ARUP

Circular thinking for data centres

How implementing circularity strategies today can reduce whole life carbon and future-proof facilities

ARUP

About us

We advise on, plan and design the future of the built environment.

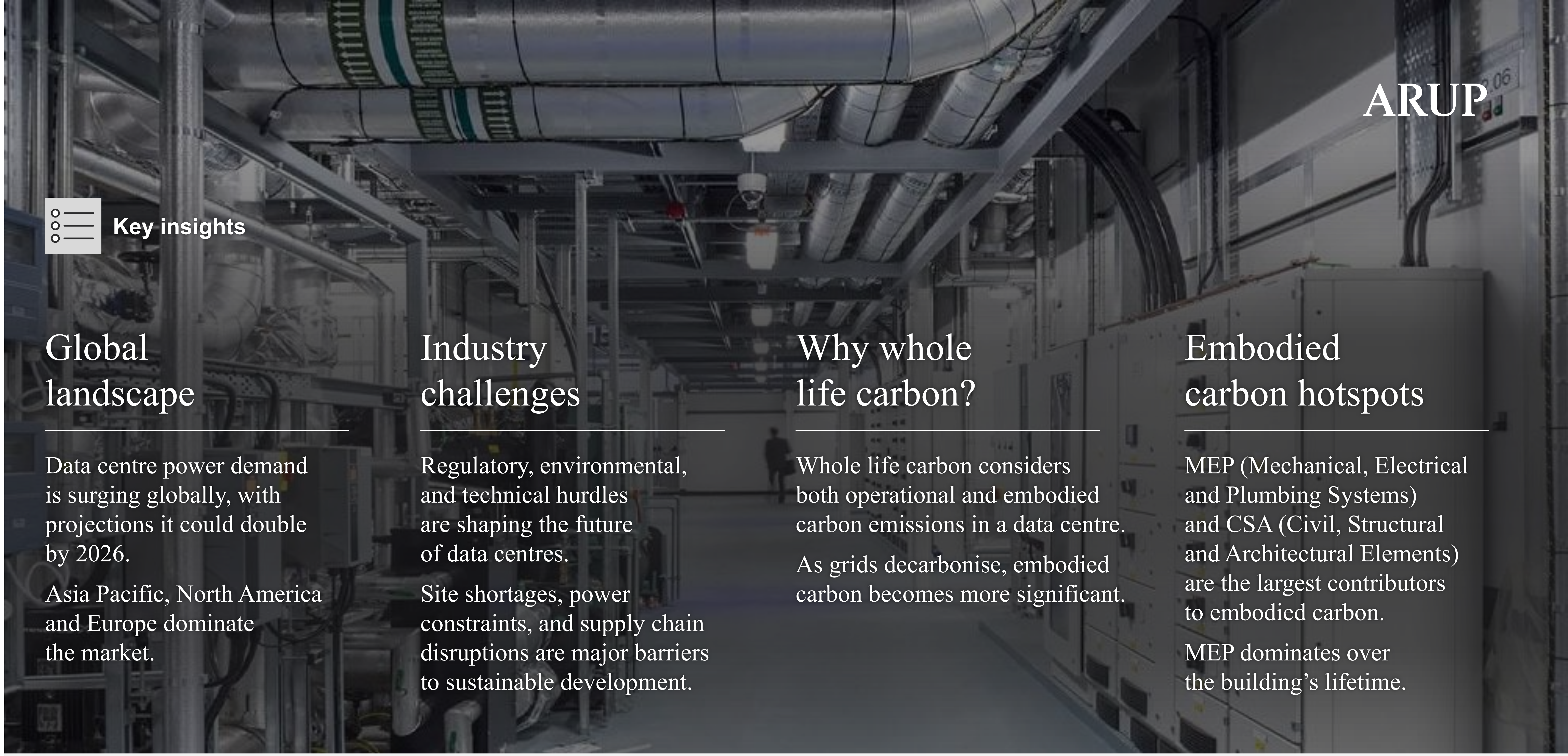
As a global consultancy with technical and advisory expertise across more than 150 disciplines, we bring a Total Design approach to our work with clients.

This is how we shape a better world.

Executive summary

The data centre industry is expanding rapidly, driven by AI and cloud demand, but this growth brings steep environmental costs. Whole life carbon emissions, especially embodied carbon from materials and equipment, are becoming the dominant footprint as electricity grids decarbonise.

Based on data from real-life projects, Arup has collected insights about the industry today and outlined circularity strategies to cut embodied carbon. These strategies can help future-proof data centres amidst increasing regulatory and public pressure to reduce environmental impact.



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Key insights

Global landscape

Data centre power demand is surging globally, with projections it could double by 2026.

Asia Pacific, North America and Europe dominate the market.

Industry challenges

Regulatory, environmental, and technical hurdles are shaping the future of data centres.

Site shortages, power constraints, and supply chain disruptions are major barriers to sustainable development.

Why whole life carbon?

Whole life carbon considers both operational and embodied carbon emissions in a data centre.

As grids decarbonise, embodied carbon becomes more significant.

Embodied carbon hotspots

MEP (Mechanical, Electrical and Plumbing Systems) and CSA (Civil, Structural and Architectural Elements) are the largest contributors to embodied carbon.

MEP dominates over the building's lifetime.

Circularity strategies to cut embodied carbon

Build nothing

Retrofitting existing data centres can be challenging in terms of efficiency but should be explored for small facilities or specific upgrades.

Build for long-term use

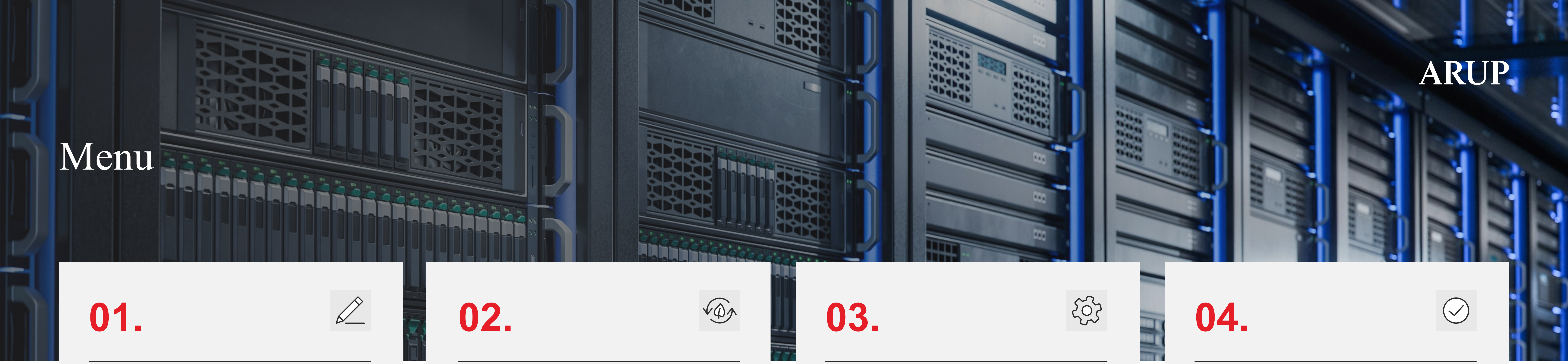
Relying on leasing models for specific components or systems (e.g. plant leasing) can help keep the facility in use for longer.

Build efficiently

Material efficiency can be increased with strategies such as optimising structural column grids or prefabrication to reduce waste.

Build with the right resources

Selecting low-carbon alternatives and biobased materials whenever possible can influence supply chains to enable change at scale.



Menu

Foreword

"Circularity is key to future-proofing data centres and decarbonising the industry for sustainable growth."

This report on circularity strategies for reducing whole life carbon in data centres is for anyone dedicated to promoting sustainable practices within the industry.

The rapid expansion of data centres has led to a significant increase in power consumption, with projections indicating that demand for energy could double by 2026. This growth comes with challenges.

The industry must address environmental considerations, regulatory restrictions, and technical requirements to ensure development is sustainable. Additionally, infrastructure limitations and supply chain disruptions pose significant hurdles, affecting site availability and construction costs.

Using data gathered by our experts from projects and internal studies, this report explores how circularity is key to decarbonising the industry and is a business priority for future-proofing data centres.

Mechanical, electrical, and plumbing (MEP) systems are a particular area of focus due to their prevalence in data centre facilities. The report outlines how circularity strategies can be applied to MEP systems and other elements in facilities.

We encourage you to read, review, and comment on this report. Apply circularity strategies and actions to your project and reach out if you need assistance. Our teams are willing to offer advice and would welcome a conversation to discuss circularity strategies in more detail.

Together, we can work towards a more sustainable future for data centres.

Jennifer DiMambro
Global and Americas Data Centres and Technology Leader

Global landscape

The data centre industry is poised for an unprecedented expansion, driven by AI, cloud computing, and the relentless surge in global data consumption.

Global data centre power consumption has increased by 20-40% annually in recent years and it's projected that demand could double by 2026.

This exponential growth puts pressure on developers building greenfield facilities, with new developments expected to grow sixfold by 2027. Data centre construction market value is predicted to grow by more than 10% annually until 2029.

Globally, the development of data centres is moving towards high density and large-scale facilities to meet the demand for increased data transfer and storage.

Data centre market share, by region (2024)*

41%
North America
Power demand is expected to grow to 35 gigawatts by 2030 – more than double consumption in 2022.

28%
Europe
The demand for power capacity is projected to increase rapidly by 27% by 2027 reaching 13,100MW.

21%
Asia Pacific
The region attracts continuous investment, especially in Japan, Korea and China, with demand also surging in New Zealand.

7%
Central and South America
Growing demand, a rise in 5G coverage and the introduction of tax incentives is attracting new investments.

3%
Middle East and Africa
Development in the region is backed by substantial government investment in IT and cloud services.

Source: Precedence Research, 2024

Data centre industry challenges

With rapid growth come challenges that will shape the future data centre landscape.

Policies and reporting

The data centre industry faces increasing regulatory restrictions and stricter reporting requirements. For example, the UK government recently rejected a large-scale server farm proposal due to energy supply concerns. The European Union's Energy Efficiency Directive requires data centres over 500kW to report their energy usage and emissions.

Additionally, there is a lack of a standardised methodology and database for whole life carbon assessments, complicating the evaluation of a data centre's total carbon emissions.

Environmental considerations

Data centres are often built in locations without optimal conditions such as access to renewable energy sources or protection from extreme climate events. Public opinion on data centre developments is becoming more critical, especially in the context of climate change and environmental sustainability. As climate change becomes a more pressing concern, there may be a shift in the sites selected for new data centres to enhance their resilience.

Technical developments

AI data centres require robust structural designs to support the heavy weight of specialised hardware, often necessitating floor loading capacities of 50kN per m^2 or more. These facilities typically feature heightened floor-to-ceiling spaces to accommodate advanced cooling systems and enhanced electrical infrastructure to handle higher power densities.

Sources: Socomec, *EU Energy Efficiency Directive: what the new rules mean for Data Centres*; Techerati, *UK tightens energy regulations: challenges and opportunities for data centres;* Schneider Electric, *The EU Energy Efficiency Directive and its impact on CIOs, data centre owners and operators*

Data centre industry challenges

Infrastructure limitations

Growing demand for data centres is leading to a shortage of suitable sites, particularly for hyperscale facilities that require large areas of land. Additionally, a global power shortage is severely hindering the growth of the data centre market and making power sourcing a top priority for operators worldwide. Access to a reliable and secure power grid is one of the most important site selection criteria, alongside energy costs and access to renewable energy sources.

Supply chain disruptions

Construction costs for new data centres have increased significantly due to a combination of supply chain issues, inflation, labour shortages, and limited site availability. Financial considerations present a significant impediment for data centre developers thinking of adopting circular solutions. Supply chain disruptions are a key factor in the delay of projects, and the intense competition for materials has led businesses to consider stockpiling as a viable method to pre-empt demand surges.

> In Europe, construction costs for data centres increased by more than 6% a year between 2020 and 2023.

Sources: GE Vernova, *Data centre Site Selection*; CBRE, *Global Data centre Trends 2024*; Savills, *Costs on the Rise*

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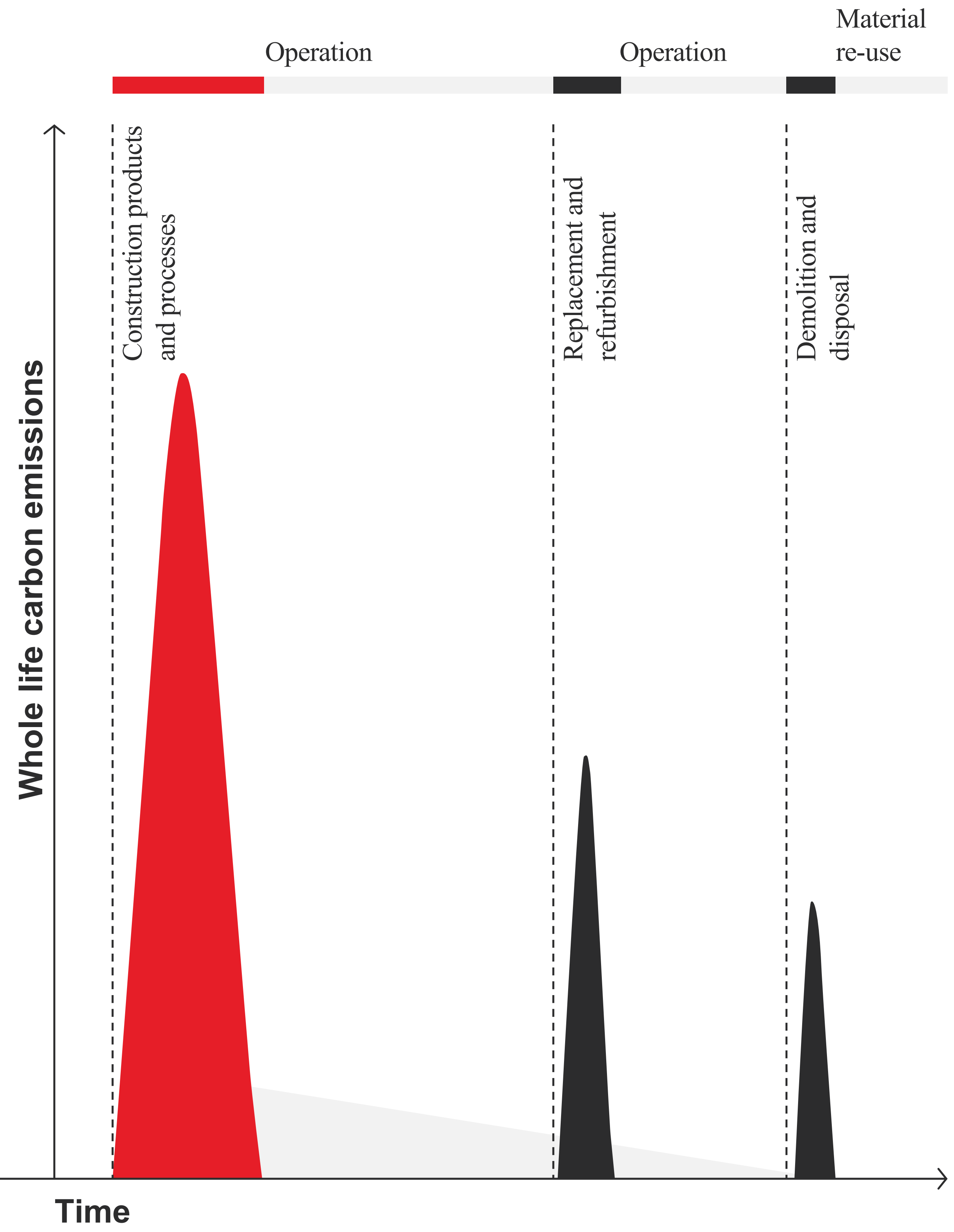
Whole life carbon

Whole life carbon is the total carbon associated with the construction and operation of a built asset.

Whole life carbon is understood in two dimensions:

– Operational carbon emissions: those that are produced by the building's day-to-day use and occupancy. Currently, one of the main challenges data centres face is their high levels of electricity consumption.

– Embodied carbon emissions: from the materials and energy used to produce and assemble them. Embodied carbon is measured throughout the project's lifetime. It includes the initial emissions generated in production and construction of the asset, but also replacement components during the building's lifetime and end of life emissions.



*Whole life carbon emissions, Arup (2020)
Net Zero Carbon Buildings: Three Steps to Take Now

Whole life carbon

Product	A1	Raw material supply	Upfront carbon; Embodied carbon
Product	A2	Transport	Upfront carbon; Embodied carbon
Product	A3	Manufacturing	Upfront carbon; Embodied carbon
Construction	A4	Transport	Upfront carbon; Embodied carbon
Construction	A5	Construction and installation processes	Upfront carbon; Embodied carbon
In-use	B1	Use	Embodied carbon
In-use	B2	Maintenance	Embodied carbon
In-use	B3	Repair	Embodied carbon
In-use	B4	Replacement	Embodied carbon
In-use	B5	Refurbishment	Embodied carbon
Operational carbon	B6	Operational energy	Operational carbon
Operational carbon	B7	Operational water	Operational carbon
End of use	C1	Deconstruction and demolition	Embodied carbon
End of use	C2	Transport	Embodied carbon
End of use	C3	Waste processing	Embodied carbon
End of use	C4	Disposal	Embodied carbon
Beyond life cycle	D	Benefits and loads Reuse, Recovery, Recycling	

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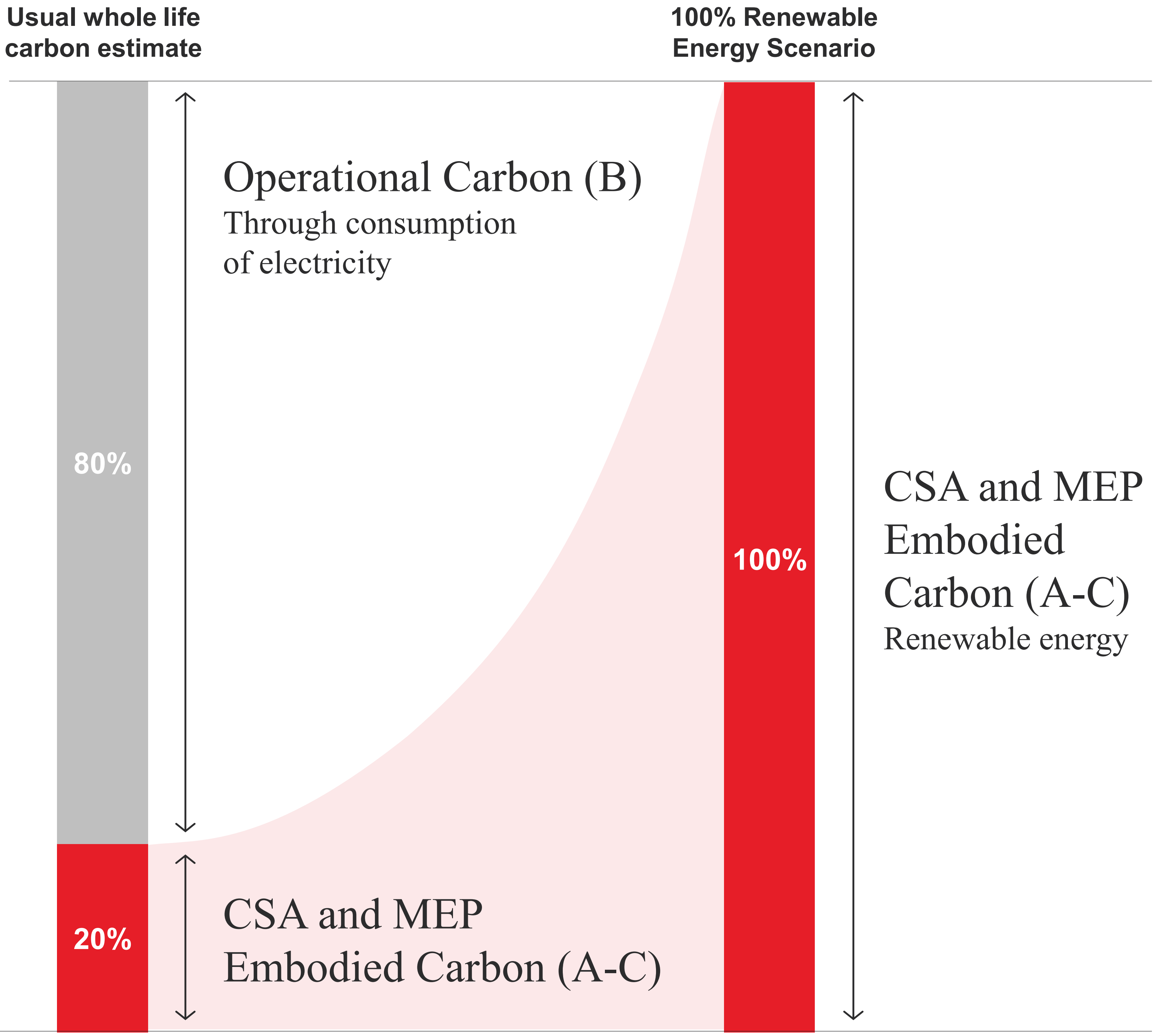
Why focus on whole life carbon?

As the electricity grid is decarbonised, embodied carbon may surpass operational carbon.

Operational carbon can account for up to 80% of a project's total emissions before applying renewables or offsets, with embodied carbon accounting for the remaining 20%.[1] As the energy supply becomes cleaner, the relative importance of embodied carbon increases.

This graph shows the typical balance of embodied and operational carbon in data centres assessed by Arup. When powered entirely by renewables from day one, operational emissions are minimal,[2] making embodied carbon the primary source of emissions.

CSA: Civil, Structural and Architectural Elements
MEP: Mechanical, Electrical and Plumbing Systems



[1] This estimation is based on electricity usage only, based on an average UK grid decarbonisation factor averaged over 60 years from 2023 to 2050.
[2] There would still be some operational carbon due to fuel use on site.

Data centres vs other buildings

Key differences between whole life carbon in data centres and other buildings

Assumed building lifetime

Most whole life carbon assessments are conducted against a lifespan of 60 years.

However, for data centres, the design life of assets is sometimes set to only 25 years.

What's in, what's out?

Assessments typically only consider items within the building footprint. For data centres it is crucial to consider the whole site and supporting infrastructure.

Operational energy / carbon

Data centre operational energy consumption is significantly higher than for a typical building.

Embodied carbon of MEP services

Typically, MEP services are excluded from whole life carbon assessments as they are deemed 'too hard'.

In data centres they must be considered due to their significance.

Phased development

Data centres tend to be developed in phases.

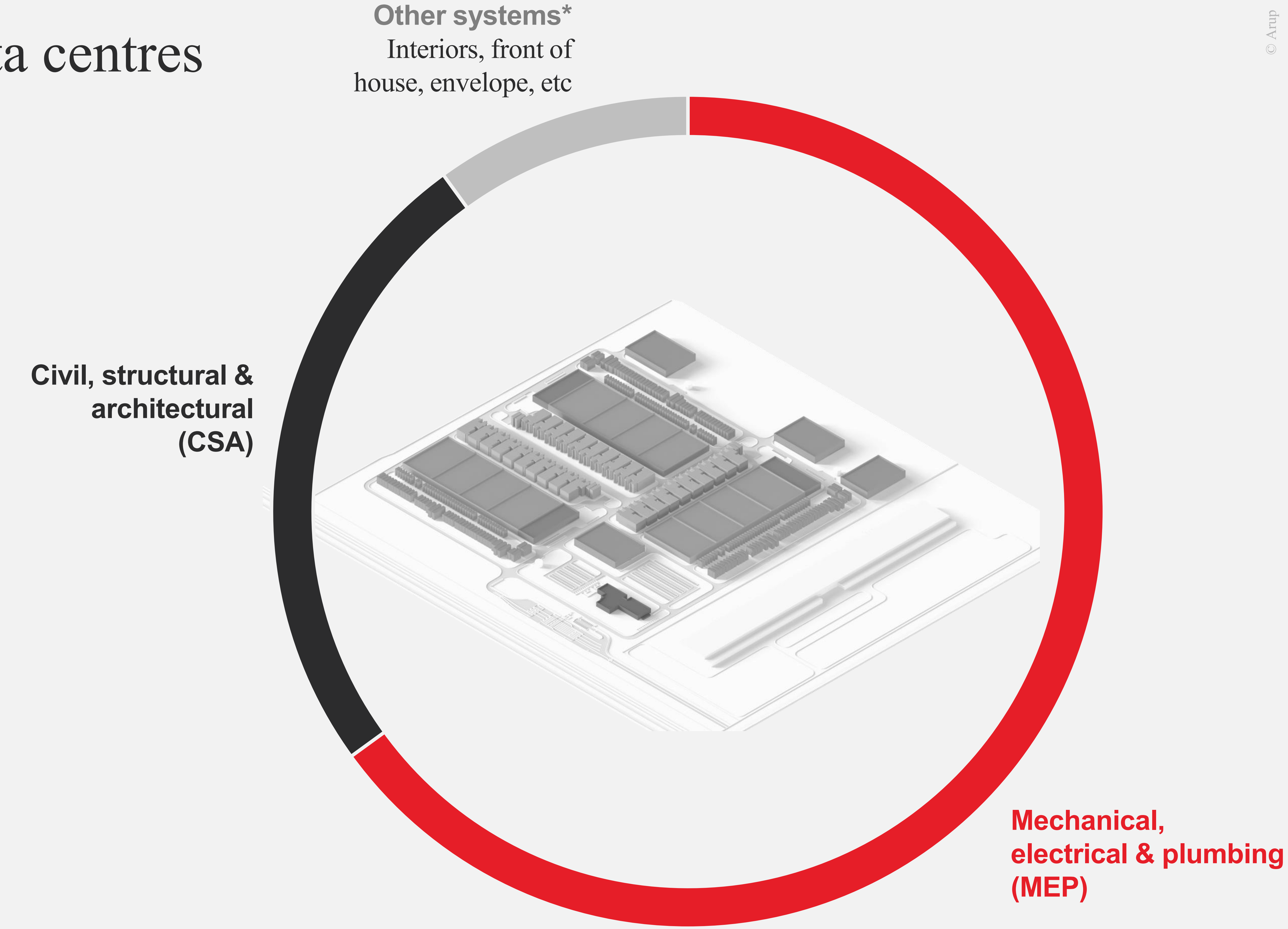
Assessment results must be delineated correctly to ensure comparability.

Embodied carbon hotspots in data centres

By assessing design and construction stages of data centres, as well as existing facilities, we now have a good understanding of which elements contribute the most embodied carbon.

Although there are significant variations, depending on factors such as layout type or cooling typology, broad conclusions can be drawn.

The graph to the right shows an outline breakdown of lifecycle module A1-A3, or upfront emissions of a data centre.



Hotspots for reducing embodied carbon

When considering whole life embodied carbon (A-C), the carbon footprint of the MEP can be up to seven times larger than that of the CSA.

A high-level estimate based on several whole life carbon assessments shows that the highest contributing elements to upfront embodied carbon are the civil, structure (superstructure and substructure) and MEP systems.

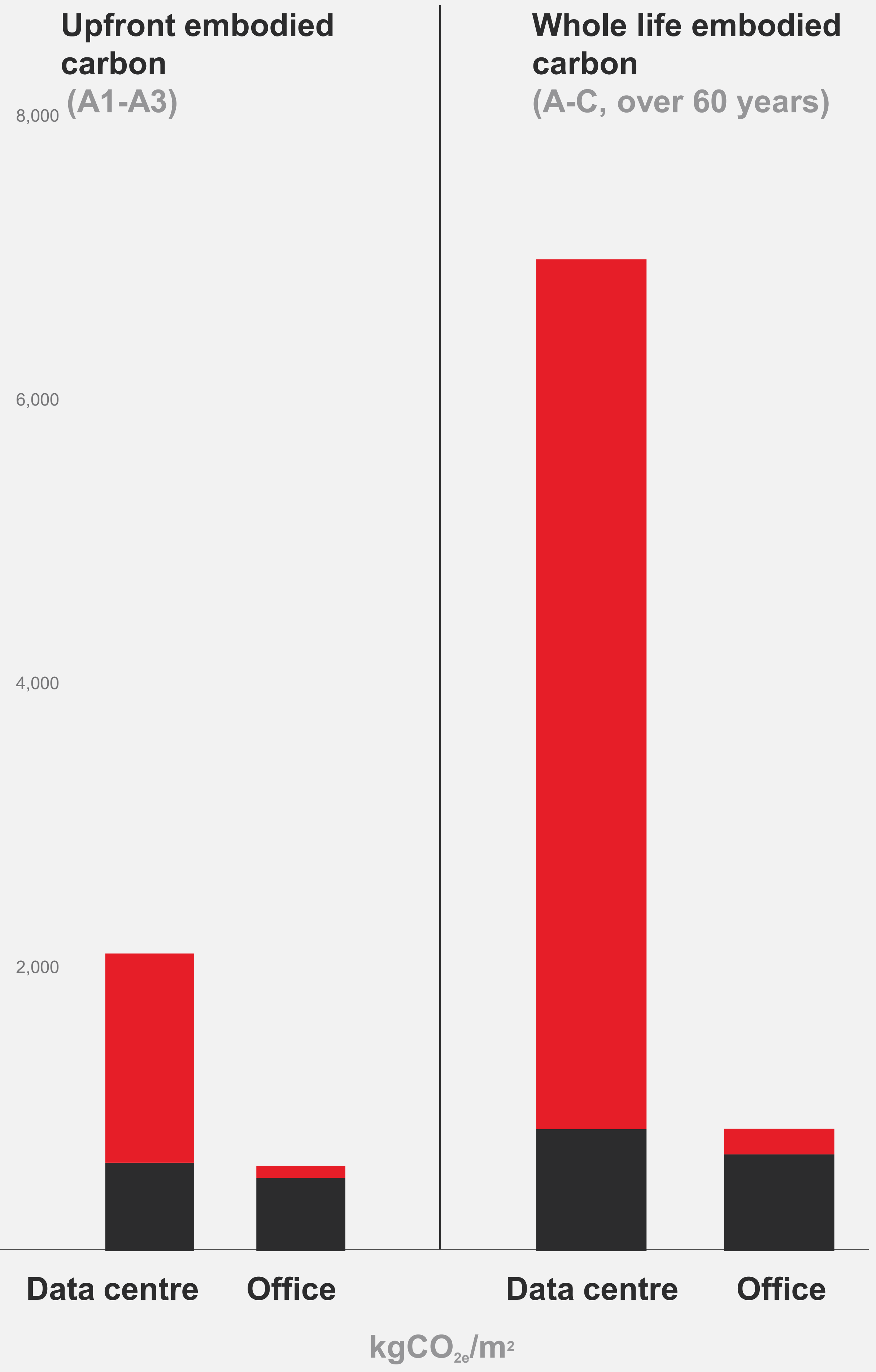
CSA/MEP proportions vary depending on the form of the building and the design philosophies applied, but the results are relatively consistent across all data centres we have assessed.

On average, the split is 30% CSA / 70% MEP for upfront embodied carbon, and 12% CSA / 88% MEP for whole life embodied carbon.

This increased proportion for MEP is because the equipment is typically replaced 2-3 times during the building's lifetime.

This analysis highlights the importance of including MEP (even at a high level) and undertaking whole life assessments.

- Civil, structural and architectural (CSA)
- Mechanical, electrical and plumbing (MEP)



*Office benchmark is taken from the GLA WLCA Guidance benchmarks and is an aspirational target figure, it includes for structure (substructure, superstructure, façade), fittings, finishes and MEP

MEP hotspots

Despite contributing significantly to upfront embodied carbon and making up an even higher proportion of whole life embodied carbon, MEP is often not accounted for.

Equipment vs distribution

Equipment includes main plant items such as generators, chillers, transformers etc.

Distribution of services includes pipework, ductwork, containment and cables.

Upfront carbon

Data centres require large quantities of distributed services and their supporting elements. This makes distribution a carbon hotspot. Pipework valves and fittings can be a significant contributor and offer an opportunity for reduction through careful routing and consideration of valve quantities.

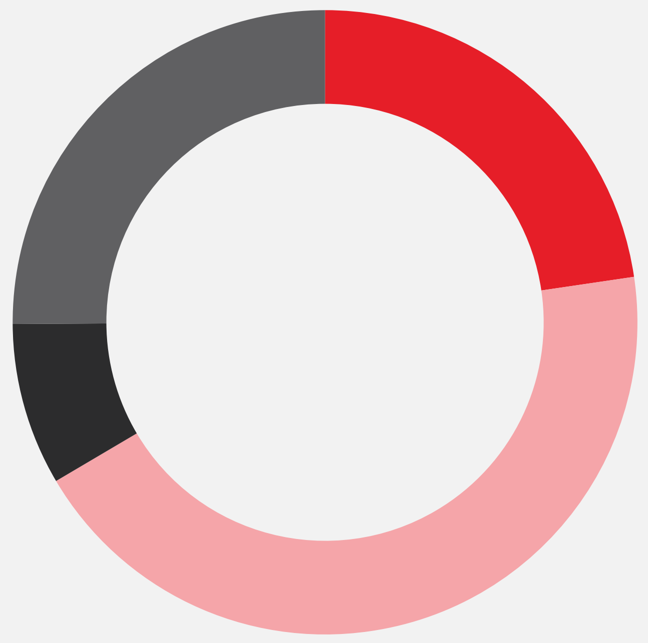
However, electrical equipment tends to dominate the upfront carbon for MEP services due to the complex nature of the manufacturing supply chain and the materials used in manufacture.

Whole life carbon

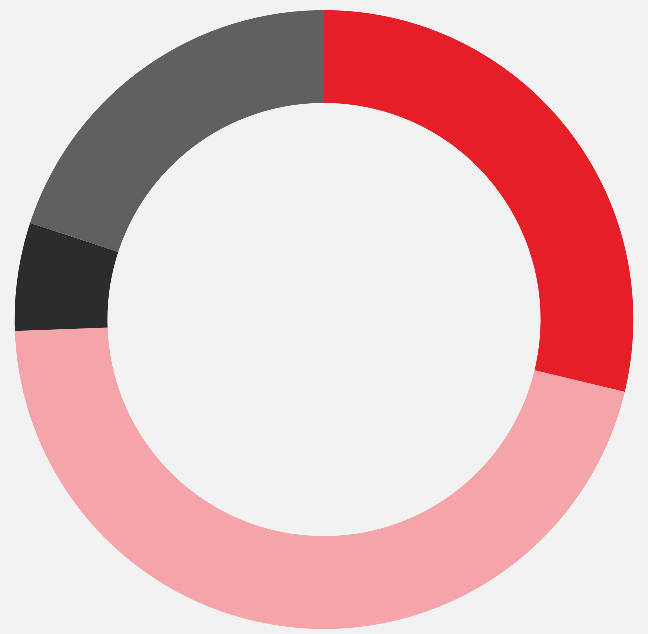
Plant replacement cycles are a key driver of whole life carbon for MEP services. Plant items are typically replaced every 10-25 years. But some items, such as batteries, are replaced as frequently as every 5 years. Extending longevity through maintenance regimes and adhering to manufacturer-recommended environmental conditions can reduce whole life carbon.

Depending on which type is used, refrigerant can be a significant contributor to whole life carbon and is a relatively easy target for reducing carbon. Leakage over the lifetime of the building has a much bigger impact when high global warming potential refrigerants are used.

Upfront carbon
(A1-A3)



Whole life carbon
(A-C, excl. operational over 60 years)



Mechanical equipment
Mechanical distribution
Electrical equipment
Electrical distribution

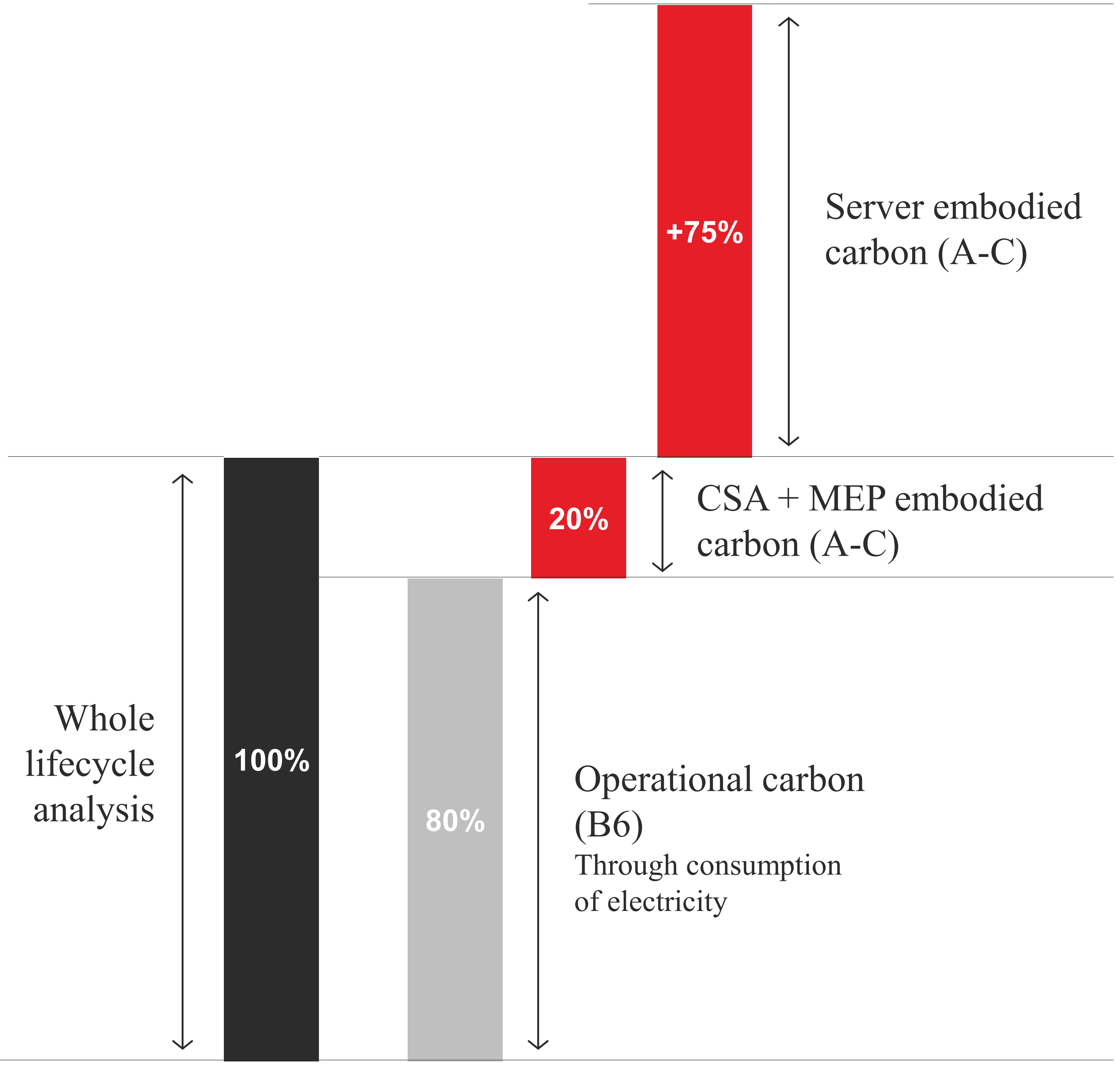
Embodied carbon of servers

Even the limited available data* shows the dramatic whole life carbon impact of server racks.

Due to their high precious metal content and complex manufacturing processes, servers have extremely high embodied carbon. And they are typically replaced every three years.

As designers of the facility, server emissions are outside our control and not included in our whole life carbon assessments. But we believe it is important to highlight their impact and call for reductions in this area.

Many large data centre operators try to reduce these emissions by creating dedicated facilities to recover and re-use server parts.



*EPD Data used from OneClickLCA

How can circularity help bring down embodied carbon?

Circularity strategies and actions enable you to go beyond simple material decarbonisation and realise a host of benefits, in addition to reducing whole life carbon.

Key circularity strategies to cut embodied carbon:

Build nothing

Build for long-term use

Build efficiently

Build with the right resources

Check the Circular Buildings Toolkit to see how these strategies can be applied to any building design.

A. Key circularity strategies	B. Key circularity actions	C. Exemplary sub-actions
Build nothing	Retrofit and improving existing facilities	Opportunities for smaller facilities Consider MEP systems layout
Build for long-term use	Explore leasing models Keep assets at highest value as long as possible	Standardisation for adaptability and reuse Take-back programs Alternative procurement strategies Water-based cooling systems
Build efficiently	Increase material efficiency Re-evaluate fundamental design criteria and building form	Optimise structural spans Prefabrication Dematerialisation of pipework and duct banks
Build with the right resources	Switch to less carbon-intensive materials Source reused materials	Low-carbon concrete and metals Source biobased materials

Build nothing

Intervention on existing facilities

EMC^2's Ireland Centre of Excellence

Following an energy utilisation feasibility report by Arup, EMC^2 decided to undertake a full retrofit to implement energy-saving technologies at its information technology and data centre site in Cork, using free cooling technology systems. The work will reduce annual carbon emissions by 7,000 tonnes.

Improving existing facilities and retrofitting

In the context of data centres, building nothing is challenging. New facilities are required to meet global demand for data.

There are opportunities for refurbishing and retrofitting existing facilities. For these projects, given the dominance of MEP in whole life carbon, it is important to design and install systems as efficiently as possible.

In the course of our work, we have assessed all kinds of other buildings that could potentially be reused as data centres. But we have found that existing constraints usually mean the reused building will be so compromised that it is generally better to demolish and rebuild.

In addition, new builds are often preferred by developers due to the speed to market they require and the associated risks of delays.

Opportunities for smaller facilities or upgrades to existing data centres should always be reviewed.

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Build for long-term use

Explore leasing models

Kaer leasing model

Kaer offers cooling as a service for data centres. By retaining ownership, Kaer ensures systems are efficiently operated, maintained, and upgraded over time. This extends asset life, reduces waste, and avoids premature replacements. Continuous monitoring and optimisation make it possible to apply circular principles of durability, adaptability, and resource efficiency.

Server racks

The materials used for server racks can account the same, or even more, whole life carbon emissions than the MEP systems of a data centre. This is because they are often changed with the servers, well before the building systems.

As the rack configurations are repetitive, there is an opportunity to consider standardisation so that racks could be adapted and reused when servers are changed. This will require agreement across the industry – something that may be difficult to accomplish.

MEP equipment

Numerous, repetitive units such as fan coil assemblies (FCA), dry air coolers (DAC) and water-cooled chillers can make up a high proportion of the MEP carbon footprint. At the same time, electrical equipment like generators, transformers, switchgear, and uninterruptable power supplies (UPS) contribute substantial amounts of embodied carbon because of their size.

Many clients are exploring take-back programmes with their vendors and end-of-life recovery schemes. Some are also exploring alternative procurement strategies, such as plant leasing, which can help to prolong plant life. Both strategies will require engagement with vendors.

Build for long-term use

Keep assets at highest value as long as possible

Cooling system

Direct expansion (DX) refrigeration plants tend to have a shorter life span than water-based plants and require more frequent replacement. If water can be used instead of refrigerant based cooling, this would reduce both refrigerant volumes and the amount of refrigerant piping. Fewer replacements would cut carbon during the operational phase. And removing refrigerant plant would remove associated refrigerant from the site.

Batteries

Environmental conditions are crucial for batteries. If they are in less than ideal (warmer) conditions, they will need replacing prematurely.

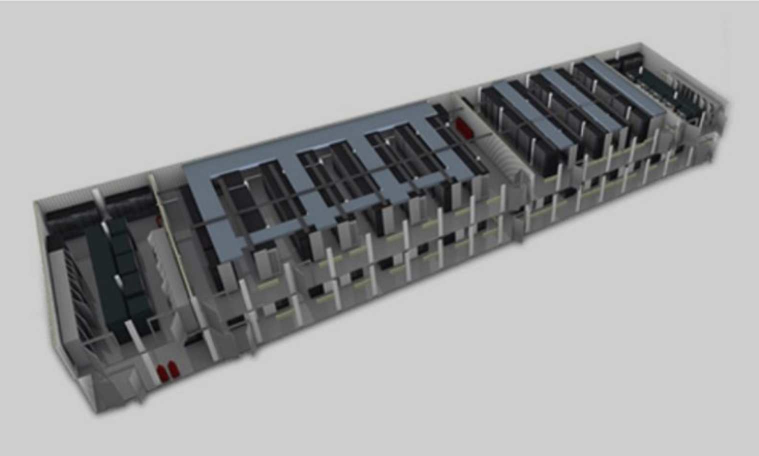
One of our studies showed that even creating a dedicated room with specific cooling lowered whole life carbon, because the battery system needed replacing less frequently.

Enhanced maintenance

Plant replacement cycles are a key determinant of whole life carbon for MEP services. Extending the longevity of equipment through enhanced maintenance regimes and housing it in manufacturer-recommended environmental conditions can extend its operational life so that it doesn't need replacing as often.

Build efficiently

Increase material efficiency



Column grid model

We were recently able to show a 35% reduction in superstructure carbon by reducing the slab span.

Structural column grid

Large clear spans in data halls help to maximise flexibility and rack count. But fine-tuning column spacing and shortening clear spans in areas where long spans are less essential can significantly reduce steel tonnage, cutting embodied carbon.

Aligning the grid with the façade and roof enables a more efficient structural solution, reducing secondary cladding and roofing support. Shorter spans carrying lighter loads also allow for sustainably sourced timber or alternative systems that lower embodied carbon.

Prefabrication

Data centre construction is already exploring prefabrication, perhaps the most common structural approach in Europe, as a way to compress construction schedules. It can nearly eliminate construction waste: offcuts that would have been produced at the site and gone to landfill are more likely to re-enter the raw material stream because they have not been contaminated. It may also be possible to use less material because fabrication in controlled environments allows for greater precision. The materials themselves may incur greater carbon emissions per kg though, as is often the case with precast compared to in situ concrete, for example. So comparisons should be made on the basis of functional equivalence, such as CO_2e per unit of wall or floor area or per MW capacity of the data hall.

Secondary steel / services support systems

Multi-trade racks to support cabling, conduit, piping, and other distribution systems can contribute a substantial portion of embodied carbon.

Options for reducing material use include:

– A cold-aisle-based racking system would provide support for the cold aisle ceiling and simplify the support of the rack services.

– A more flexible racking system with adjustable service support arms that can be more readily adjusted, relocated, and reused as requirements evolve.

– A structure decoupled from the racking layout / cooling system could be more easily adapted as requirements within the space change.

Build efficiently

Focus example: strategies for dematerialisation of duct banks

00. Baseline

Solid precast

Duct banks are among the uses of concrete for hyperscale data centres.

01. Refuse

Direct bury

Where soil conditions and overhead traffic allow, direct bury offers greater carbon savings than other options.

02. Reduce

Trench with lid

Replaces high cement concrete with lower carbon flowable fill between forms.

03. Rethink

Cast in place concrete

Allows the use of higher cement replacement in the concrete resulting in lower carbon across the site.

Build efficiently

Focus example: move rooftop mechanical plant to ground

Re-evaluating fundamental design criteria and building form

Moving rooftop plant to ground level

Moving heavy equipment off the roof can enormously lighten the structure needed at roof level, reducing the materials needed for columns and foundations below.

This change to the data centre layout has been shown to reduce the total embodied carbon of the structure by up to 40%.

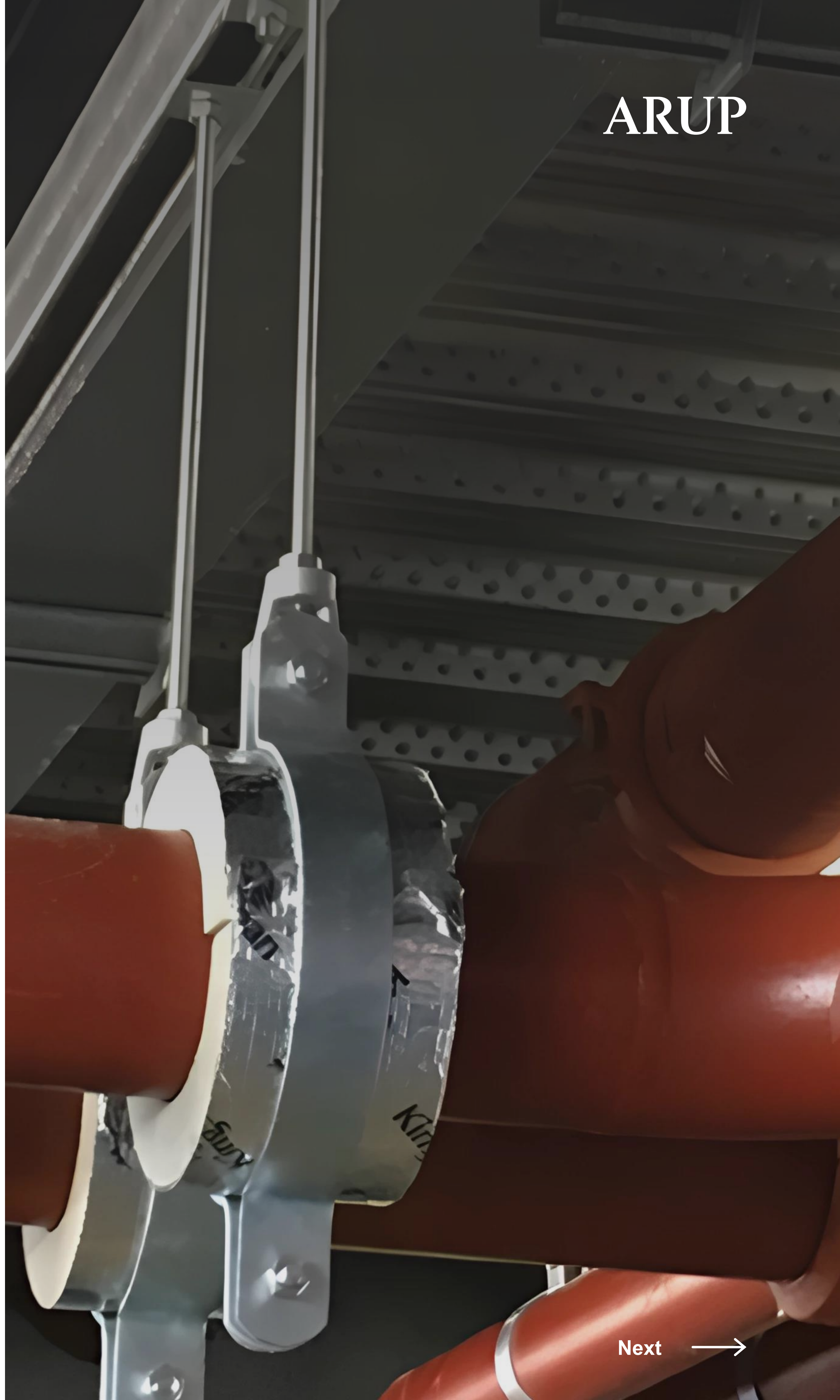
Reducing material in pipework and pipework insulation

As the temperature of chilled water in cooling systems increases, pipes carrying that water are less likely to cause condensation. Designers should check the dew point – the temperature at which condensation happens – to see if insulation in the pipes can be removed. This not only reduces carbon but also costs and programme.

Increasing the temperature difference in the cooling system means less water needs to flow through the pipes. This can enable smaller pipes to be used throughout the building. However, terminal units might need to be larger – so the overall cost savings should be carefully reviewed.

Another consideration is the type of pipes used. Most cooling systems use carbon steel pipes. If the water quality is well-managed, as it often is, designers may be able to use thinner pipes, saving materials and costs.

There may also be an opportunity to work with pipe manufacturers to make recycling easier. Pipes that are bolted together can be taken apart and reused when building layouts change or when the system reaches the end of its life.



Build with the right resources

Decarbonise the most carbon-intensive materials

Concrete

Sourcing lower carbon concrete depends heavily on the materials available locally to the concrete supplier and construction site. Data centre developers can work with their construction partners to use the best available low-carbon mixes tailored for each application, being more aggressive for low-risk areas like ancillary structures and less aggressive in high-risk areas like the data hall floor.

Several hyperscalers have been collaborating to explore novel materials, conduct testing, develop standards, set goals, and accelerate advancement of low-carbon concrete.

Meta’s approach to integrating low-carbon concrete.

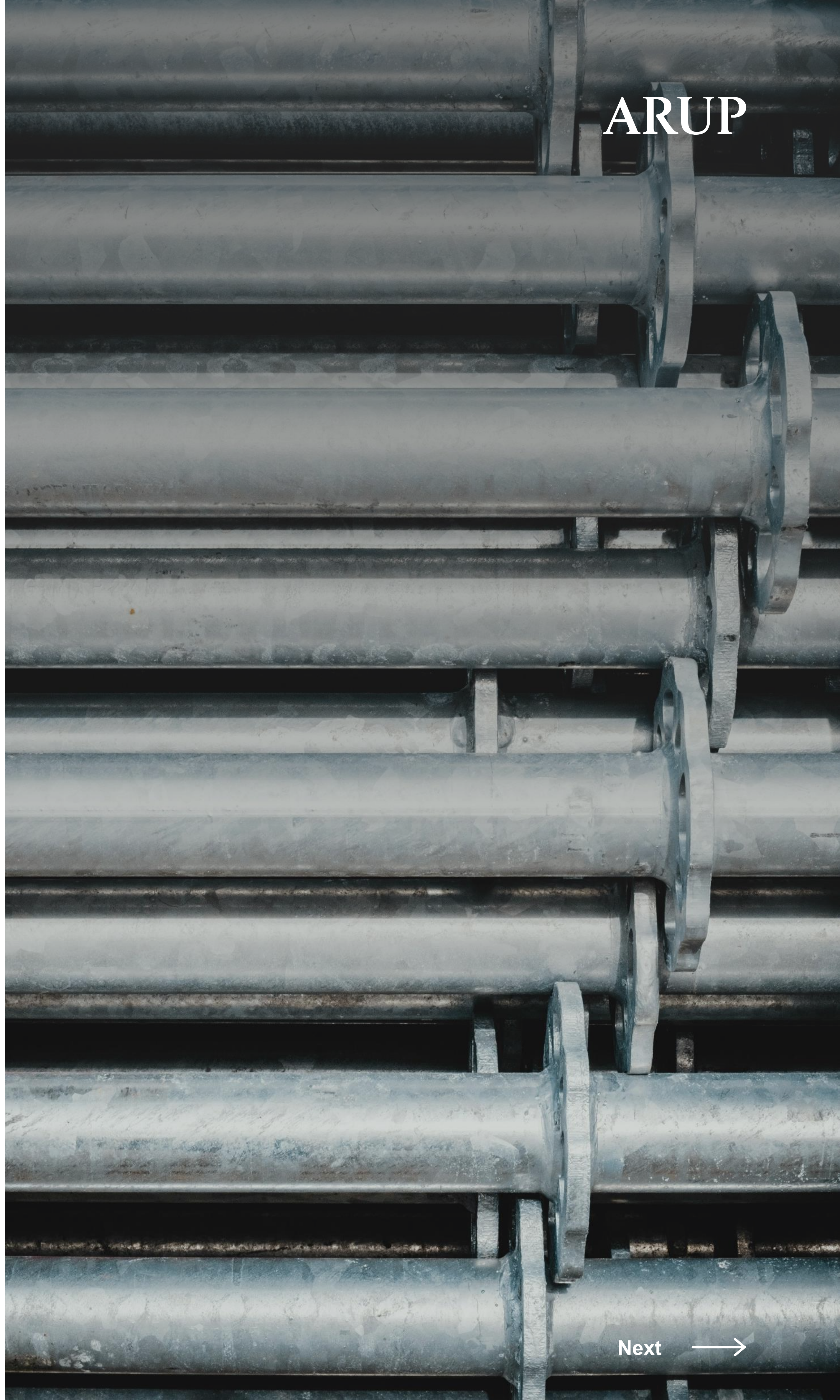
Metals

The vast majority of carbon emissions come from metals embedded in mechanical and electrical equipment, MEP pipework and the superstructure. So decarbonising these primary materials can have a big impact. Data centre developers cannot directly procure low-carbon metals for their electrical and mechanical equipment. But they can use their relationships with preferred vendors to influence decisions in the supply chain.

The first step is asking for greater transparency of the carbon impact of products made primarily of hard-to-abate materials like steel, aluminium and copper.

Reusing structural steel can reduce upfront carbon emissions by up to 97% compared to virgin steel.* Although sourcing suitable reclaimed steel can be challenging, the environmental benefits make a compelling case. Designing with standardised materials and dimensions today will also support greater circularity and material reuse in future construction projects.

*Data based on this EPD and generic UK data for steel beams.



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Build with the right resources

Switch to less carbon-intensive materials

Microsoft

Builds first data centres with wood to slash carbon emissions.

Mass timber

Mass timber can be used as floor and roof decks to replace concrete slabs. Several data centre developers are exploring the use of mass timber for parts of their sites – typically introducing it in the ancillary and administrative areas, or as cladding.

Insulation and hot aisle containment

Insulation offers a wide range of material options. In general, moving from fossil-fuel based insulation to insulation with a high biobased content will reduce embodied carbon, and may even sequester carbon.

Hot aisle containment panels are ubiquitous throughout data halls. Biobased polymers are becoming available that could offer a much lower carbon solution made from renewable resources.

When looking at biobased alternatives, it’s important to consider fire resistance, durability, maintenance, availability, speed of construction, cost, and other performance requirements.

Build with the right resources

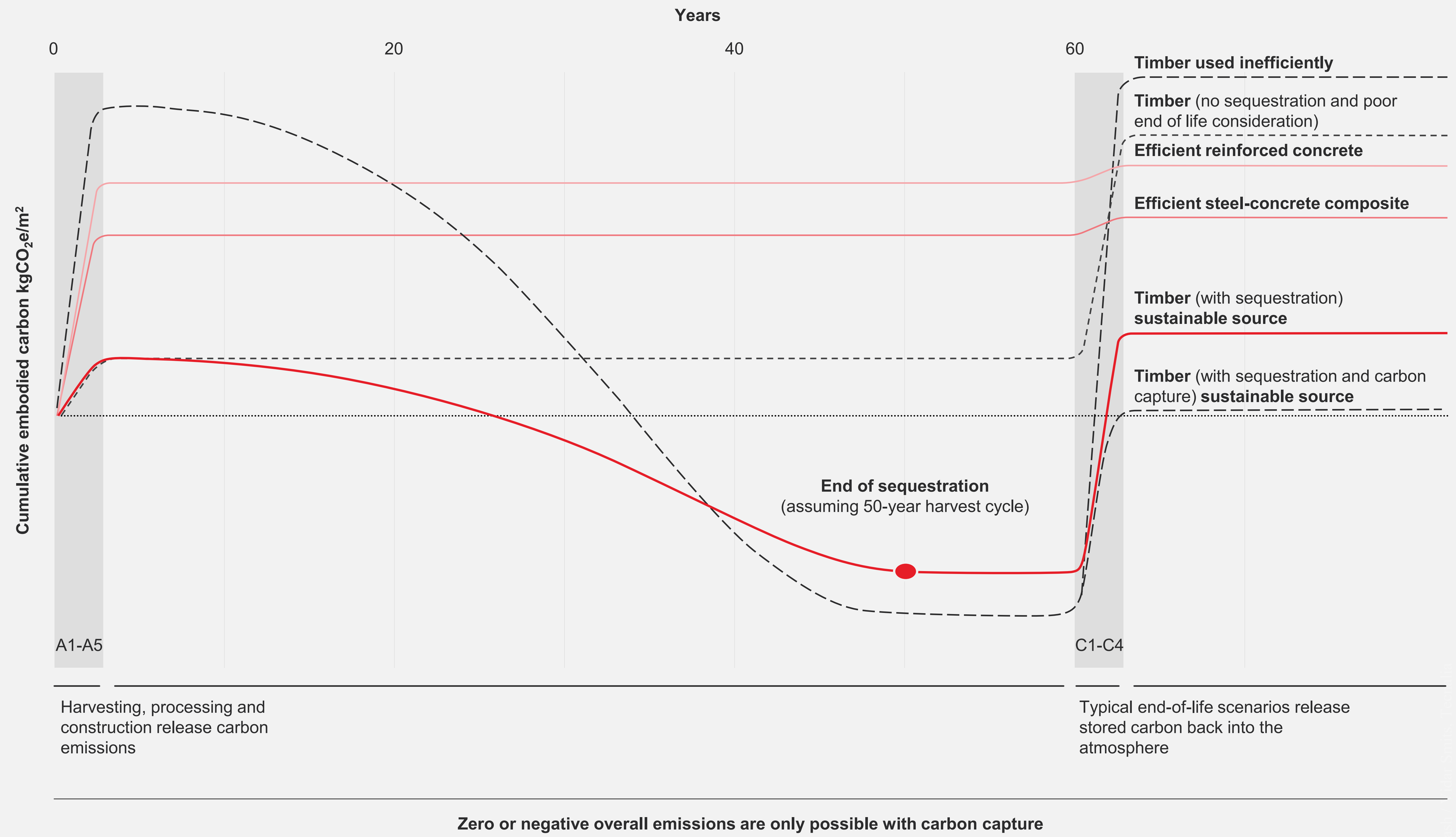
Source biobased materials from lands practising carbon sequestering resource management

Other biobased materials

Using biobased materials instead of fossil-fuel based ones can significantly reduce greenhouse gases and other pollution. These materials can even sequester carbon dioxide as long-term carbon stores until their end of life.

To maintain the carbon-sink function products must be trackable from the source of their raw materials. Data centre developers will need to commit to sourcing biobased materials responsibly, requiring suppliers to provide chain-of-custody-based certification when applicable.

Materials made from crop waste demonstrate how waste from one sector can become a resource to another, one of the best examples of the circular economy in action.



Taking action

How to start your embodied carbon reduction and circularity journey

1 Goal and scope

Conduct baseline WLCAs and develop client-specific guidance for consistency. Obtain product-specific Environmental Product Declaration (EPD) for best accuracy.

Key steps

+ Identify data requirements
+ Develop data collection procedure, quality checks and iterations
+ Compile and review data (e.g. supplier engagement)
+ Include CSA, MEP and fit-out items (if applicable)

2 Undertake assessments

Identify hotspots for carbon reduction. Test sensitivity of regional difference.

+ Calculate emissions (whole life carbon assessment)
+ Analyse results and report findings
+ Set targets and pathway
+ Complete third-party verification if relevant

3 Strategise

Identify reduction opportunities. Assess impact reduction potential, feasibility and cost. Consult with design and construction teams. Open a dialogue with vendors and supply chain.

+ Deep dive into prioritised hotspots
+ Explore and define carbon reduction opportunities (e.g. circularity)
+ Quantify potential impact of interventions
+ Prioritise measures (carbon vs costs / supply risks)

4 Implementation at scale

Integrate reduction measures into template specifications and drawings. Collect information to fill gaps and improve data quality. Continuously review baseline estimates.

+ Engage with suppliers, reshape requirements
+ Monitor and improve interventions
+ Incorporate baseline requirement in reference designs

5 Report

Feed into annual greenhouse gas reporting. Actively share results across industry, stakeholders, supply chain and peers.

+ Raise awareness with data consumers, corporates and citizens
+ Carry out training and organisational transformation
+ Initiate a global programme with localised solutions

Acknowledgments

This report is the result of a collaborative effort by a dedicated group of experts committed to advancing circularity in the data centre industry.

To all the contributors and reviewers: thank you for your invaluable insights, technical contributions, and thoughtful reviews.

Your collective expertise has shaped a comprehensive and forward-looking perspective on how circular design strategies can cut whole life carbon in data centres.

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