Cloud Operations & Innovation ("CO+ I")

A Feasibility Framework for Waste Heat from Data Centers to a Water Capture System from Uravu Labs

Milestone-3 Preliminary Report

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Contents

1. Introduction

The findings from Milestones 1 and 2 highlight how the Uravu system enables concurrent cooling and water production by harnessing waste heat from data centers. This report further explores the economic and environmental feasibility of integrating the Uravu system with data center operations. The chosen locations are the same as those reported in the Milestone-2 report: Frankfurt (FRK), Madrid (MRD), London (LON), Stockholm (SHM), Phoenix (PNX), Chicago (CHG), Seattle (STL), Houston (HSN), Hyderabad (HYD), Bengaluru (BLR), Mumbai (MUM), Chennai (CHN), and Singapore (SGP).

System Configurations:

i. ***Uravu-waste heat (Unblended)***: The system operates solely on the available data-center waste heat to drive the Uravu system. Any additional cooling required for the facility water is supplied by the indirect evaporative cooler (IEC).
ii. ***Uravu-waste heat (blended)***: Similar to the unblended case, the Uravu unit is powered by waste heat. However, any remaining cooling demand for the facility water is met using a combination of IEC and a chiller, based on the target outlet temperature.
iii. ***Uravu-electric***: Waste heat is used only for pre-heating the desiccant, subject to ambient conditions. The remaining cooling requirement for the facility water is met through IEC and a chiller.
iv. ***Baseline-1 (Air-cooled chiller (ACC))***: The entire cooling load of the facility water is met using an air-cooled chiller.
v. ***Baseline-2 (Dry cooler (DC) + ACC)***: Facility water is cooled using a dry cooler, depending on the target temperature and ambient conditions. When the DC cannot meet the demand, the remaining cooling is provided by the air-cooled chiller.
vi. ***Baseline-3 (Cooling tower (CT) + ACC)***: Facility water is first cooled using a cooling tower based on the target temperature and local wet-bulb temperature (WBT). The air-cooled chiller meets any additional cooling demand.

A pictorial representation of all the configurations is shown in **Figure 1** for better clarity.

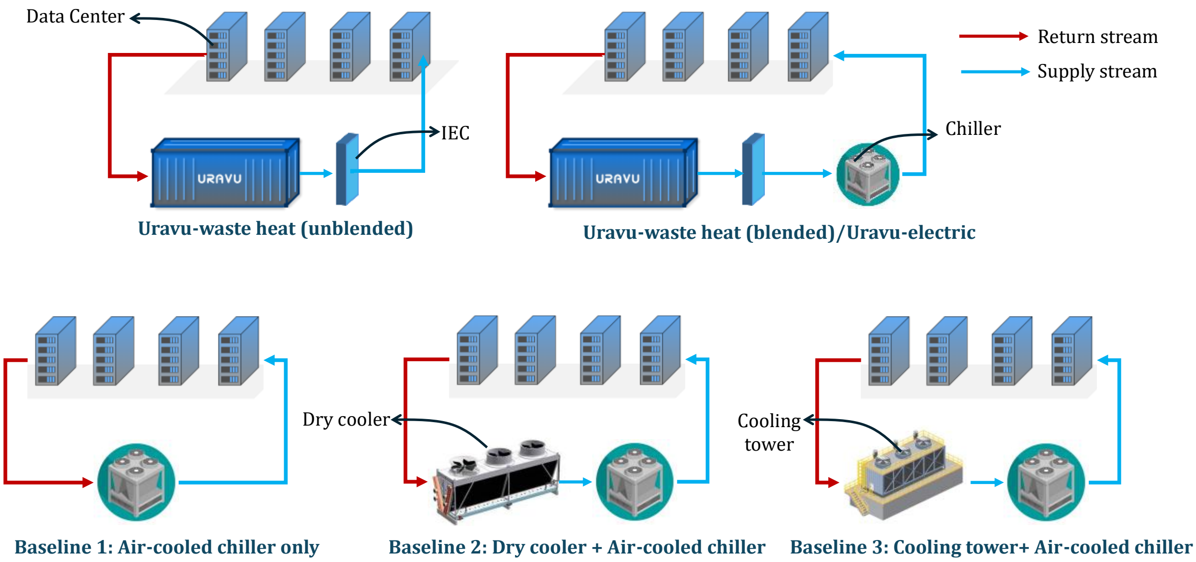

Figure 1: Pictorial representation of the different system configurations.

2. Key Assumptions for Environmental and Economic Evaluation

To facilitate a systematic and transparent evaluation, a set of baseline assumptions has been established to underpin both the environmental and economic analyses of the Uravu system integrated with data center operations. These assumptions delineate the key techno-economic parameters considered in the study. Establishing such assumptions ensures consistency in the comparative assessment, enhances the credibility of the analysis, and provides a coherent framework for interpreting the resulting environmental and economic performance indicators. The key assumptions considered for economic and environmental assessment are presented in **Table 1**.

2.1 Environmental assumptions and metrics

The environmental analysis is conducted under conditions representative of typical data center operations and the integration of the Uravu system for waste heat utilization. Environmental indicators assessed include the system's carbon footprint, water footprint, and sustainability performance relative to conventional cooling and water supply systems. Greenhouse gas emissions are estimated using region-specific grid emission factors, while the water footprint accounts for both direct and indirect water usage. The analysis also incorporates the potential environmental benefits associated with waste heat recovery and on-site water generation, which contribute to resource efficiency and reduced environmental impact.

Table 1: Summary of key parameters and assumed values.

Parameters	Value/source	Unit
Project lifetime	15	Years
Electricity cost	0.1 – 0.3 (source)	$/kWh
CO_2 Emission factor	0.02 – 0.45 (source-1 and source-2)	g/kWh
Water footprint factor	1 – 3.97 (source)	L/kWh
CAPEX (Uravu-waste heat)	500,000	$/MW
CAPEX (Uravu-electric)	650,000	$/MW
CAPEX (Air-cooled chiller)	350,000	$/MW
CAPEX (Dry-cooler)	100,000	$/MW
CAPEX (Cooling tower)	150,000	$/MW
Maintenance rate (Uravu unit)	2	%
Maintenance rate (Air-cooled chiller)	3	%

2.2 Economic assumptions and metrics

The economic evaluation considers representative cost parameters and operational conditions relevant to the integration of the Uravu data center for the selected cities. Key assumptions include the project lifetime, system throughput, and local electricity tariff. Capital expenditure (CAPEX) and operational expenditure (OPEX) are estimated based on available technology benchmarks and scaled to the system capacity.

a) ***Levelized cost of cooling (LCoC)***: This metric represents the average cost of delivering 1 unit of cooling (**typically in $/MWh**) over the whole lifetime of a cooling system. It accounts for all expenses — capital cost (equipment and installation), operating cost (electricity, fuel, water, maintenance), and replacements — divided by the total useful cooling delivered during its lifetime. By combining both upfront and ongoing costs into a single number, **LCoC enables a fair comparison between different cooling technologies (e.g., System configuration explained in Section 1),** regardless of their investment scale or operating patterns.

b) ***Net Value of Water (NVW)***: It is defined as the net economic outcome of producing water after incorporating the monetary credit associated with avoided cooling energy consumption (**measured in $/m^3**). **NVW combines the cost of water production with the financial benefit** from displaced cooling-system operation, providing a unified metric to evaluate the overall economic performance of a system.

Table 2: Interpretation of Net Value of Water.

NVW Value	Meaning	Practical Interpretation
NVW > 0	Net economic **cost**	Producing water results in a net expenditure; the cooling credit does not offset the full cost of water production.
NVW = 0	**Cost–benefit neutral**	The savings from avoided cooling exactly balance the water production cost, resulting in an economic break-even.
NVW < 0	Net economic **benefit**	The savings from avoided cooling exceed the cost of water production, resulting in an overall financial gain.

NVW provides a clear and intuitive economic indicator even when cooling-energy credits outweigh production costs. Unlike LCOW, NVW remains meaningful when the metric crosses zero or becomes negative, making it suitable for systems where thermal energy reuse yields substantial financial offsets.

3. Site-specific environmental and economic analysis

Based on the parameters listed in Table 1, economic and environmental analyses have been performed for different European Union (EU) and United States (US) cities. As discussed in the Milestone-2 report, for the baseline, the facility water inlet temperature ($T_{\mathrm{fac,in}}$) is maintained at 30°C, with a target outlet temperature (T_{target}) of 18°C. The facility water is maintained at a rate of 1.3 kg/s, and the desiccant flow rate is adjusted based on the available waste heat. Additionally, the Uravu system is programmed with a downtime trigger temperature (T_{trigger}) of 9.5°C, specific to 30°C operating conditions only. Based on the available waste heat temperature, the downtime trigger temperature can also be adjusted. The downtime trigger temperature indicates that Uravu's waste heat-based system is suspended whenever the ambient wet-bulb temperature (WBT) falls below this threshold. Also discussed in the Milestone-1 report, the facility water temperature should follow the given constraint, where $\boldsymbol{T_{\mathrm{fac,in}} \geq T_{\mathrm{vap}} + \Delta T_{\mathrm{system}} + BPE}$, where $\Delta T_{\mathrm{system}}$ is approximately 5°C, and the boiling point elevation (BPE) is around 12°C, along with saturation temperature (T_{vap}) which can be adjusted by controlling the vacuum according to the available waste heat temperature.

3.1 Levelized Cost of Cooling (LCoC)

United States: Across the US cities (Phoenix, Chicago, Houston, and Seattle), the LCoC for Uravu-based systems decreases sharply when the available waste-heat temperature rises.

At lower temperatures (near 30 °C), the system's uptime is relatively low, resulting in a higher LCoC and often making it comparable to or slightly higher than existing baseline cooling systems. However, as the temperature increases beyond 40–45°C, the Uravu-waste heat configurations become significantly more cost-effective, eventually reaching lower LCoC values of up to $10/MWh.

In simple terms: the hotter the waste heat, the cheaper the cooling becomes, and beyond 45 °C, Uravu consistently outperforms Baseline cooling systems in every US city studied.

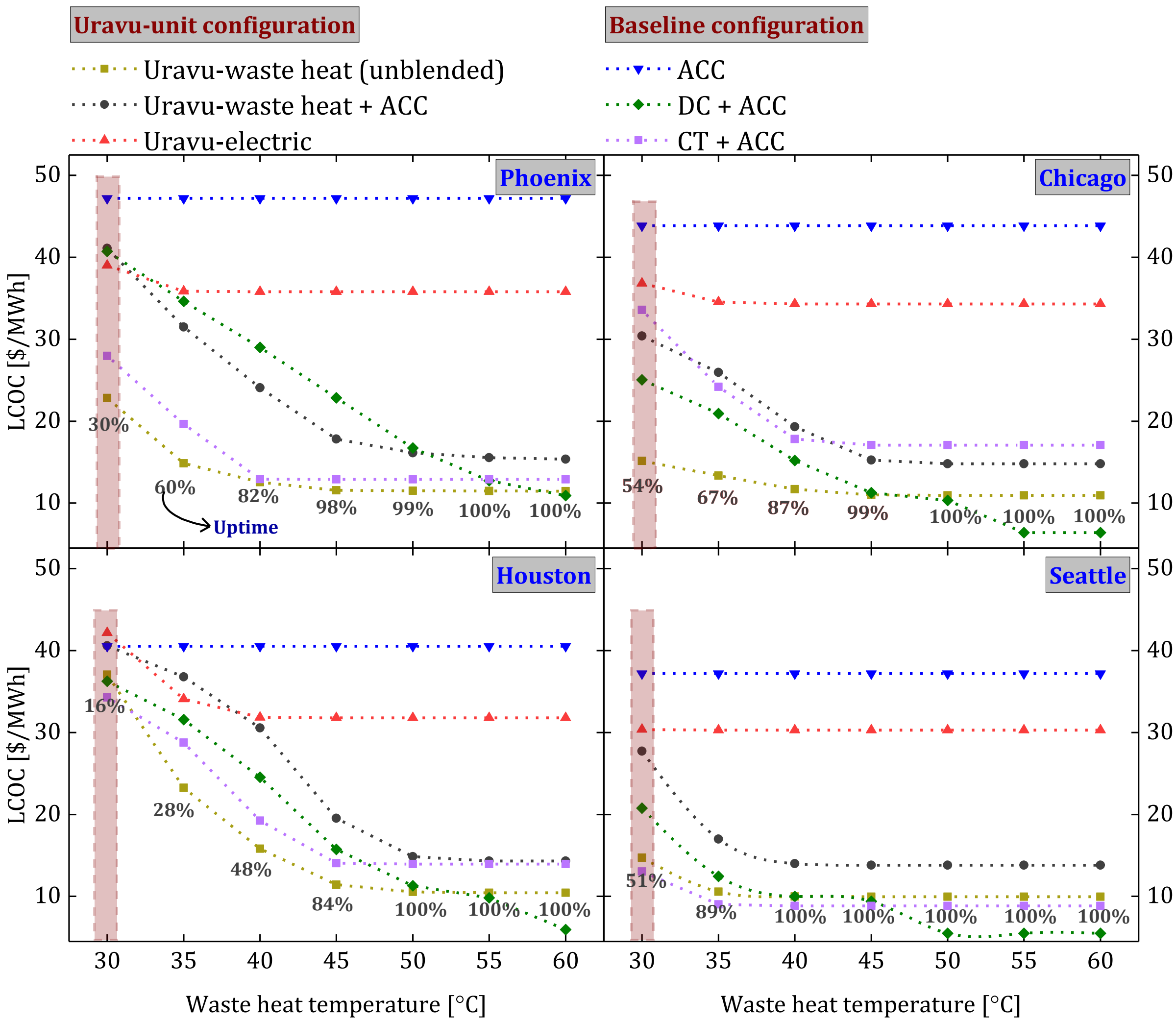

Figure 2: Variation of LCoC with waste heat temperature for US-based cities.

European Union: A similar trend is observed in EU cities (Frankfurt, Madrid, London, and Stockholm), although with slightly different starting points due to cooler climatic conditions. At a waste-heat temperature of 30–35 °C, the LCoC is relatively high for the Uravu-waste heat (blended) system, because the system cannot run continuously. However, once the temperature exceeds 40–45 °C, uptime approaches 100%, and the LCoC drops significantly.

When the waste-heat temperature is moderate or high, the Uravu waste-heat configuration consistently delivers lower LCoC than baseline cooling systems. The benefit becomes more pronounced beyond 45–50 °C, where the system runs continuously, and the cost advantage becomes stable.

In summary, Uravu becomes significantly more economical than traditional cooling in EU cities when waste heat reaches 45 °C or higher, regardless of whether the climate is warm (e.g., Madrid) or cool (e.g., Stockholm).

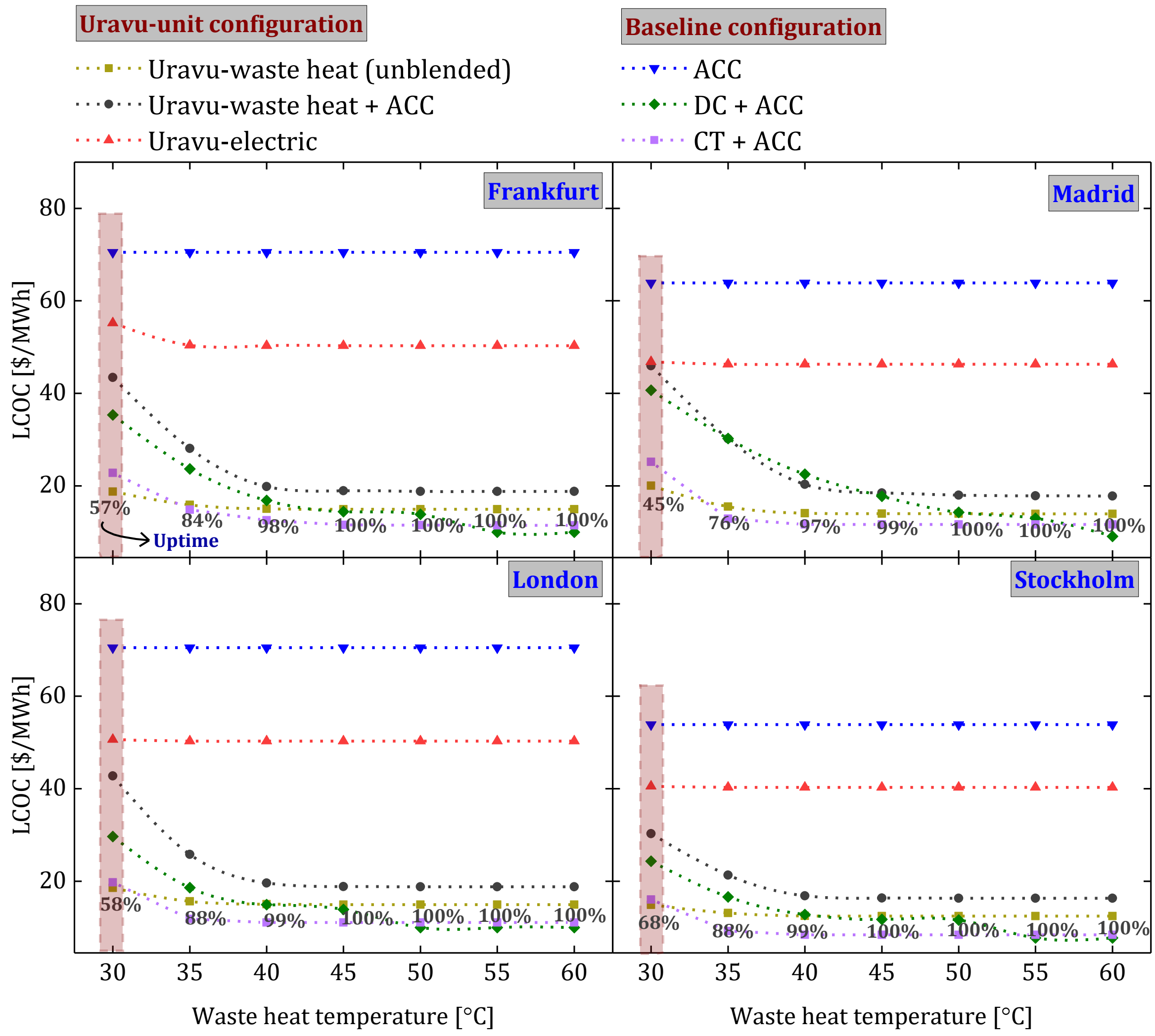

Figure 3: Variation of LCoC with waste heat temperature for EU-based cities.

India and Singapore: The drop in LCoC with rising waste-heat temperature is even more pronounced in Asian cities (Hyderabad, Bengaluru, Mumbai, New Delhi, Chennai, and Singapore). At lower temperatures, high humidity, and elevated cooling demand make the baseline systems expensive. When waste-heat temperature rises to around 40–45 °C, the LCoC reduces rapidly because (i) Uravu systems reach full uptime and (ii) they replace a significant portion of mechanical cooling. At low-temperature waste heat in humid regions, the Uravu-electric system will result in comparable or lower LCoC than the baseline system.

Beyond 45 °C, the Uravu-waste heat configuration consistently becomes the lowest-cost cooling solution, achieving a larger cost margin over baselines compared to the US and EU, due to higher avoided electricity demand.

Put simply, in Asia, the financial benefit of using Uravu increases most rapidly as waste heat temperature rises, especially in high-humidity climates such as Chennai and Singapore.

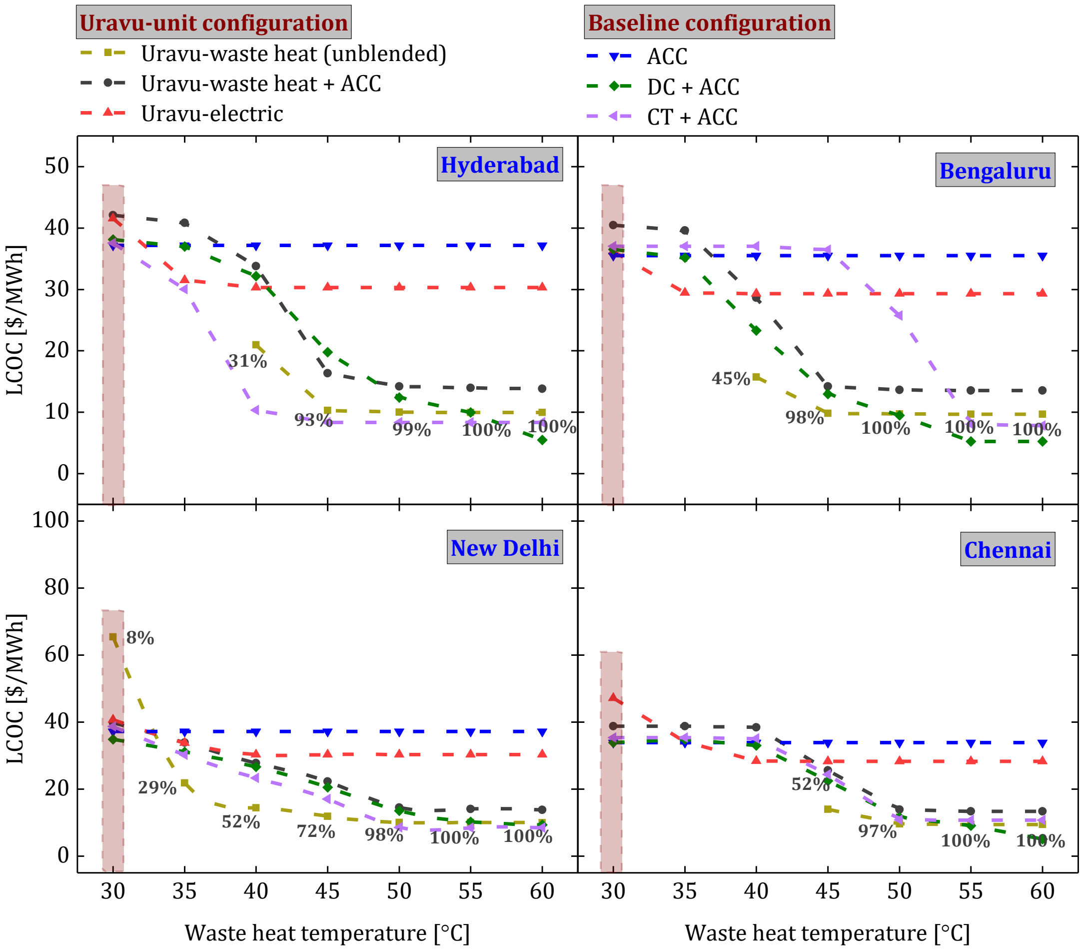

Figure 4: Variation of LCoC with waste heat temperature for Indian cities.

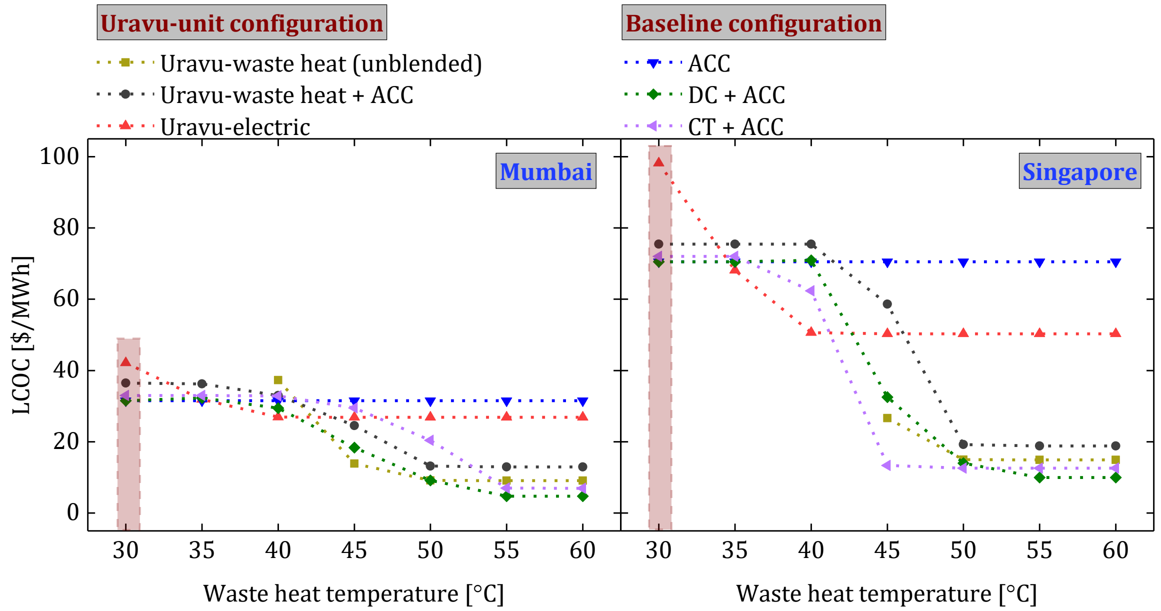

Figure 5: Variation of LCoC with waste heat temperature for Mumbai and Singapore.

Even though the starting LCoC varies from region to region due to climate and electricity market differences, a universal trend is visible:

Waste-heat temperature	LCoC trend for Uravu
30–35 °C	Highest cost – low uptime
35–45 °C	Substantial cost reduction – uptime rapidly increases
≥45 °C	Lowest cost – consistent, continuous operation

3.2 Net Value of Water

United States: In US cities, the NVW decreases gradually as waste-heat temperature increases. At low temperatures (30–35 °C), all Uravu configurations exhibit a positive NVW, indicating that water production still incurs costs even when no cooling credits are applied. The credit lines (with respect to ACC and DC + ACC) lie below the "no-credit" line, reflecting additional financial value from cooling savings.

As the waste-heat temperature rises to 40–45 °C, system uptime improves, and the NVW begins to approach zero, indicating almost cost-neutral water production. At higher temperatures (≥45 °C), credit with respect to ACC increasingly pushes NVW into the negative range, indicating that the economic benefit from avoided cooling energy exceeds the cost of producing water. Higher waste-heat temperature steadily improves NVW, and monetizing cooling savings (credits) significantly enhances economic value.

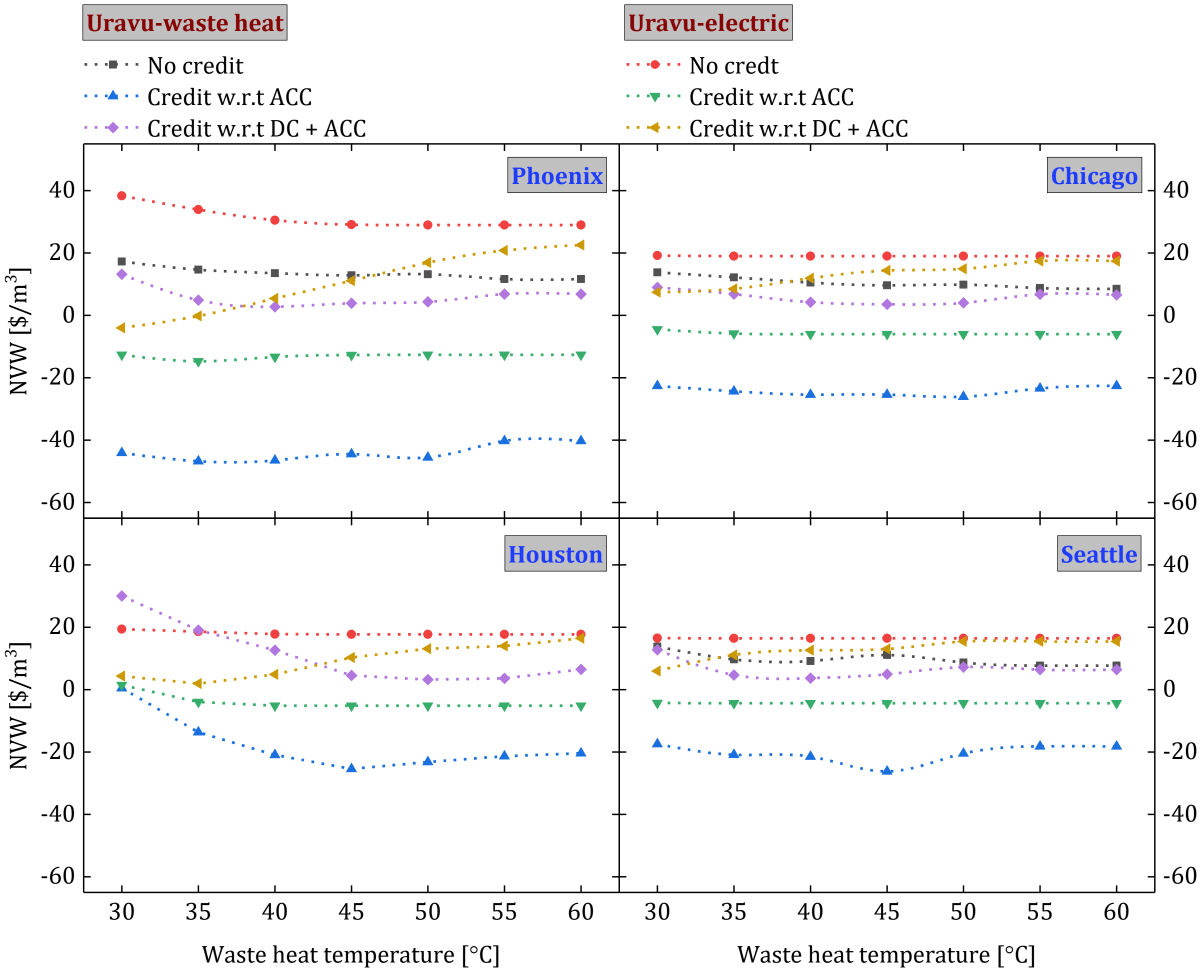

Figure 6: Variation of Net Value of Water with waste heat temperature for US-based cities.

European Union: The EU cities exhibit a similar pattern, albeit with slightly slower improvement, compared to the US at low temperatures, due to their cooler climate and lower cooling demand. At 30–35°C, NVW is still positive across all curves, and the credit lines are grouped moderately below the no-credit lines.

As the waste-heat temperature increases above 40 °C, the differences between the curves become more pronounced — credits with respect to ACC and DC + ACC significantly improve the NVW, thereby reducing the net cost of water. At ~45 °C and beyond, with Uravu-waste heat (blended) unit credit w.r.t. DC + ACC typically is close to zero NVW, demonstrating that in many EU locations, heat-driven Uravu systems can create net economic benefit when cooling energy savings are counted.

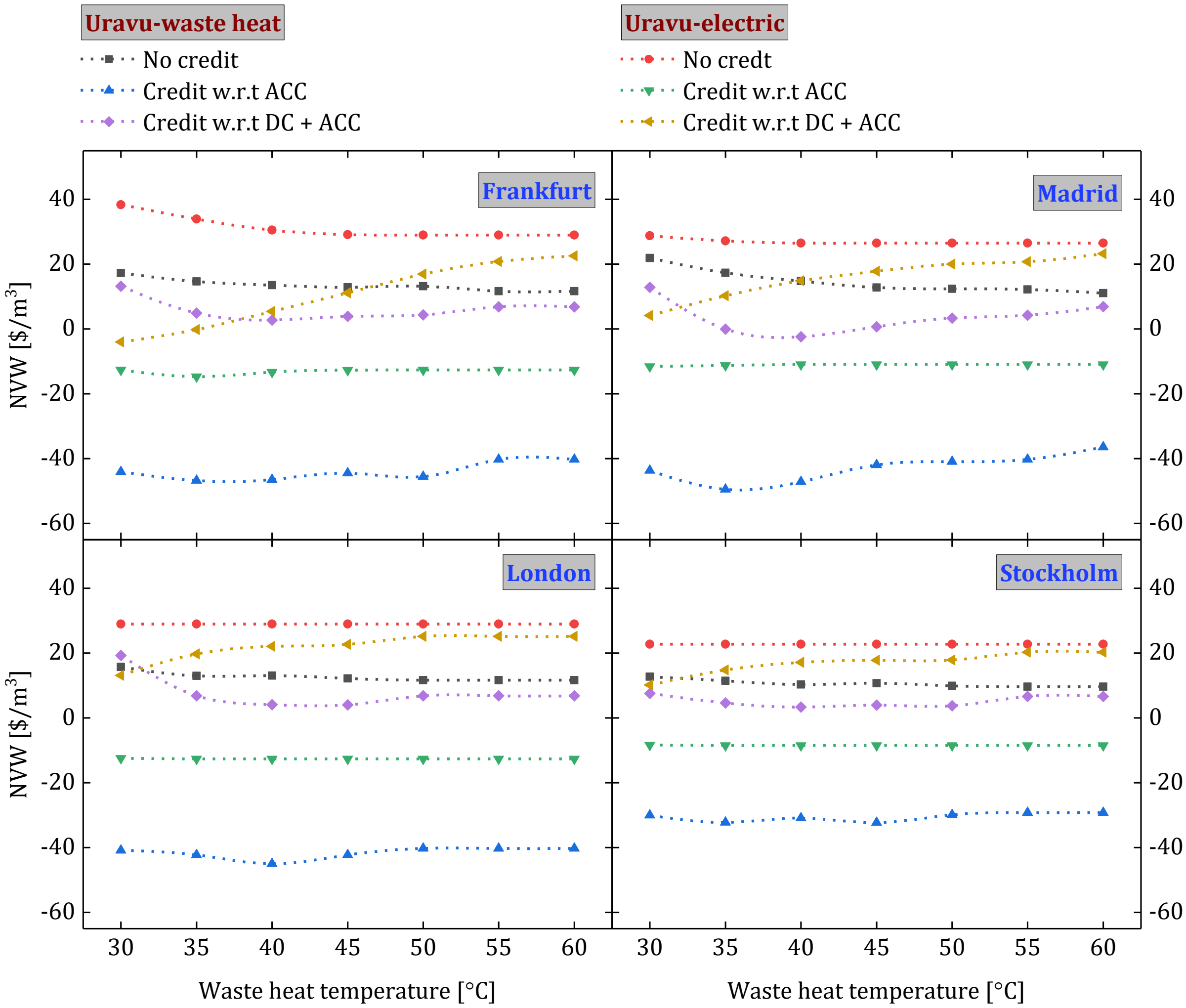

Figure 7: Variation of Net Value of Water with waste heat temperature for EU-based cities.

India and Singapore: NVW trends in Asian cities are the most sensitive to waste-heat temperature due to high cooling demand and humidity. At low temperatures (30–35 °C), NVW is significantly positive, especially in the no-credit case, because the unit cannot run continuously, and limited cooling savings are available. Only with the Uravu-electric unit is the credit line close to zero.

As the temperature rises, the NVW curves drop sharply. At around 40°C for humid regions like Chennai and Singapore, credit lines for the Uravu-waste heat system with respect to ACC and DC + ACC already approach zero NVW, and above 45°C, nearly every city shows negative NVW under both credit cases. This negative NVW means that cooling savings alone fully pay for the cost of producing water and even create additional financial value.

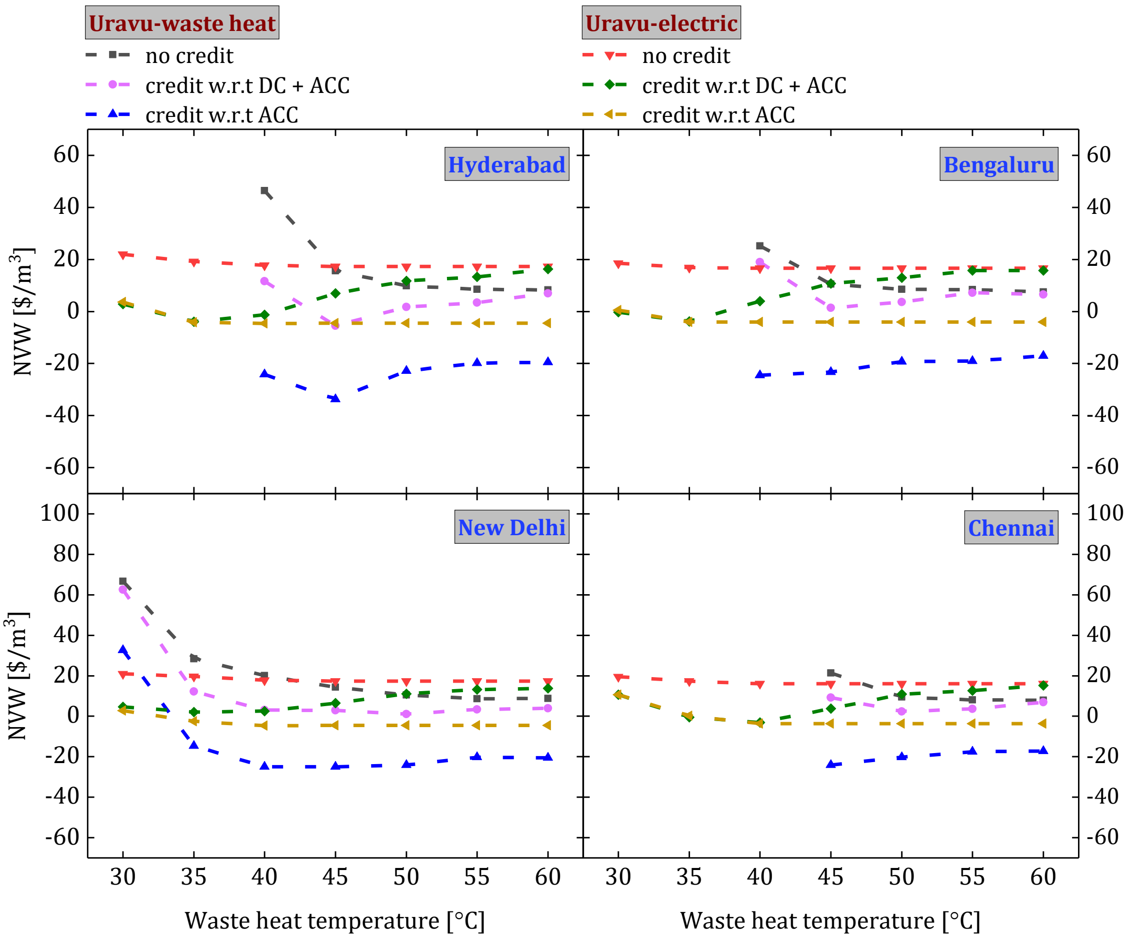

Figure 8: Variation of Net Value of Water with waste heat temperature for Indian cities.

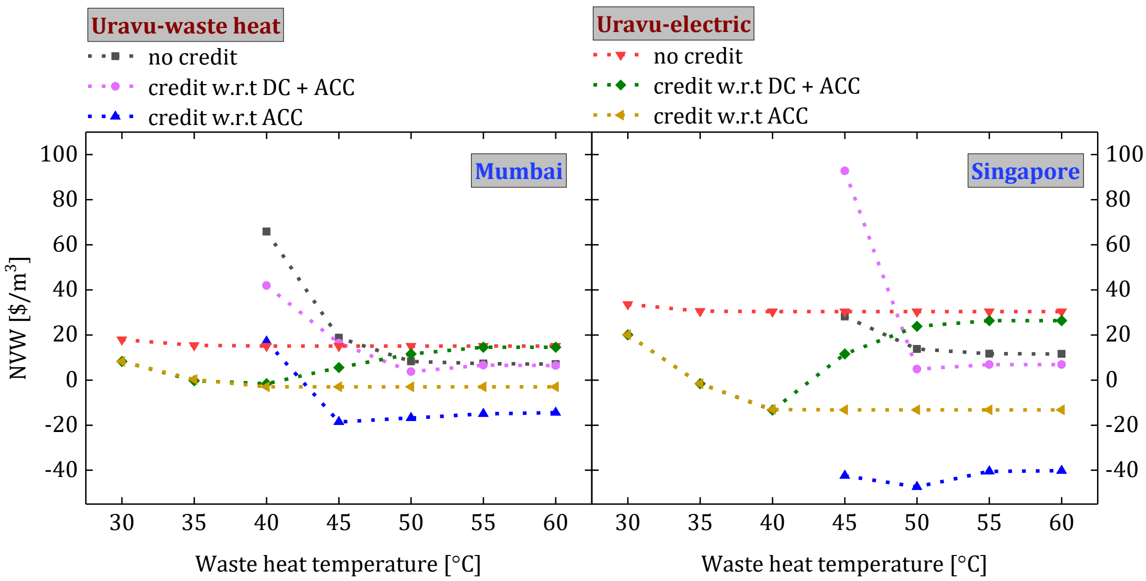

Figure 9: Variation of Net Value of Water with waste heat temperature for Mumbai and Singapore.

Table 3: City-wise NVW behavior vs. waste-heat temperature.

City	Uravu-waste heat no credit	Uravu-waste heat w.r.t DC +ACC	Uravu-waste heat w.r.t ACC	Uravu-electric heat no credit	Uravu-electric w.r.t DC +ACC	Uravu-electric w.r.t ACC
Phoenix	NVW > 0	NVW > 0 (30 -35°C) NVW ≈ 0 (>35°C)	NVW < 0	NVW > 0	NVW < 0 (30 -35°C) NVW > 0 (>35°C)	NVW < 0
Chicago	NVW > 0	NVW > 0 (30 -35°C, 50-60°C) NVW ≈ 0 (35 -50°C)	NVW < 0	NVW > 0	NVW > 0	NVW < 0
Houston	NVW > 0	NVW > 0	NVW < 0	NVW > 0	NVW > 0	NVW < 0
Seattle	NVW > 0	NVW > 0 (30 -35°C) NVW ≈ 0 (>35°C)	NVW < 0	NVW > 0	NVW > 0	NVW < 0
Frankfurt	NVW > 0	NVW > 0 (30°C) NVW ≈ 0 (>30°C)	NVW < 0	NVW > 0	NVW < 0 (30°C) NVW > 0 (>30°C)	NVW < 0
Madrid	NVW > 0	NVW > 0 (30°C) NVW ≈ 0 (>30°C)	NVW < 0	NVW > 0	NVW > 0	NVW < 0
London	NVW > 0	NVW > 0 (30°C) NVW ≈ 0 (>30°C)	NVW < 0	NVW > 0	NVW > 0	NVW < 0
Stockholm	NVW > 0	NVW > 0	NVW < 0	NVW > 0	NVW > 0	NVW < 0

City	Uravu-waste heat no credit	Uravu-waste heat w.r.t DC +ACC	Uravu-waste heat w.r.t ACC	Uravu-electric heat no credit	Uravu-electric w.r.t DC +ACC	Uravu-electric w.r.t ACC
Hyderabad	NVW > 0	NVW > 0 (>40°C)	NVW < 0	NVW > 0	NVW ≈ 0 (30 -40°C) NVW > 0 (>40°C)	NVW ≈ 0
Bengaluru	NVW > 0	NVW > 0 (40°C) NVW ≈ 0 (>40°C)	NVW < 0	NVW > 0	NVW ≈ 0	NVW < 0
Mumbai	NVW > 0	NVW > 0 (30 -35°C) NVW ≈ 0 (>35°C)	NVW > 0 (40°C) NVW < 0 (>40°C)	NVW > 0	NVW < 0 (30 -35°C) NVW > 0 (>35°C)	NVW < 0
New Delhi	NVW > 0	NVW > 0 (30 -35°C) NVW ≈ 0 (>35°C)	NVW < 0	NVW > 0	NVW < 0 (30 -35°C) NVW > 0 (>35°C)	NVW > 0 (30°C) NVW ≈ 0 (>30°C)
Chennai	NVW > 0	NVW > 0	NVW < 0	NVW > 0	NVW > 0 (30-35°C) NVW ≈ 0 (>35°C)	NVW > 0 (30°C) NVW ≈ 0 (>30°C)
Singapore	NVW > 0	NVW > 0 (45°C) NVW ≈ 0 (>45°C)	NVW < 0	NVW > 0	NVW < 0 (30 -35°C) NVW > 0 (>35°C)	NVW > 0 (30°C and >40°C) NVW < 0 (>30-35°C)