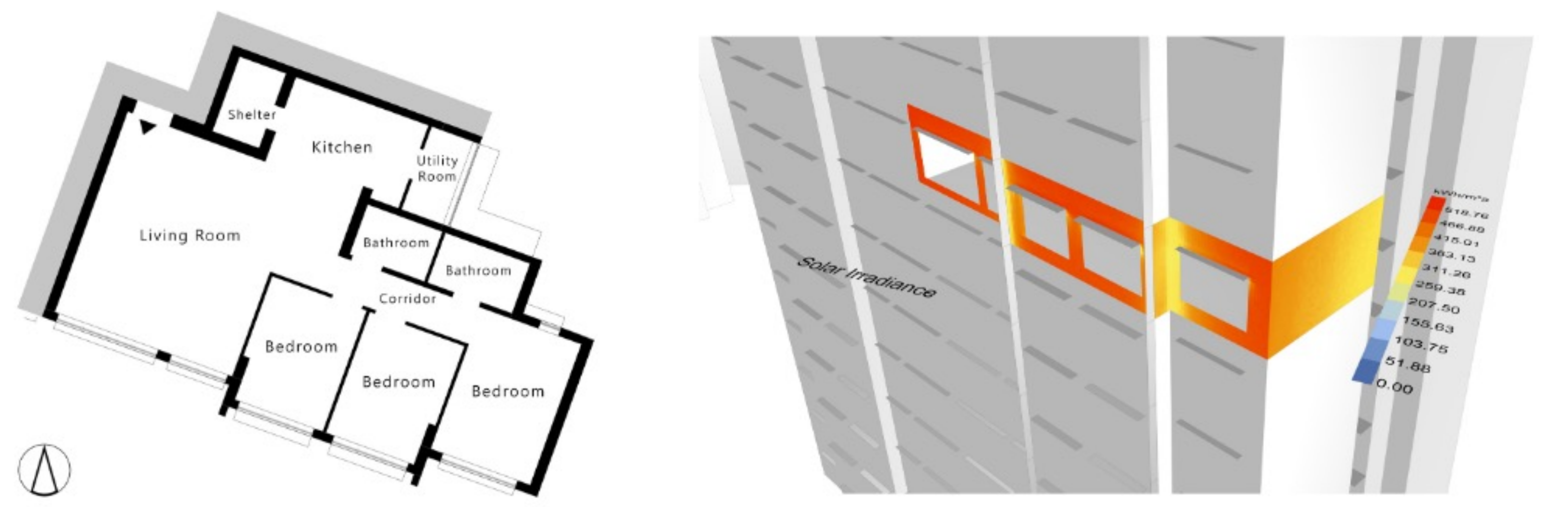
(a) T1: 1970s (b) T2: 1980s (c) T3: 1990s (d) T4: 2000s



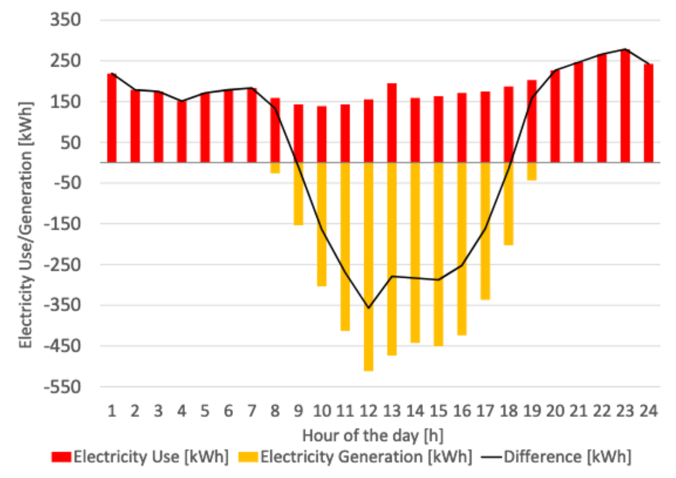


Key takeaways:

- Older HDB typologies have higher roof solar potential compared to newer, which often have obstructions limiting roof space.
- BIPV on facades can cover household energy needs, though morning and evening peaks require storage solutions.
- Contemporary buildings are well-suited for BIPV due to their high facade ratio, could be built BIPV-ready, but safety concerns and policy adjustments need to be addressed.



(b) Floorplan and façade irradiation.



(a) Yearly aggregated day and duck curve.

Gester, M., Waibel, C., Grammatas, A., Sing, T. F., & Schlueter, A. (2023). Upscaling potential of BIPV for public housing typologies in Singapore. *Journal of Physics: Conference Series*, *2600*(4), 042008.

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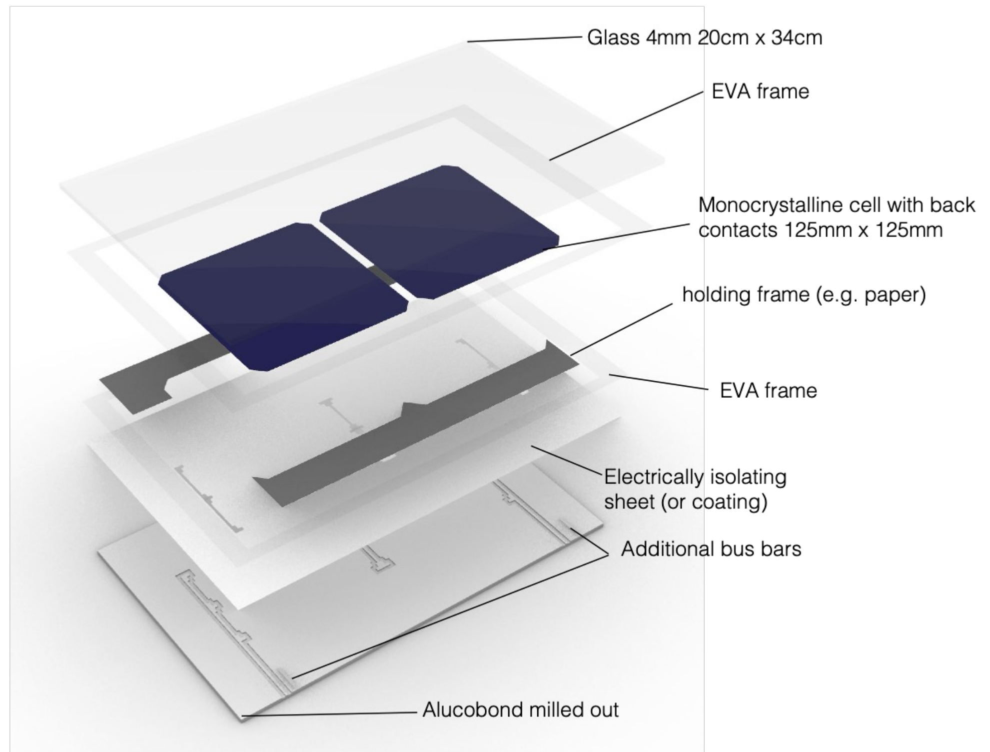
BIPV Retrofit: Lightweight Composite PV Modules

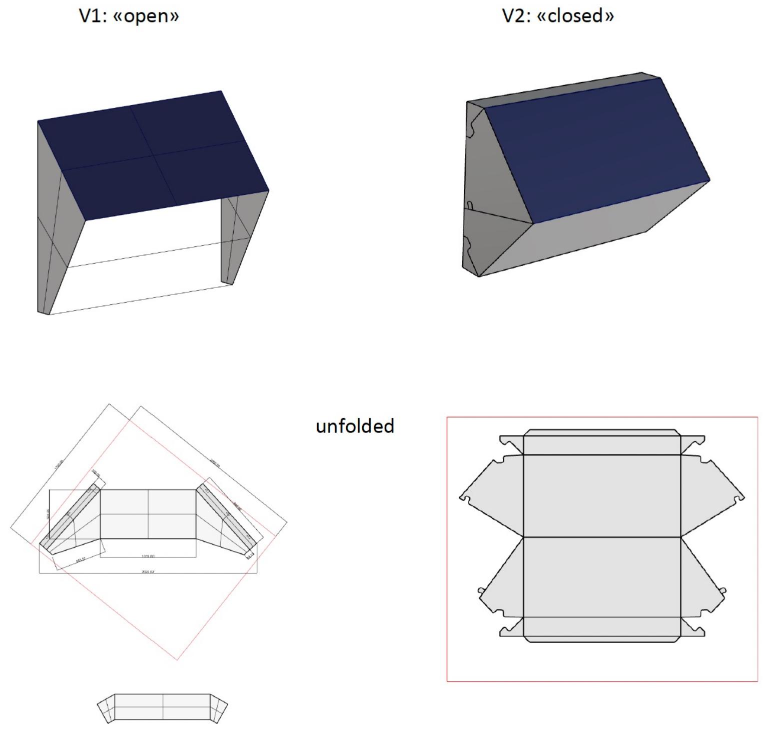
WP1: Max Gester, Christoph Waibel, Ayca Duran, Justin McCarty

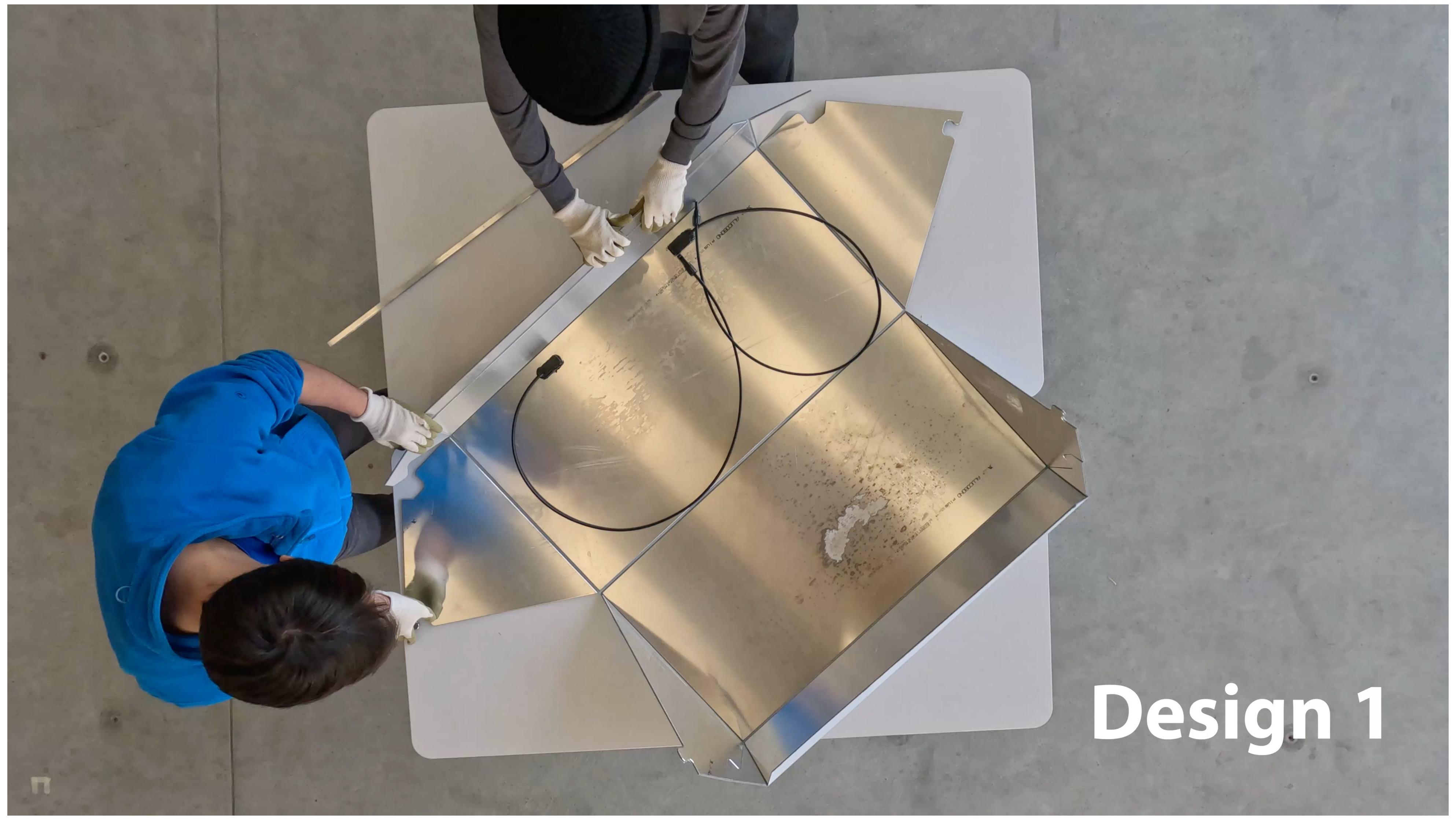
Industry Partners

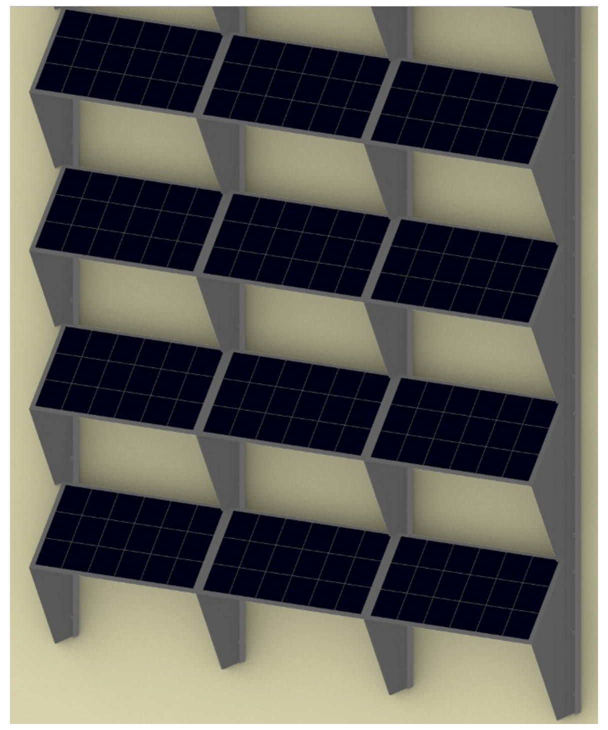
3S Swiss Solar Solutions

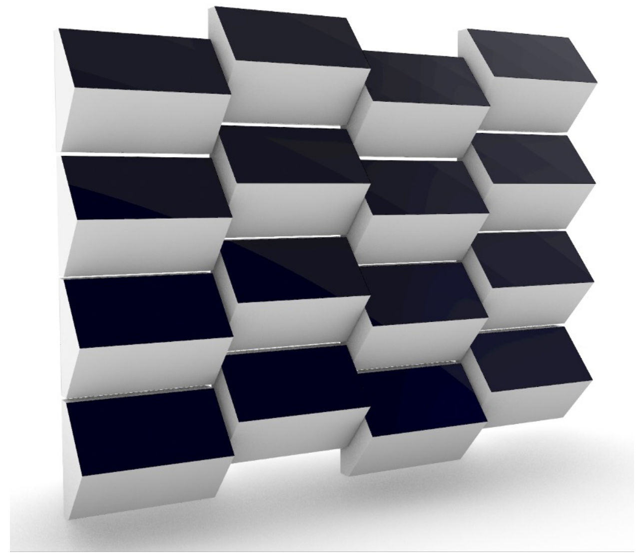
3A COMPOSITES

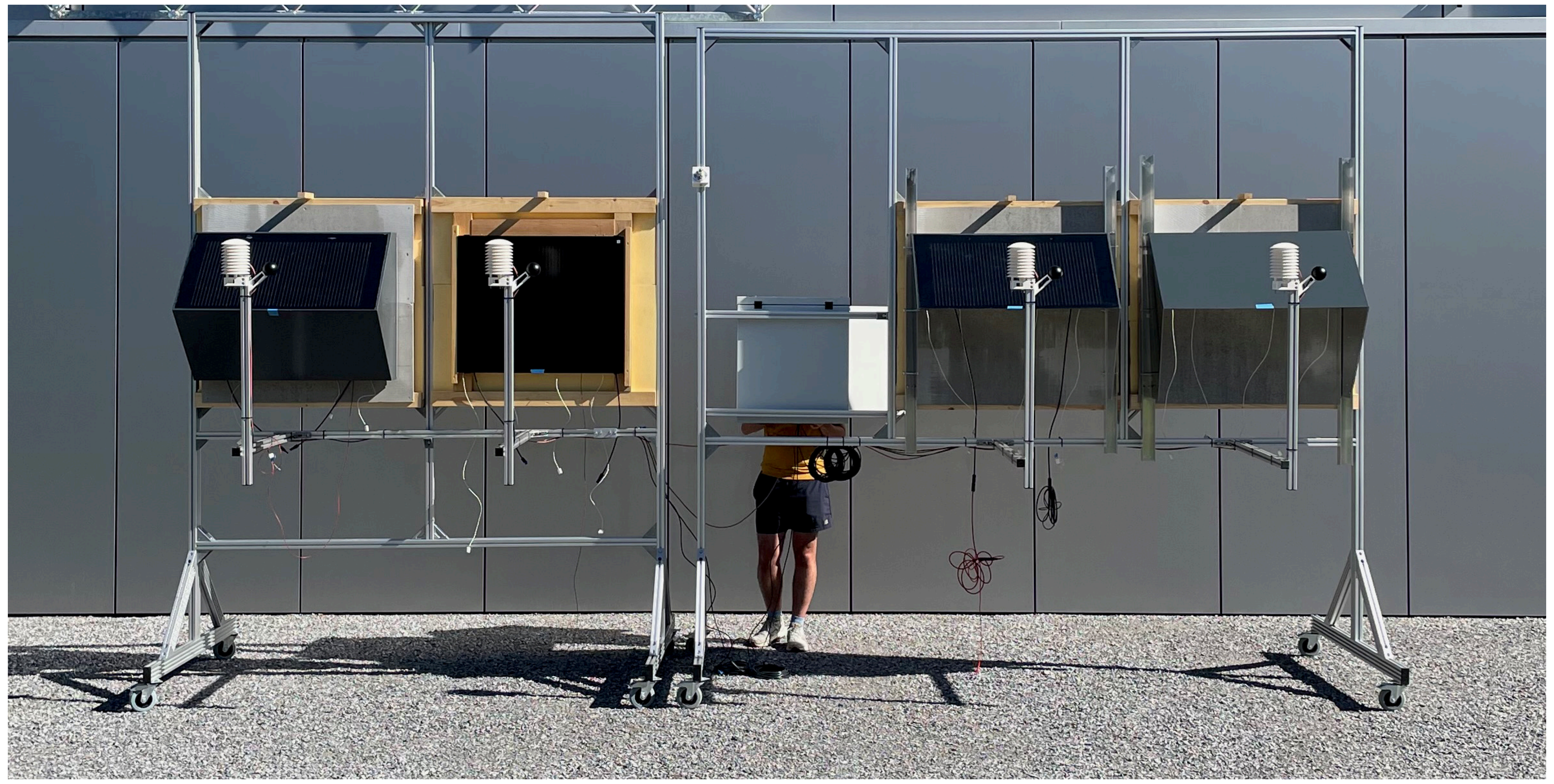


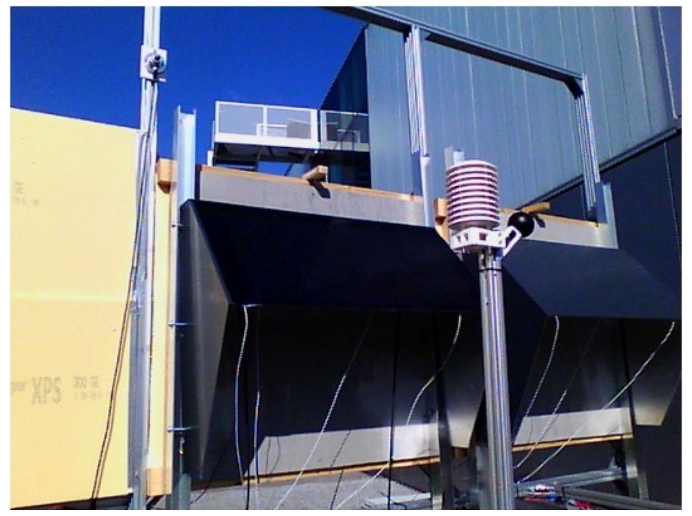






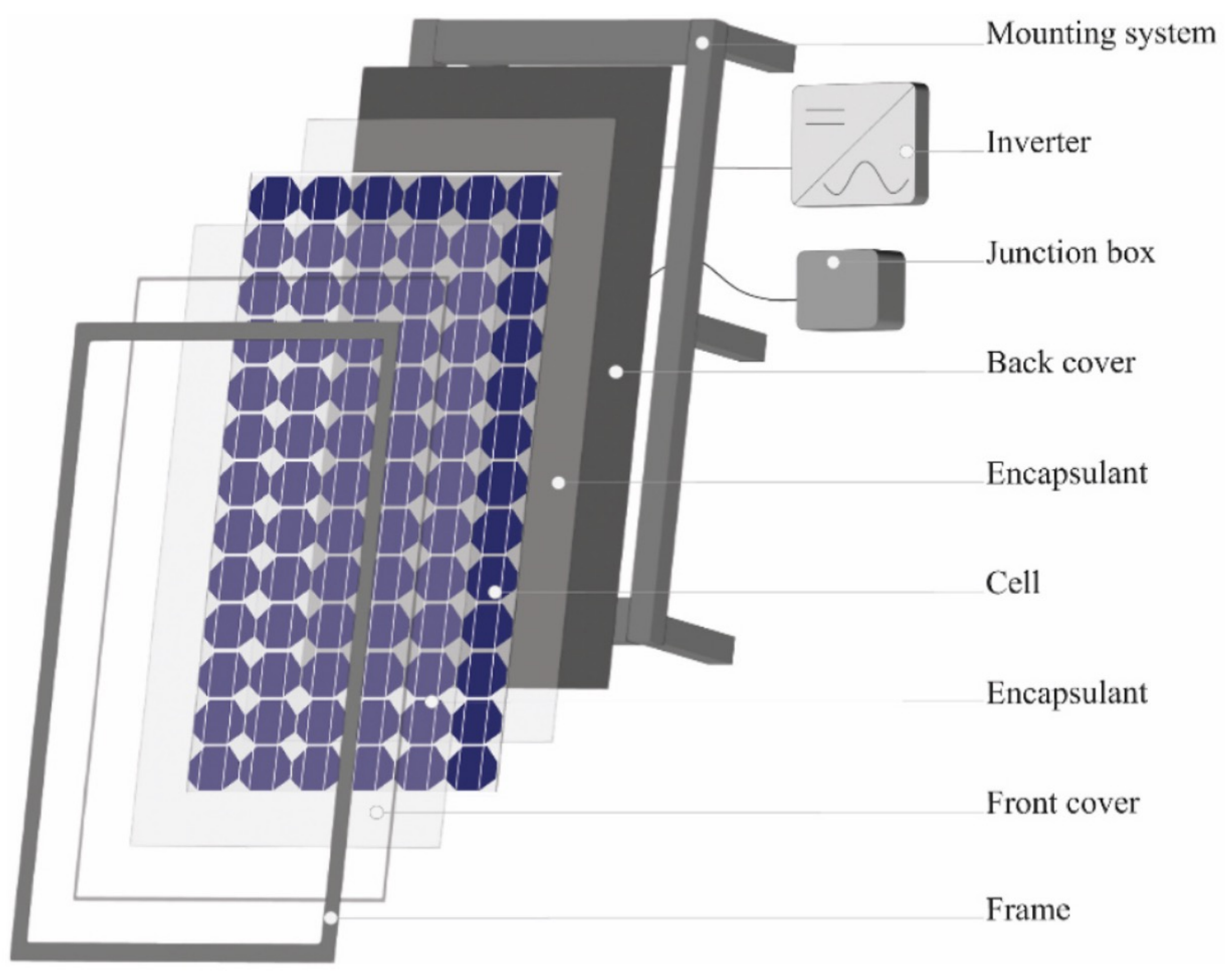






Life Cycle: Solar Energy from a Carbon Perspective

WP3: Alina Galimshina, Justin McCarty, Alex Hollberg



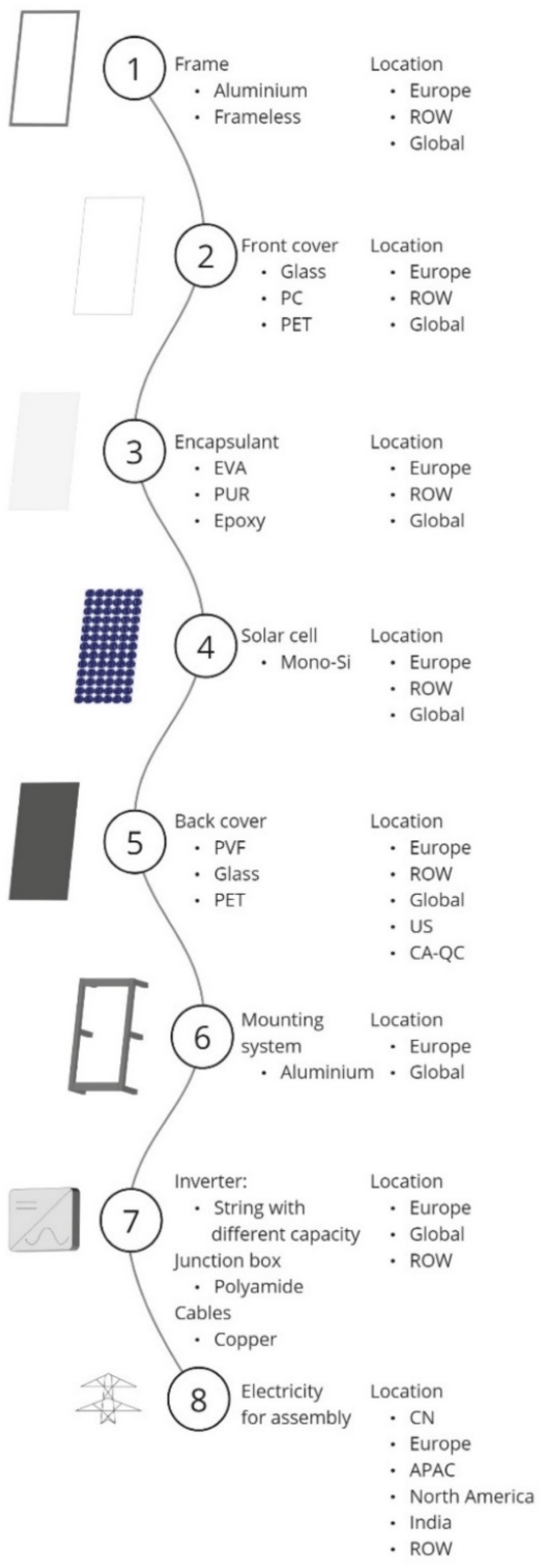
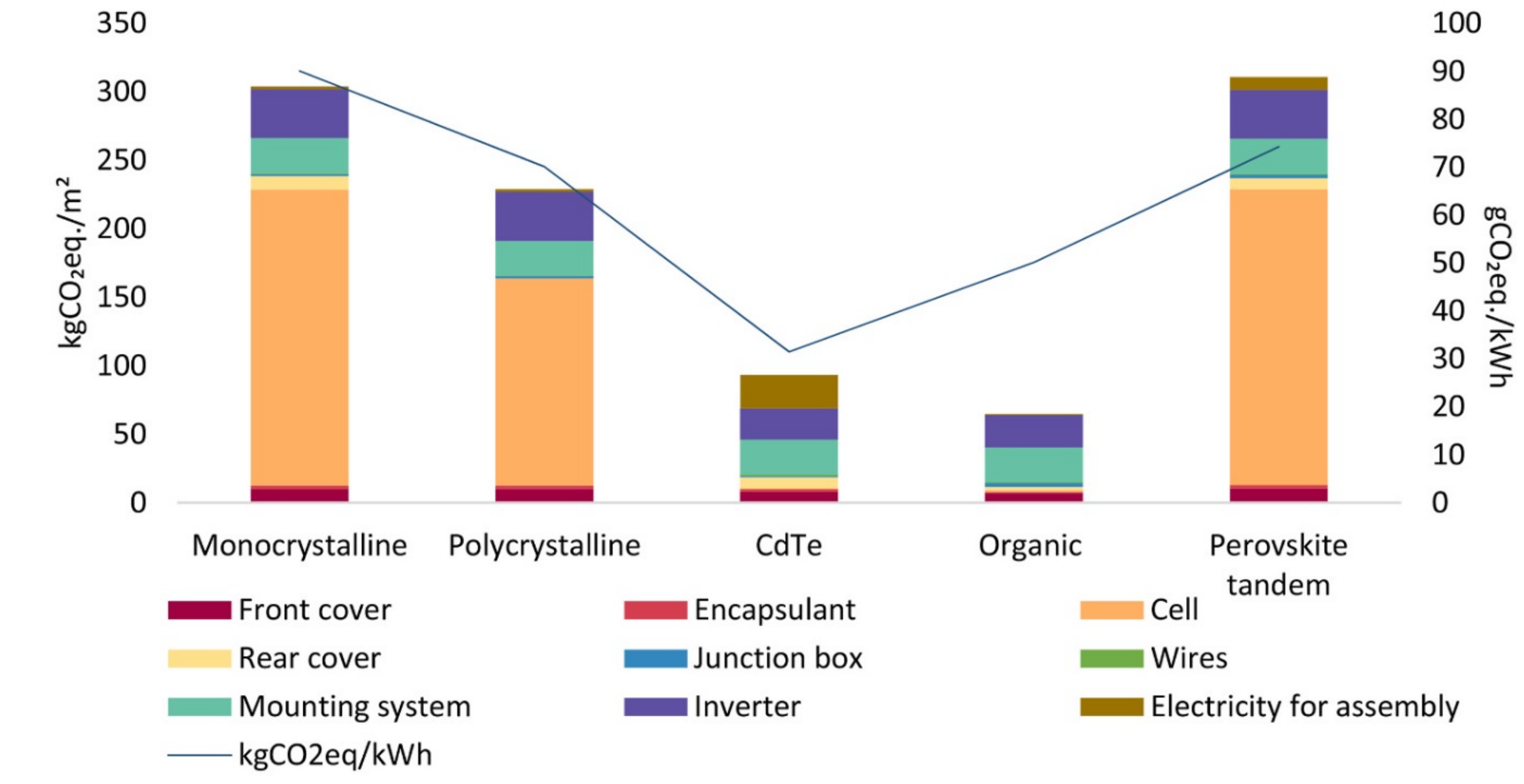


Fig. 6. Components' process selection based on an example of Mono-Si panel.



Embodied GWP of different European-produced panel system types and components' contribution

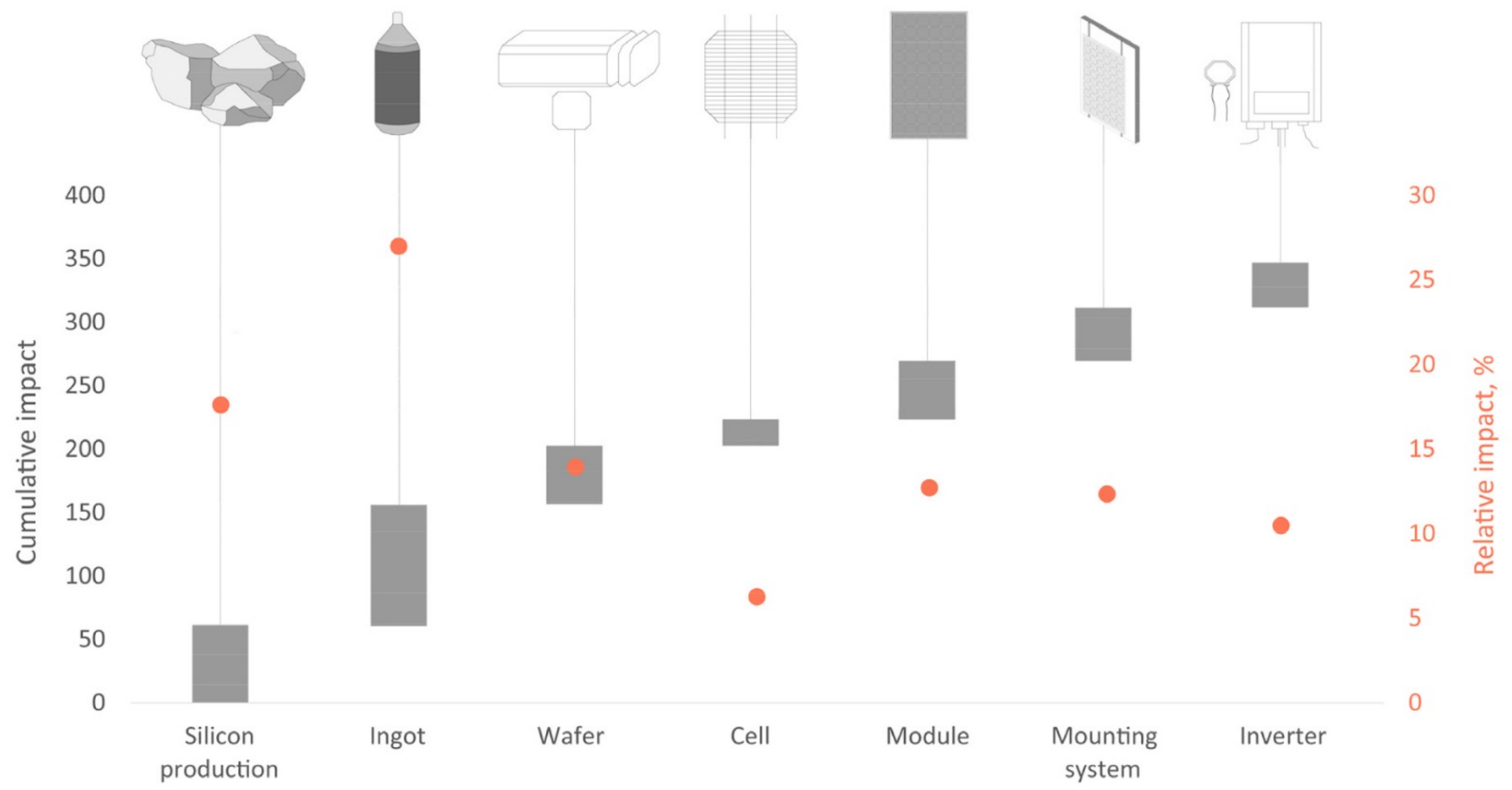


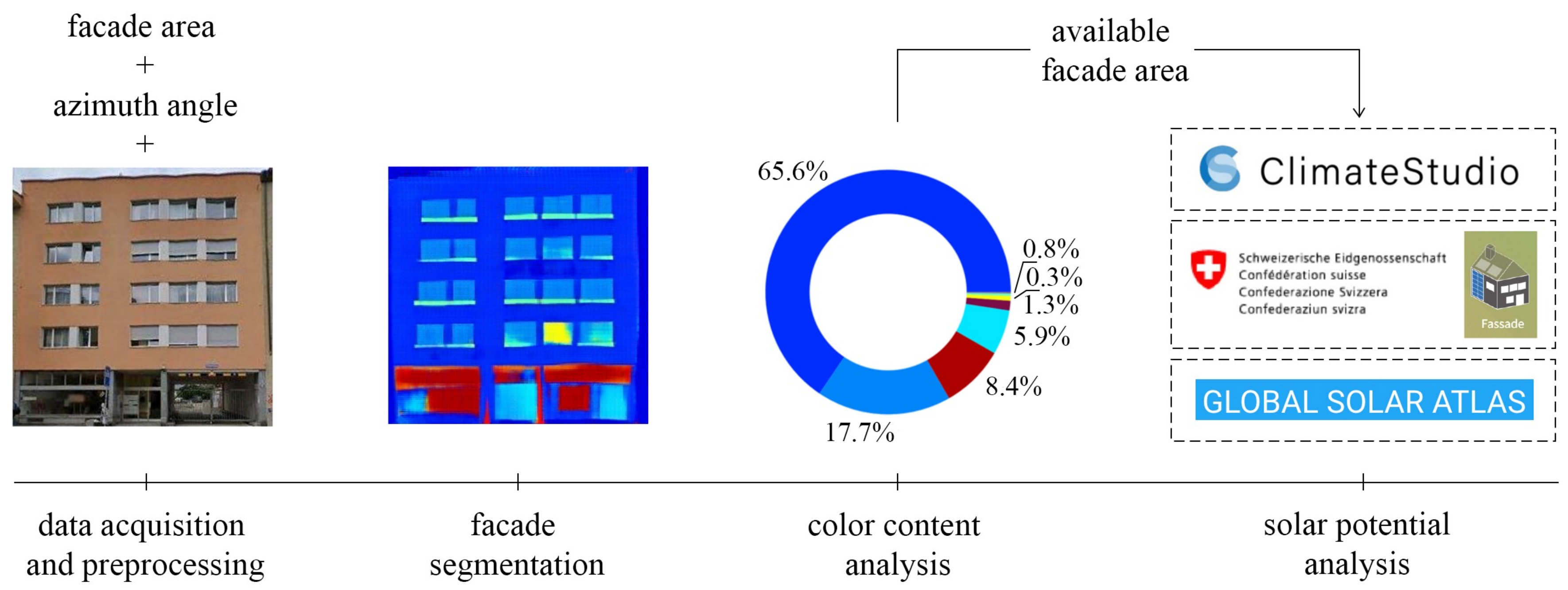
Fig. 13. Panel manufacturing process and associated GHG emissions ($kgCO_2eq./m^2$).

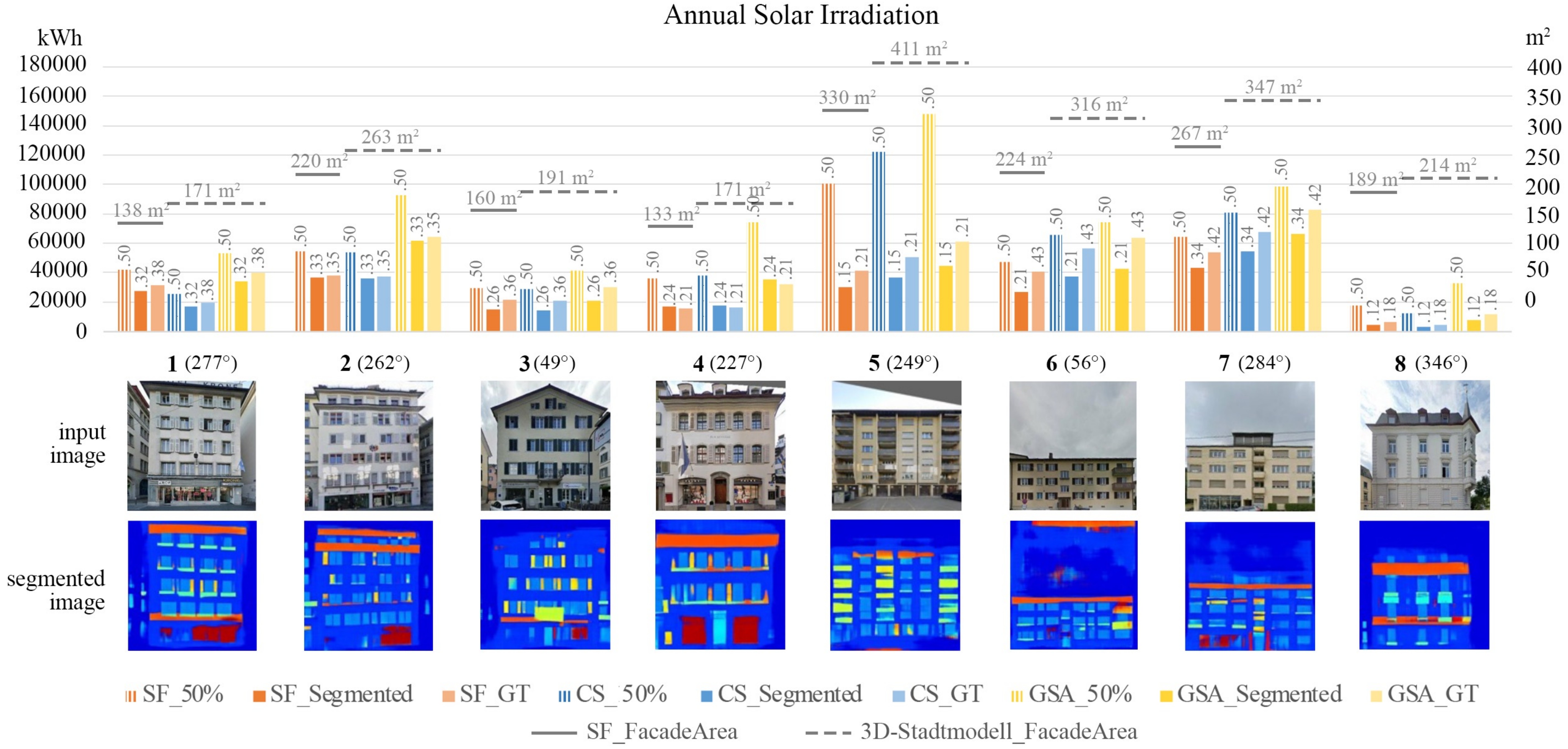
Key takeaways:

- PV global warming potential (GWP) varies significantly based on component selection, highlighting the importance of careful design
- PV cell type has largest impact on cell type; crystalline solar cells feature higher GWP as compared to thin-film

Generative Modeling (GAN) for Solar Energy Production

WP1: Ayca Duran, Christoph Waibel, Arno Schlueter





Key takeaways:

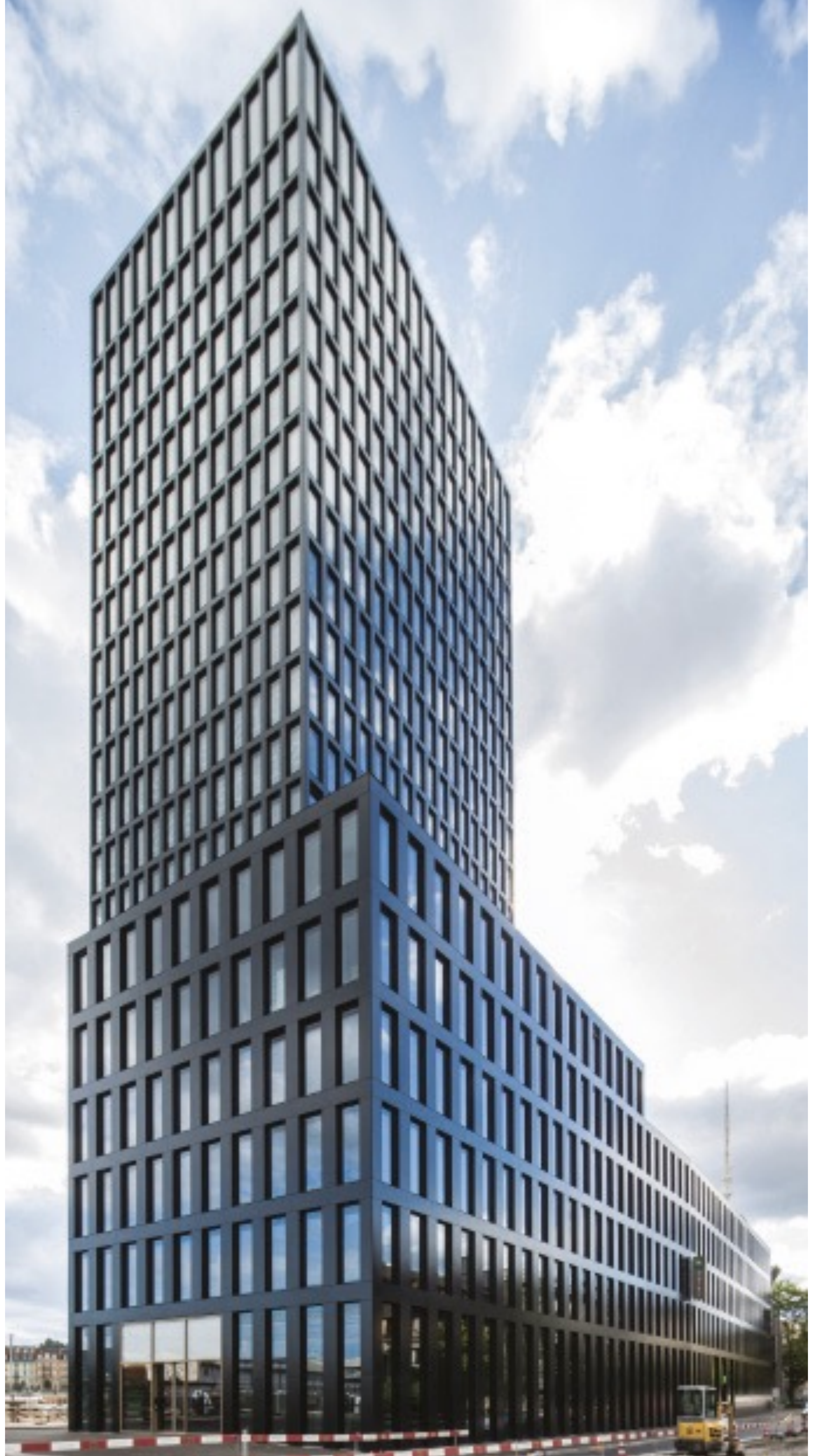
- Building facades are diverse in design, with varying arrangements of windows, balconies, and other elements.
- BIPV potential should be calculated by considering the variability of available areas on facades.
- Image-based techniques allow for fast identication of useable area and realistic calculation of solar yield

Duran, A., Waibel, C., & Schlueter, A. (2023). Estimating surface utilization factors for BIPV applications using pix2pix on street captured façade images. Journal of Physics Conference Series, 2600(4), 042005

Conclusions

- Urban Solar has **significant potential** to contribute to decarbonization of cities through local renewable energy production
- Economic and ecological benefits are dependent on local context, with solar **yield**, **seasonality** and **grid context** as the most dominant factors
- **Urban form and typology** dominate energy demand, local generation and utilization capacity
- From an architectural perspective, energy generating envelopes are highly flexible and ‘**designable**’
- Short term storage such as EV provide opportunities for better **utilization of solar electricity**, however highly dependent on mobility behaviour
- BIPV ‘heats (day) and cools (night)’* the city, however impact on occupant comfort likely low; other parameters (e.g. surfaces) more influential

Duran, A., Waibel, C., & Schlueter, A. (2023). A parametric approach to evaluate the impact of BIPV fazades on outdoor thermal comfort in different urban contexts. Proceedings of Building Simulation 2023: 18th Conference of IBPSA, 18, 1177–1184.
Anand, P., Garshasbi, S., Khatun, R., Khorat, S., Hamdi, R., Niyogi, D., & Santamouris, M. (2024). Rooftop photovoltaic solar panels warm up and cool down cities. Nature Cities, 1–11



KPI’s

Reports and Scientific Publications

Caviezel, D., Waibel, C., Schläpfer, M., & Schlueter, A. (2023). Vehicle-To-Grid Coupled Photovoltaic Optimization for Singapore at a District Resolution. 36th International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems (ECOS 2023), 3327–3338. https://doi.org/10.52202/069564-0299

Duran, A., Waibel, C., & Schlueter, A. (2023, September). A parametric approach to evaluate the impact of BIPV façades on outdoor thermal comfort in different urban contexts. Proceedings of the 18th IBPSA Conference. 18th International IBPSA Conference and Exhibition Building Simulation (BS 2023). https://doi.org/10.3929/ethz-b-000633070

Duran, A., Waibel, C., & Schlueter, A. (forthcoming). An image-based approach for estimating solar potential of building facades. CISBAT 2023, Lausanne.

Galimshina, A., Hollberg, A., McCarty, J., Waibel, C., & Schlueter, A. (2023). High-resolution and localized parametric embodied impact calculator of PV systems. IOP Conference Series: Earth and Environmental Science, 1196(1), 012014. https://doi.org/10.1088/1755-1315/1196/1/012014

Gester, M., Waibel, C., Grammatas, A., Sing, T. F., & Schlueter, A. (2023). Upscaling potential of BIPV for public housing typologies in Singapore. Journal of Physics: Conference Series, 2600(4), 042008. https://doi.org/10.1088/1742-6596/2600/4/042008

McCarty, J., Waibel, C., Galimshina, A., Hollberg, A., & Schlueter, A. (2023). Do we need a saw? Carbon-based analysis of facade BIPV performance under partial shading from nearby trees. Journal of Physics: Conference Series, 2600(4), 042002. https://doi.org/10.1088/1742-6596/2600/4/042002

McCarty, J., Waibel, C., & Schlueter, A. (2023a). Detailed Modeling Framework for Integrated Photovoltaic in Partial Shading Conditions. 36th International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems (ECOS 2023), 3409–3420. https://doi.org/10.52202/069564-0306

McCarty, J., Waibel, C., & Schlueter, A. (2023b). Multi-Period Optimisation of District-Scale Building Integrated Photovoltaic Deployment. IOP Conference Series: Earth and Environmental Science, 1196(1), 012015. https://doi.org/10.1088/1755-1315/1196/1/012015

McCarty, J., Waibel, C., & Schlüter, A. (2022). The Repository for Integrated Solar Energy in the Built Environment.

Schläpfer, M., Chew, H. J., Yean, S., & Lee, B.-S. (2021). Using Mobility Patterns for the Planning of Vehicle-to-Grid Infrastructures that Support Photovoltaics in Cities. https://arxiv.org/abs/2112.15006v1

Waibel, C., Hsieh, S., & Schlüter, A. (2021). Impact of demand response on BIPV and district multi-energy systems design in Singapore and Switzerland. Journal of Physics: Conference Series, 2042(1), 012096. https://doi.org/10.1088/1742-6596/2042/1/012096

Zhang, Y., Schlueter, A., & Waibel, C. (2023). SolarGAN: Synthetic annual solar irradiance time series on urban building facades via Deep Generative Networks. Energy and AI, 12, 100223. https://doi.org/10.1016/j.egyai.2022.100223

Zhang, Y., Waibel, C., & Schlüter, A. (2022). Stochastic Solar Irradiance from Deep Generative Networks and their Application in BIPV Design. IOP Conference Series: Earth and Environmental Science, 1078(1), 012040.

+ forthcoming

Exhibitions, Symposia, Roundtables and Stakeholder Exchange

Exchange with HDB BRI


Venice Biennale 2023

CEA user day 2023


SERIS Exchange 2022/2023

Thank You