

From energy efficiency to resource efficiency

Advancing the circular economy in lighting

September 2026

Prepared by Academics for Circular Economy e.V. and the Circular Economy and Sustainability Lab, University of Oxford.

Funded by Signify

Foreword

Lighting is undergoing a global transition. Energy-efficiency standards and restrictions on hazardous substances are phasing inefficient and mercury-containing technologies out of regulated markets. LEDs deliver more light with less electricity and enable responsive control. This first wave has produced substantial energy savings. A second is now beginning as legacy stock remains in use, early LEDs approach the end of life and connected systems become more widely available.

The next challenge lies behind the light itself. A luminaire sits within a wider installation of metals, plastics, glass, electronics, controls, cables and mounting systems; some applications also include batteries and solar equipment. Some materials account for most of the mass and embodied impact. Others appear only in small quantities but are essential to semiconductor, phosphor or control functions and depend on concentrated supply chains.

Rapid technological change can lead organisations to replace whole installations, discarding functioning components, valuable materials and remaining asset value.

This report examines how business and public-sector users can retain that value while improving lighting performance. It explains when to maintain, repair, retrofit, upgrade, reuse, remanufacture or replace, and how information, service relationships, procurement and return systems can support those choices. The transition to a more circular approach aims to deliver the required lighting service with less energy and fewer virgin resources, while extending asset life and creating credible routes for products and components to be used again.

Executive summary

Since the early 2000s, LEDs have moved from a niche technology to the dominant form of new lighting in many markets. Adoption is now widespread but varies considerably by region. One forecast values the global LED market at US\$78.7 billion in 2026.

Lower operating costs, environmental benefits and policy incentives have driven LED adoption. LEDs can use up to ten times less electricity to provide the same lighting service. In the cited life-cycle assessment, operational energy accounts for about 96% of a luminaire's fossil global-warming potential. Regulations have set minimum performance standards, while smart controls can reduce demand by adjusting light to daylight, occupancy and the needs of the space.

Energy efficiency alone cannot eliminate lighting's environmental footprint. As operational energy use falls, production and end-of-use impacts account for a larger share. The next phase of the transition must combine continued energy savings with lower material demand, longer product life and upgradeability. Components and materials should remain at their highest useful value when this produces the best whole-life environmental and economic outcome. Total impact still depends on how many products are installed, how intensively and how long they are used, and how they are treated at the end of use.

Circular strategies can support this shift while delivering environmental and business benefits.

- **Chapter 1** explains how technological development and stricter efficiency regulation are driving replacement and adoption, including in previously underserved markets.
- **Chapter 2** examines the remaining resource impacts of production and how retaining components and materials at their highest useful value can reduce them.
- **Chapter 3** provides a decision process to guide users towards circular lighting systems.
- **Chapter 4** draws on 50 business cases across several countries to show how circular strategies can deliver environmental and commercial outcomes.
- **Chapter 5** identifies the business, policy, technology and market conditions needed to scale circular lighting.

About this report

This report was prepared by Lucas Tzemos Meneguim, Paniz Baradaran Kazemian, Alessio Landi, Richard Asante and Mrinali Kakamare of Academics for Circular Economy e.V., and Priya Saikumar and Lucia Corsini of the Circular Economy and Sustainability Lab, Department of Engineering Science, University of Oxford.

The underlying research methods, datasets and supporting evidence are available through the project repository.

This report was funded by Signify.

Suggested citation: Meneguim, L. T., Kazemian, P. B., Saikumar, P., Landi, A., Asante, R., Kakamare, M., & Corsini, L. (2026). From energy efficiency to resource efficiency: Advancing the circular economy in lighting. Academics for Circular Economy e.V. and the Circular Economy and Sustainability Lab, Department of Engineering Science, University of Oxford. <https://doi.org/10.25446/oxford.34695042>

Table of contents

Foreword	2
Executive summary	3
About this report	4
Chapter 1 - The lighting transition is underway	7
The first wave of the LED transition	8
LEDs enable a substantial reduction in electricity per lumen	8
LED technology changes what lighting can do	9
Policy is raising the performance floor	9
The market is entering a second wave	11
Chapter 2 - Beyond energy efficiency in lighting	13
The resource challenge behind lighting	14
Different materials, different risks	14
Retaining value through circularity in lighting	16
Chapter 3 - Choosing the right circular pathway	18
Circularity is a continuous context-dependent process	19
Three priorities and ten steps towards circular lighting	19
Priority I: Clarify existing assets	20
Priority II: Define lighting needs and demand	22
Priority III: Choose tailored circular solutions	23
Chapter 4 - How circular choices can strengthen the lighting investment case	26
Circularity helps strengthen the business case in six ways	27
Comparing project value across circular and replacement options	29
Retaining assets can reduce the need for new investment	29
Circularity can shorten the time needed to recover an investment	30
A buying guide to navigating circular decisions	31
Chapter 5 - Making circular lighting mainstream	34
Seven intervention points	35
From niche pilots to standard practice	37
The next lighting transition: go circular	38
Endnotes & references	39
Research materials	39
Selected references	39



CHAPTER 1

The lighting transition is underway

Since the early 2000s, LEDs have become the dominant form of new lighting in many markets, and they are now used in an estimated 70% of buildings worldwide. In this chapter, the drivers of that first wave are reviewed, including technological development and stricter efficiency and hazardous-substance regulation. Readers are shown what the transition has achieved in energy terms and how policy attention is being extended from energy use to the full product lifecycle. Readers are thereby equipped to understand why early-generation LEDs, which are now reaching the end of their useful lives, mark the beginning of a second wave of replacement and upgrading.

Advice

- Lighting experts may skip to Chapter 2.

Lighting is undergoing a large, policy-supported technology transition. It is becoming more energy-efficient, controllable and increasingly smart, while creating a second wave of replacement and upgrades.

The first wave of the LED transition

Since the early 2000s, LEDs have moved from a niche technology to the dominant form of new lighting in many markets. An estimated 70% of buildings worldwide use LEDs in 2026. The IEA reports market shares above 85% in China and 75% in India. Europe and North America are around 75%, while sales shares across much of Africa, Southeast Asia and Latin America range from 50% to 85%. The large majority of LEDs is used for residential purposes (80%), and the remaining for commercial use (20%), driven by distinct replacement habits. One forecast values global investment in LEDs at US\$118.4 billion by the end of 2029.

Lower operating costs and policy incentives have driven the widespread adoption of LEDs. Despite their higher upfront cost, LEDs can use up to 10 times less energy to provide the same lighting, making them less resource-intensive and more cost-effective over their lifetime. Advances in digital technology and smart controls can further reduce consumption by responding to the characteristics of the space, available daylight and user needs. Regulatory frameworks have also encouraged LED adoption and set minimum performance standards.

The following subsections examine what this transition has delivered, why LEDs made it possible, and how policy is extending its focus from energy efficiency to the full product lifecycle.

LEDs enable a substantial reduction in electricity per lumen

The energy outcome is substantial. The IEA estimates that a typical halogen lamp produces about 20 lumens per watt, a compact fluorescent lamp about 50, and LEDs sold today close to 100. The most efficient commercially available LED products, mainly in the professional segment, reach around 230 lumens per watt, although these products represent a small part of the market. Typical products, including consumer models, perform at lower consumptions. Signify estimates that efficient and connected LED lighting could deliver annual global savings of 1,550 TWh of electricity, €196 billion in energy costs and 647 MtCO₂e of avoided emissions. Combined indoor lighting demand in buildings would have been around 70% higher, even as global built floor area expanded by more than 20%.

United States modelling attributes about 185 billion kWh of annual electricity savings, 79 MtCO₂e of avoided emissions and more than US\$20 billion in avoided energy costs to LED adoption. As energy per unit of light falls, the strategic focus must expand to the products and installations that deliver it.

LED technology changes what lighting can do

LEDs have changed the energy equation and made lighting more efficient by offering instant switching, dimming, precise optical control, compact size and long useful life. They offer instant switching, dimming, precise optical control, compact size and long useful life, allowing them to serve homes, offices, factories, streets, healthcare, horticulture, transport, shops, hospitality, schools, warehouses, tunnels, parks, plazas and specialist applications. Smart controls and artificial intelligence can extend these gains from the light source to the entire system. Occupancy sensing, daylight harvesting, schedules, task tuning and adaptive operation can reduce output when full illumination is unnecessary.

Retrofit studies report reductions in lighting energy use of about 40% to 80%, depending on the application, thanks to controls. In one university building, occupancy sensing increased energy savings from 50.1% to 59.8%. A meta-analysis of field studies found average savings of about 24% to 36% for individual control strategies and 38% when strategies were combined. Smart and connected systems can also support fault detection, maintenance planning and asset visibility. These benefits depend on effective commissioning, interoperability, cybersecurity, software support and the continued availability of compatible components.

Policy is raising the performance floor

Alongside technological development, regulation has driven the transition to efficient lighting. The EU Ecodesign Regulation sets minimum energy-efficiency requirements for lighting. The global Minamata Convention on Mercury and the European Union's RoHS Directive restrict or prohibit hazardous substances and certain components. Other measures raise performance thresholds or use procurement and finance to shift demand. Together, these measures require new lighting to be energy-efficient, mercury-free, and capable of meeting higher performance standards. The Minamata Convention phases out specified fluorescent lamps, while the EU WEEE Directive governs electronic waste.

More recent frameworks extend beyond use-phase efficiency to address impacts across the product lifecycle. These policies draw on circular economy principles and seek to retain resource value through reduction, reuse and recycling, subject to environmental and economic outcomes. In Europe, the Eco-design for Sustainable Products Regulation (EU) 2024/1781 introduces requirements that can include component replaceability and material recyclability. Digital Product Passports will provide records of product histories, materials and impacts. The proposed EU Circular Economy Act is expected to build on these measures by supporting a single market for secondary raw materials, more harmonised extended producer responsibility and high-quality material recovery across value chains.

Table 1-1 summarises the main regulations shaping circular lighting, grouped by energy use, design for long life, product information, hazardous substances, the legal status of modified products, end-of-life and waste flows and critical raw materials. For each group, the table lists the main instruments in the EU and other regions and explains their practical implications.

Read from top to bottom, the table shows a shift from minimum efficiency levels, which encourage owners to retrofit or replace, towards requirements for durability, repairability, data, liability and material recovery across the lifecycle. Several instruments remain under development, particularly the lighting rules under ESPR, the European Product Act and the WEEE revision, so their final scope and timing are uncertain.

Table 1-1: Regulations shaping circular lighting, grouped by what they act on

Focus	Main instruments	What it means for circular lighting
Energy use	EU: Ecodesign for light sources and separate control gear (Regulation (EU) 2019/2020) and Energy Labelling (Regulation (EU) 2019/2015). Both are under review and will move under ESPR; new rules are expected after 2029. Outside EU: Minimum efficiency rules in about 110 countries, for example US federal lamp standards and China's GB 30255-2026 for indoor LED products (applies from September 2027).	Sets the minimum efficiency a product must reach to be sold. Older, less efficient products leave the market, which pushes owners to retrofit, upgrade or replace.
Design for long life, repair and upgrade	EU: Ecodesign for Sustainable Products Regulation (ESPR, Regulation (EU) 2024/1781). The current lighting rule already requires light sources and control gear in luminaires to be replaceable. ESPR will add recyclability and recycled-content rules for electrical and electronic products (indicative 2029). Outside EU: Mexico's General Circular Economy Law (2026) asks producers to design for circularity where viable.	Extends requirements from how much energy a product uses to how long it lasts and how easily it can be repaired, upgraded and recycled. This favours products that can be opened, maintained and upgraded in place. Lighting rules under ESPR are expected after 2029; their shape and scope are not yet clear.
Product information (Digital Product Passport)	EU: The Digital Product Passport (DPP) is created by ESPR; each product rule decides what the passport must contain. No lighting passport exists yet; it is expected to come with the new lighting rules. The proposed European Product Act would add a digital record for products that have no passport.	Gives each product a digital record that can hold its materials, substances, spare parts and repair instructions. This is the information repairers, refurbishers, remanufacturers and recyclers need to decide what to do with a product that is already installed.
Hazardous substances	EU: RoHS (Directive 2011/65/EU) and REACH (Regulation (EC) No 1907/2006). EU Mercury Regulation Global: Minamata Convention on Mercury: compact fluorescent lamps phased out by 2025, fluorescent lamps generally by 2027. Outside EU: State bans on fluorescent lamps in the US; RoHS-type laws in China and proposals in Brazil and Vietnam.	Removes mercury-based lighting from the market, so installed fluorescent fittings need a decision: retrofit, upgrade or replace. Prohibits manufacturing, importing and exporting mercury-containing lighting.

Focus	Main instruments	What it means for circular lighting
Legal status of modified products and liability	EU: European Product Act (Commission proposal expected in October 2026), replacing today's framework for placing products on the market and market surveillance. Product Liability Directive (Directive (EU) 2024/2853), applying from December 2026.	Is expected to define when a refurbished or remanufactured luminaire counts as a new product and who is responsible for it. Anyone who substantially modifies a product can be held liable as its manufacturer. Clear rules here lower the risk of remanufacturing and of Lighting-as-a-Service models.
End of life and waste flows	EU: WEEE Directive (2012/19/EU), to be revised through the Circular Economy Act (Commission proposal expected in the second half of 2026). Packaging and Packaging Waste Regulation (Regulation (EU) 2025/40), applying from August 2026. Global: Basel Convention e-waste amendments, in force since January 2025. Outside EU: Producer responsibility schemes, for example under Mexico's General Circular Economy Law.	Producers finance the collection and recycling of lighting products. The WEEE revision is expected to add recycled-content and material-recovery goals. Under Basel, all cross-border shipments of e-waste now need prior consent, and each country decides whether a used luminaire sent for repair counts as waste. This affects refurbishment across borders.
Critical raw materials and supply security	EU: Critical Raw Materials Act (Regulation (EU) 2024/1252) and the RESourceEU action plan (December 2025). Outside EU: China's export controls on gallium and other metals.	Makes materials used in LEDs and electronics, such as gallium and rare earths, a matter of supply security. Keeping products and parts in use and recovering materials at end of life reduces exposure to supply disruptions.

Together, these regulations aim to retain the highest possible material value throughout the product lifecycle. Products must be energy-efficient, designed to meet sustainability requirements, and traceable throughout their lifecycle. Regulation is gradually shifting from individual product specifications towards impacts across the value chain and lighting system.

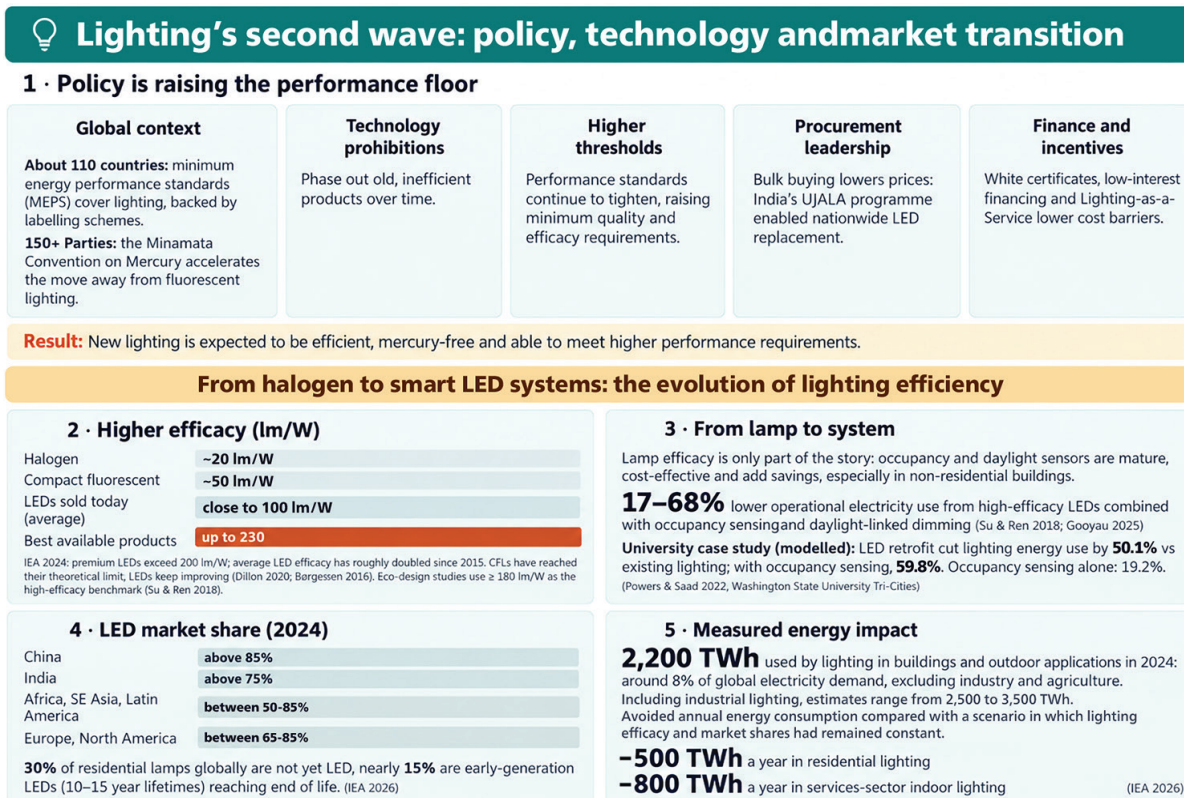
The market is entering a second wave

The first wave of LED adoption has largely addressed energy efficiency by substantially reducing the energy consumed to deliver a unit of light. The focus must now shift to resource efficiency and the circular economy, with the dual challenge of managing waste from existing LED and traditional lighting products while redesigning future products to minimise resource use and waste generation.

Greater use-phase efficiency may reduce the impact of delivering a defined quantity of light, but the overall environmental impact still depends on the number of installed products, their intensity of use, their expected useful life and their end-of-use treatment.

As the market enters a second wave of adoption, providers will need to serve users while managing early-generation LEDs that are reaching the end of their useful lives. This transition creates an opportunity to improve resource efficiency while further increasing the energy savings achieved during the first wave. Circular strategies can reduce resource use and enable products, components and materials to be reused across multiple lifecycles.

Figure 1-1: The global transition to LED lighting: technology, adoption and energy impacts





CHAPTER 2

Beyond energy efficiency in lighting

As energy use during operation falls, a larger share of lighting's environmental impact is accounted for by production and end of use. In this chapter, the luminaire is examined as a layered system of metals, plastics, glass, electronics and controls, whose components differ in lifespan, material composition and recoverability. Readers are shown which materials dominate mass and embodied impact, and which are needed only in small quantities but are exposed to concentrated supply chains. At last, circular economy strategies by which the resource value of assets can be retained are introduced, and their relevance for enhancing resource efficiency is understood.

The resource challenge behind lighting

A product that is more efficient during use may reduce the impact of delivering a defined quantity of light, but its aggregate market impact still depends on the number of installed products, their intensity of use, their expected useful life, their end-of-use treatment and the value-retention strategies available.

The resource impact becomes visible when the system boundary extends from a single light point to the full product lifecycle. A typical LED luminaire contains a driver, printed circuit boards, optics, thermal management, housing, wiring, connectors, controls and mounting hardware. Connected lighting also adds sensors, communications equipment, software and data. The system boundary may extend further. Lighting depends on cables, control panels, ceilings, tracks, building management systems and the layout of the space. Off-grid systems may also include batteries, solar modules and communications infrastructure.

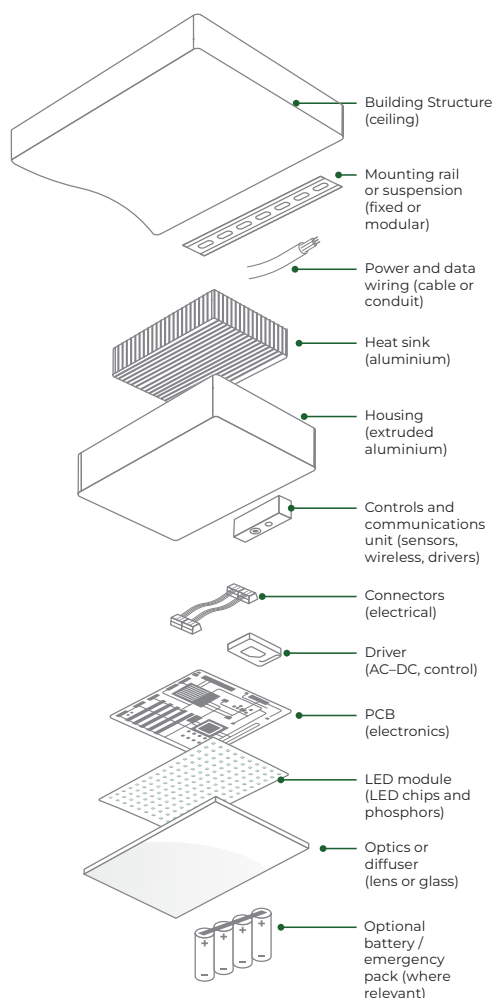
This broader view shows that lighting is a layered system whose components differ in lifespan, material composition and recoverability. The following subsections examine the materials that carry the greatest risks, then outline circular strategies for retaining the value of these assets across product lifecycles.

Different materials, different risks

Materials used in lighting have different impacts and require different retention strategies during and after use. **Figure 2-1** maps the components of a luminaire to the different material types, showing that supply is concentrated in a few countries and that lighting demand is small compared with competing sectors.

Aluminium, steel, copper, plastics and glass can account for most of a product's mass. In a 23.58 kg modular office fixture studied by Lakdawala and Mair (2025), aluminium, steel and copper represented about 89% of the material mass and associated embodied carbon. Aluminium alone represented about 60% of the mass and 71% of cradle-to-gate emissions. A smaller 42 W luminaire studied also contained a large aluminium body, copper wiring, a polycarbonate diffuser, electronics, coatings and fasteners. Product architecture and application can therefore change the bill of materials considerably.

Figure 2-1: Material footprint and hotspot of lighting system



Central working scenario



1.0 billion luminaires per year



5 kg average mass



5.0 Mt annual luminaire mass

Working scenario, not a forecast. Central model assumes 1.0 billion luminaires per year, 5 kg average mass, and 5.0 Mt annual luminaire mass.

Definitions

Critical materials have high economic importance and supply risk under the EU methodology.

Strategic materials matter for strategic technologies, projected demand growth, and resilience.

Toxic refers to hazardous or controlled handling concerns and is not the same as criticality.

Wider global demand

The source material does not provide robust, comparable numeric estimates for wider global demand across sectors. This column is therefore shown qualitatively as competition context, not as a single commensurate value.

Material	Critical	Strategic	Toxic	Other sectoral pressures	Implications for lighting
Aluminium	✓	✓	–	Construction, transport, packaging	Aluminium creates one of the largest mass exposures in lighting. Circular strategies should retain housings and heat sinks, increase recycled content, and avoid alloy contamination.
Iron	–	–	–	Construction, vehicles, machinery	Iron underpins poles, cabinets, brackets, and structural parts. Lighting should prioritise retaining these high-mass assets and keeping ferrous recycling streams clean.
Copper	✓	✓	–	Grids, EVs, renewables	Copper is essential for wiring, coils, connectors, and printed circuit boards. Lighting should preserve cables where safe and recover clean conductor fractions.
Silicon	✓	✓	–	Solar PV, semiconductors	Silicon links lighting electronics to wider semiconductor and solar supply chains. Design should prioritise long component life and recovery from electronic assemblies.
Gallium	✓	✓	–	RF and 5G, power electronics	Gallium is used in LED semiconductor layers and comes with extreme supply concentration. Lighting should reduce manufacturing loss and retain LED modules where possible.
Indium	–	–	–	Displays, ITO, thin-film PV	Indium appears in trace quantities and is difficult to recover. Lighting should preserve electronic assemblies and aggregate high-grade fractions through specialist treatment.
Yttrium	✓	–	–	Magnets, EVs, wind	Yttrium supports phosphor chemistry in lighting. Circular approaches should avoid dissipation and aggregate relevant phosphor-bearing fractions where recovery is viable.
Cerium	✓	–	–	Magnets, EVs, wind	Cerium supports phosphor performance in LED lighting. Circular strategies should avoid dissipating these small but functionally important material flows.
Europium	✓	–	–	Magnets, EVs, wind	Europium is used in phosphor systems that support colour quality. Lighting should aggregate relevant fractions by chemistry where recovery is feasible.
Terbium	✓	–	–	Magnets, EVs, wind	Terbium is used in phosphor systems and matters despite very small volumes. Lighting should avoid material dissipation and support specialist recovery where scale exists.
Gadolinium	✓	–	–	Magnets, EVs, wind	Gadolinium appears in selected phosphor chemistries and reflects wider rare-earth concentration risks. Circularity should focus on retention and aggregation rather than dilution.
Lanthanum	✓	–	–	Magnets, EVs, wind	Lanthanum appears in selected phosphor chemistries and lighting depends on concentrated rare-earth processing. Recovery only becomes meaningful when relevant fractions are kept together.
Lithium	✓	✓	–	EVs, grid storage, consumer electronics	Lithium matters most where lighting systems include batteries. These batteries should be maintained and replaced separately, with dedicated collection and treatment.
Nickel	–	✓	–	EVs, grid storage, consumer electronics	Nickel exposure arises mainly in battery-backed lighting systems. Circular strategies should treat batteries as separate assets rather than as generic luminaire waste.
Cobalt	✓	✓	–	EVs, grid storage, consumer electronics	Cobalt becomes relevant where lighting systems rely on rechargeable batteries. Battery management, take-back, and specialist recycling are therefore important.
Manganese	–	✓	–	EVs, grid storage, consumer electronics	Manganese is mainly relevant through battery chemistries in emergency or off-grid lighting. Circularity should address the battery separately from the wider installation.
Lead	–	–	✓	Batteries, industrial storage, vehicles	Lead introduces a clear toxicity issue where lead-acid batteries are used. Any circular strategy must manage these batteries separately through controlled collection and recycling.

Other materials occur in much smaller quantities but can have a disproportionate environmental impact or create supply dependencies when total demand is considered. Concentrated supply chains expose production to price shocks and geopolitical tension. The EU Critical Raw Materials Act distinguishes critical materials, which face high economy-wide supply risk, from a smaller set of strategic materials needed for green, digital, defence and aerospace technologies. Several materials used in lighting appear on both lists: aluminium, including bauxite and alumina, copper, gallium, germanium, silicon metal and platinum group metals. Light and heavy rare earths are classed as critical, but only those used in permanent magnets are strategic, so phosphors in lighting do not automatically fall into the strategic category. Indium, gold, silver, tin, zinc, steel, glass and common plastics are on neither list, although they may still be economically important, price-volatile, high-impact or difficult to recover.

Quantities per light point can be very small, but total volumes can still create material demand at scale. A thin-film gallium nitride die contains roughly 7 micrograms of gallium per square millimetre and an estimated 0.05 to 0.20 micrograms of indium. Across 100 billion one-square-millimetre dies, this amounts to about 700 kg of gallium and 5 to 20 kg of indium in finished chips. Upstream manufacturing losses add further demand.

Table 2-1 presents the materials contained inside a representative LED luminaire, the location of materials, functional roles and their respective quantities.

Table 2-1 Materials contained in representative LED luminaire

Materials	Component location	Functional role	Specific concentrations / quantities
Gallium (Ga)	Semiconductors die & PCB	Blue emission (InGaN) & substrates	0.234 wt% in LED waste; 1.69 wt% in isolated chips
Indium (In)	LED die & transparent contacts	InGaN active layer & ITO electrodes	273 kg total across 2.6 Mt EU waste; trace dopant
Yttrium (Y)	Phosphor encapsulant	YAG:Ce yellow light conversion host	Up to 5.41 wt% in separated phosphor/chip fractions
Cerium (Ce)	Phosphor encapsulant	Activator ion in garnet matrix	91 kg per 2.6 Mt EU waste; concentrated in warm white
Gold (Au)	Wire bonds & contacts	Interconnects and corrosion resistance	1,204–1,550 mg/kg in SMD/COB packages; 0.03 wt% of e-waste

¹ Study conducted by Albu and colleagues

Retaining value through circularity in lighting

Resource efficiency concerns how a required lighting outcome can be delivered with the least energy, virgin material, hazardous input and loss of asset value over time. It seeks to minimise resource-value loss across product lifecycles.

Circular economy strategies provide practical ways to reduce resource use by: (1) avoiding unnecessary products or consumption; (2) reducing the resources required to deliver a lighting service over time; or (3) reusing products, components and materials across multiple lifecycles. These approaches include:

- **Refuse:** deliberately reduce unnecessary demand for lighting or materials before consumption occurs.
- **Direct reuse:** redeploy a product where it can meet functional requirements without substantial modification.
- **Maintain and repair:** maintenance keeps a product in good condition, extend useful life by preventing avoidable damage, and preserve options for later refurbishment or remanufacturing; repairing follows a failure.
- **Refurbishment:** the product is inspected, cleaned, serviced and where necessary repaired, and it is given a new statement of expected remaining lifetime.
- **Retrofit and upgrade:** improve a product rather than simply restore it, for example by enhancing energy efficiency, reducing energy consumption, improving lighting output, or increasing overall performance.
- **Remanufacture:** disassemble, keep the core and rebuild a product to an equivalent-to-new standard.
- **Recycle:** recover materials from products at the end of use and process them into secondary raw materials for new products or components. In lighting, this typically means collecting luminaires and lamps through WEEE schemes, separating them into material fractions such as metals, glass, plastics and electronics and recovering critical raw materials where technically and economically feasible.

These strategies are particularly relevant to LED lighting because the lifetime of a light source does not necessarily determine the lifetime of the wider system. LED packages gradually lose light output, while drivers and other electronic components can fail. A small component failure can lead to replacement of the entire luminaire if the failed part is inaccessible or difficult to repair, or the replacement is unavailable or incompatible. A functioning installation may also be removed during renovation or when requirements change, for example because of new expectations for controls, connectivity, light quality or energy performance.

The potential to retain resources is significant. A modelling study by Factory Lux estimated material and embodied-carbon savings of 27% to 45% under assumed component-reuse rates. Case studies also report avoided product recalls and reuse of existing fittings with new LED gear trays and drivers. These results are not yet generalisable, but they show why the analysis must include the installation as well as the light source.

The aim is to select, for each asset, the strategy that preserves the greatest useful value while meeting performance requirements and avoiding unnecessary environmental impact. This requires considering both production inputs and the expected product lifetime.

Chapter 3 explains how users can select the most suitable option based on existing assets, their value-retention potential and the functional requirements of the new lighting system.



CHAPTER 3

Choosing the right circular pathway

The appropriate treatment of an existing lighting installation is determined by its condition, its functional requirements and its context. In this chapter, a framework of three priorities and ten steps is presented, through which existing assets are mapped, lighting needs are defined, and solutions, ownership models and maintenance arrangements are selected. A rule of thumb, known as the circular compass, is also introduced. Readers are enabled to match the condition and performance of each asset to a suitable intervention, ranging from maintenance and repair to retrofit, remanufacture or recycling.

AI

Circularity is a continuous context-dependent process

Circular lighting can apply to existing assets in renovation projects or to new systems in construction projects. The appropriate pathway depends on the installation context rather than a fixed sequence or product label.

Numerous technical options can make circular lighting difficult to implement. The framework in **Table 3-1** guides decision makers and business users towards choices that maximise asset value and minimise use-phase energy consumption. It sets out three priorities, a ten-step decision process and guiding questions for selecting an appropriate circular pathway.

Three priorities and ten steps towards circular lighting

The ten steps range from product-level decisions about value-retention potential and product characteristics to sufficiency, ownership and maintenance. Maximising resource gains requires coordinated decisions across the organisation.

Advice

Renovation projects should start with **Priority I**.

Construction projects may start with **Priority II**.

Table 3-1: Priorities and steps to reach circularity in Lighting

Priority	Decision / Step	Guiding Question
I. Clarify existing assets	Start here for a renovation project.	
	Step 1: Map existing lighting assets	1.1 What are the resource characteristics of existing assets? 1.2 What are the product functionalities of existing assets?
	Step 2: Determine the resource and functional value-retention potential of existing assets	2.2 Are existing assets suitable for value-retention activities? If so, which intervention offers the greatest potential? 2.2 What can be achieved under each option? 2.3 What are the economic and environmental costs associated with these processes?
	Step 3: Determine the end-of-life treatment of discarded lighting	3.1 How can discarded lighting be processed to maximise the net economic and environmental outcomes while considering its trade-offs?

Priority	Decision / Step	Guiding Question
II. Define needs before selecting solutions	Start here for a construction project.	
	Step 4: Map lighting needs	4.1 What are the required resource characteristics of the new lighting system? 4.2 What are the required product functionalities of the new lighting system?
	Step 5: Consider self-sufficiency strategies	5.1 Does the project require as many lighting points, the same intensity and the same hours of use? 5.2 Could utilisation be reduced without compromising the lighting requirements of the space?
	Step 6: Conduct a gap analysis	6.1 Which requirements can existing assets fulfil and which require new products or services?
III. Choose tailored circular solutions	Step 7: Optimise lighting demand through smart systems	7.1 How can smart systems optimise the number of lighting units, illumination intensity and hours of use?
	Step 8: Look beyond initial cost. Consider product design and lifecycle support	8.1 Which available products have design features that retain value and how do their environmental and economic costs and benefits compare? 8.2 How does the total cost of ownership of circular lighting products compare with that of conventional alternatives over their expected service life?
	Step 9: Select the ownership model: Lighting as a Service (LaaS) or ownership	9.1 Considering initial investments, total cost-of-ownership and maintenance costs, which option delivers the highest business and environmental value?
	Step 10: Ensure proactive maintenance throughout the products' useful life	10.1 How can installed assets receive adequate maintenance and processing during and after their useful life and who will provide that support?

Priority I: Clarify existing assets

Before purchasing products or services, an organisation should understand the material and functional value of its existing assets. The first priority is to establish a baseline of current functions and resources before deciding what to retain, replace or acquire.

The guiding question in **Table 3-1** supports this assessment and helps prevent the retention of unsuitable assets. Answering these questions shows whether and to what extent existing assets can meet the new requirements of the space.

Step 1. Map existing lighting

An asset map provides a reliable record of installed lighting for comparison with future needs. It should cover luminaires, modules, drivers, controls, sensors,

software, wiring, tracks, poles, cabinets, batteries and other supporting assets. For each asset, the map should document resource characteristics and product functionality:

- Resource characteristics include age, condition, material composition, expected remaining life, compatibility, energy use, maintenance history, ownership and the reason for removal.
- Product functions include illumination, distribution, glare, colour quality, spectrum, availability, safety, controls, operating hours and resilience.

Asset mapping requires continuous documentation of product features, installation details and changes throughout the product's useful life. Connected systems and service tags can make this information easier to maintain.

Step 2. Determine the resource value-retention potential of existing assets

The next step is to assess how much of each asset's resource and functional value can be retained. The circular interventions described in Chapter 2 should be evaluated against the following dimensions:

- Product functions and components that can be retained.
- Remaining useful life after the intervention.
- Ability of the retained product to meet the new lighting requirements.

Asset mapping should be followed by an assessment of whether value-retention activities are technically and economically feasible. The answer depends on the condition of the asset, the organisation's intended use and the required lighting performance.

For each circular intervention, the assessment should consider product functionality, remaining useful life, and whether the retained product meets the new lighting requirements. It should also account for the new products and materials avoided by retaining an existing asset. Users should aim to retain the highest useful resource value because greater retention can reduce the footprint of consumption.

A lifecycle evaluation of each option's environmental and economic outcomes should inform the final decision.

Step 3. Determine the end-of-life treatment of discarded lighting

Retaining existing products does not always produce a better whole-life outcome than replacing them. Products that cannot meet the new functional requirements should enter an appropriate end-of-life route that maximises economic value and material recovery. In making this decision, it is important to consider the trade-offs associated with each option. Scrapping a product tends to be the lowest-cost solution but retains the least resource value. This step is also inherently linked to maintenance decisions during the product's useful life (Step 10), as adequate maintenance and documentation directly influence which value-retention options remain feasible and the level of resource value they can preserve.

Priority II: Define lighting needs and demand

Priority II requires a careful analysis of lighting needs before circular solutions are selected. It covers functional requirements and sufficiency strategies that can reduce resource and energy demand.

Step 4. Map lighting needs

This step defines the functional requirements of the new lighting system. It also identifies desired resource characteristics, which can be refined after available market offerings have been assessed.

Step 5. Consider sufficiency strategies

Reducing absolute resource demand can deliver greater benefits than improving recycling alone. Organisations should identify opportunities to reduce the number of lighting points, lighting output and hours of use. Sufficiency may also require changes to business processes and physical spaces, such as maximising natural light. Controls and connected functionalities can do this work during the use phase.

Sufficiency can improve resource and energy efficiency with relatively little implementation complexity. Although presented as one step, it should remain a continuing principle throughout the decision process.

Step 6. Conduct a gap analysis

A gap analysis compares existing assets with the new functional requirements. It shows which assets and functions can be retained and which requirements need another solution. **Table 3-2** provides a practical rule of thumb for choosing an intervention.

Table 3-2: Circular compass providing a rule of thumb for assessing the value-retention potential of lighting assets.

Asset condition	Still meets functional and environmental requirements	Does not meet requirements
Good, serviceable	Keep and maintain	Consider retrofit, upgrade or reuse elsewhere
Partly degraded	Repair or refurbish	Remanufacture or retrofit if the housing is reusable
End of life or obsolete	Replace like for like with a circular-ready product	Recycle

Priority III: Choose tailored circular solutions

After clarifying existing assets and the functional requirements of the new system, Priority III selects circular solutions that maximise both business and resource value.

Step 7. Optimise lighting demand through smart systems

Smart lighting systems can maintain or improve functionality while reducing the number of lighting points, illumination intensity and hours of use. Automatic dimming, for example, can adjust illumination according to occupancy, purpose, daylight availability and time of day.

Smart systems can also limit rebound effects so that efficiency gains produce an absolute reduction in energy use. Their potential is moderate to high, especially in large installations, and they may be added without fundamentally changing the existing lighting system.

Step 8. Look beyond initial cost and consider product design and lifecycle support

Product design is an important criteria when buying a new product and determines how much value can be retained at the end of use. Three features should be considered:

- **Modular, compatible and interoperable:** components are replaceable and upgradeable across product generations.
- **Durable with lifecycle support:** products are designed for a long service life and are supported throughout use.
- **Designed for disassembly and value recovery:** products can be disassembled after use, enabling the highest practicable resource value to be retained within technical and regulatory constraints.

Together with effective maintenance, these design features can extend product life and increase value-retention potential.

Step 9. Select the ownership model: Lighting as a Service (LaaS) or ownership

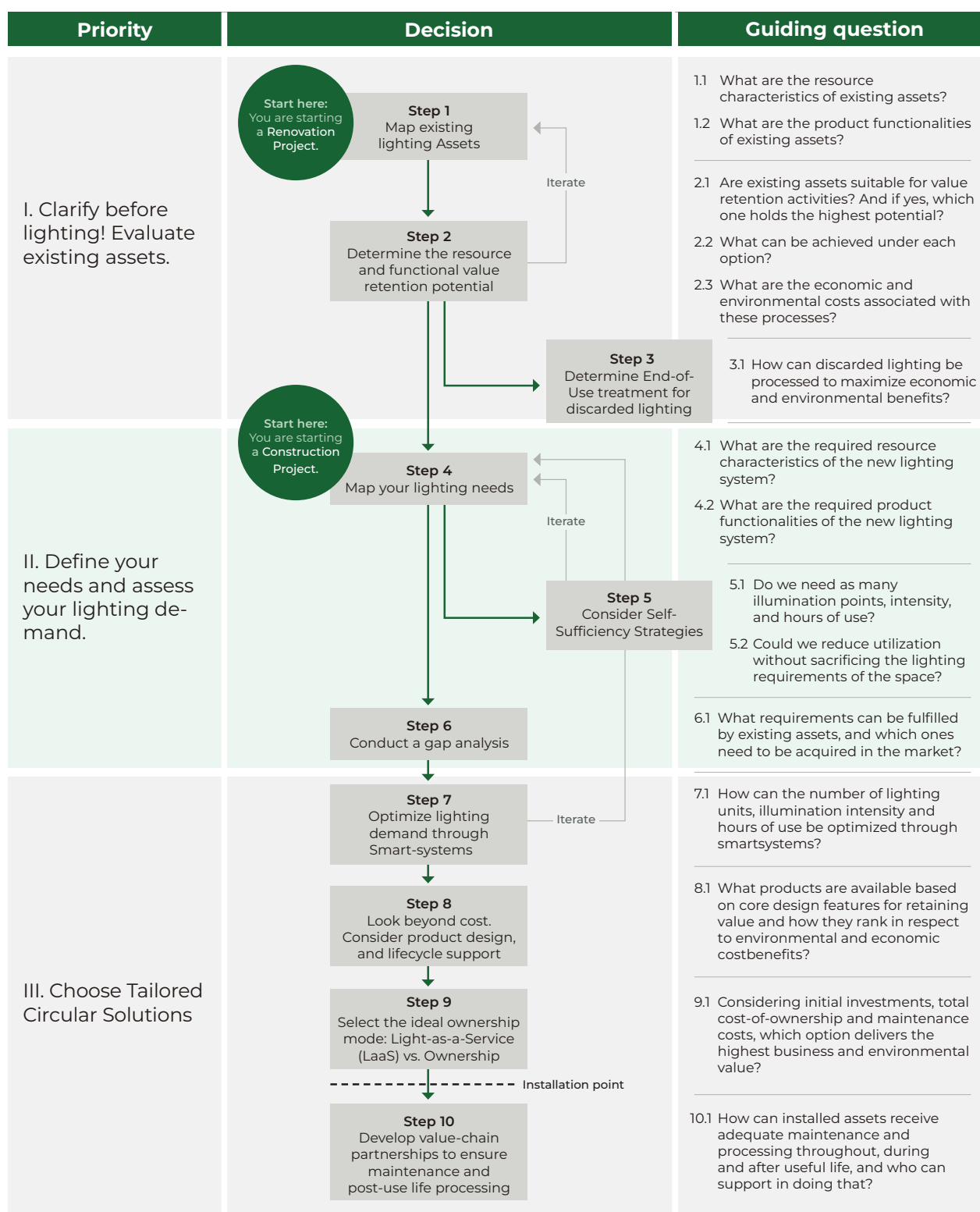
Ownership and contract terms influence every stage of the decision process by allocating responsibilities between users and LaaS providers.

A conventional sale may divide decisions about maintenance, data, removal and waste among a building owner, tenant, contractor, facilities manager and waste operator. LaaS, including leasing, managed services and performance contracts, can maintain a continuing relationship between the asset and provider. The user pays for a defined lighting outcome, while the provider manages lifecycle services intended to extend product life. Lighting as a Service (LaaS) supports circularity by giving the provider a direct interest in extending product lifetimes and keeping products in use for longer. The provider also has the best knowledge and expertise to maintain, repair, refurbish, and upgrade them over time.”

Step 10. Ensure proactive maintenance throughout the product's useful life

After the product and ownership model have been selected, effective maintenance remains essential. It preserves the option to repair, refurbish, upgrade or remanufacture the product later in its useful life. The available options are constrained by access to expertise and resources and by local regulation.

Figure 3-1 Priorities and decisions for circular lighting



Chapter 4 complements this framework with an analysis of 50 business cases involving circular solutions and provides measures for comparing circular interventions with full replacement and for developing an investment case. **Table 4-1** provides practical guidance for helping users decide between Lighting as a Service (LaaS), retrofit, or full replacement.



CHAPTER 4

How circular choices can strengthen the lighting investment case

Circular options must be compared with full replacement on commercial as well as technical grounds. In this chapter, six business benefits reported across 50 publicly documented cases are summarised and related to the circumstances of ten sectors. Three measures are then introduced, namely asset retention rate, payback period and net project cost, so that circular and replacement options can be compared on the same basis. A buying guide is also provided, through which a choice between Lighting as a Service, retrofit and full replacement can be made, with costs often omitted from supplier quotations being taken into account. Readers are thereby equipped to develop an evidence-based investment case.

Circularity helps strengthen the business case in six ways

Circular choices can protect value during an upgrade and throughout the life of the installation. Evidence from 50 publicly available business cases identified six benefits across three business areas: asset retention, business operations and environmental footprint (**Table 4-1**).

Table 4-1. Business outcomes of circular lighting across three business areas

Business Area	Benefit	Number of reports	Business significance and selected empirical evidence
Asset retention	Assets and materials retained or reduced	26/50	St Olav's: 860 existing housings kept in service. Shell Centre: reuse avoided producing 38.4 tonnes of steel, according to the supplier. APM Vado Ligure: 15 high masts refurbished instead of replaced.
Asset retention	Full replacement avoided	20/50	Yarm School: existing fittings upgraded rather than replaced. Dublin Port Tunnel: a new infrastructure installation avoided. Frenchgate: retention avoided further structural testing and alterations.
Asset retention	Capital, maintenance, or financing benefits	37/50	The Loop: designer reports 41.5% lower installed cost. Dublin Port Tunnel: Signify estimates €3 million in capital savings. BlackRock: supplier estimates £122,400 maintenance savings over five years.
Business Operations	Useful life and lifetime support	31/50	Alder Hey: lamp life reported as 2–2.5 years versus six months. Schiphol: replaceable parts and a 75% longer design life specified. The Loop: modular fittings can adapt to future style and function changes.
Business Operations	Disruption avoided or continuity supported	23/50	Yarm School: less building work and auditorium disruption reported. Hyderabad Airport: conversion completed without interrupting operations. John Radcliffe: night works limited disruption in the busy atrium.
Environmental Footprint	Product-carbon benefits discussed	8/50	Crown Estate: project assessment estimates 800 kg CO ₂ e avoided. Shell Centre: supplier calculates avoided housing-production emissions. Westminster office: local refurbishment linked to lower embodied carbon.

The significance of product-related GWP increases with scale. Product-related emission reductions may appear small in one project but can accumulate across large estates and infrastructure networks. An indicative Signify model for the EU-27 estimated that converting 24% of the installed lighting base to circular products designed for better performance, longer lifetimes and upgradeability could reduce emissions by 5–10 tonnes of CO₂e. Product-related GWP can therefore inform carbon budgets, procurement decisions and assessments in large public tenders where carbon is priced.

Capital and maintenance benefits were reported most often, in 37 of 50 cases, followed by useful life and lifetime support in 31 cases and retained assets and materials in 26.

The cases associated asset retention with lower removal and disposal costs, a smaller renovation scope and less exposure to material shortages and price volatility.

23 cases reported avoided disruption or supported operational continuity, while 20 reported that full replacement was avoided. In the Husky Terminal case, preventive maintenance reduced specialist call-outs, unplanned inspections and replacement of faulty equipment.

Only 8 of the 50 cases discussed product-related carbon benefits. These benefits arise at different points in an installation's life: some lower the cost of the upgrade, some reduce spending over its lifetime and others protect value that never appears in the project budget.

Table 4-2 links each sector's asset context and operating constraints to its commercial priorities and the financial effect of circularity.

The six benefits in **Table 4-1** explain where value may arise, but users must include them in the investment appraisal to compare circular and replacement options. The next section shows how to translate them into numbers that can be compared across a circular and a replacement scenario.

Table 4-2. Sector contexts and financial implications of circular lighting.

Sector	Asset context	Primary commercial pressure	Sector Priority	Financial impact of Circularity
Hospitals and healthcare	Wards, corridors, atria and integrated fittings.	Continuity of care; difficult access; limited shutdown windows.	Maintain reliable light without interrupting care.	Retain housings and ceiling interfaces; limit access work and ward disruption.
Schools and universities	Classrooms, laboratories, sports halls and auditoria.	Constrained capital; ageing fittings; term-time access.	Meet learning and activity needs within budget.	Use kits and reuse to avoid new fittings and changes to fixing positions.
Offices and commercial real estate	Occupied offices, bespoke fittings and integrated ceilings.	Tenant changes; redesign; disruption; technology changes.	Preserve visual quality and adapt to changing use.	Retain and redeploy fittings rather than repeat complete lighting fit-outs.
Airports and passenger terminals	Lounges, gates, concourses and associated facilities.	Passenger flow; continuous operation; access and capital constraints.	Upgrade safely while maintaining passenger movement.	Serviceable designs and contracts manage outlay, maintenance and upgrades.
Retail and hospitality	Stores, guest areas and shopping-centre spaces.	Long hours; energy costs; brand quality; changing occupancy.	Match light to use while protecting trading and guest experience.	Upgrade controls on suitable systems; reduce equipment and servicing needs.
Municipal street lighting	Dispersed street and park networks, including historic fittings.	Public budgets; ageing assets; fault patrols; safety.	Provide reliable light and locate faults efficiently.	Retain suitable fittings; reduce inspection visits and reactive maintenance.
Roads, bridges and tunnels	Linear installations, housings, mounts, cabling and controls.	Closures; difficult access; safety; costly infrastructure works.	Maintain visibility with less work in live infrastructure.	Reuse housings and networks; avoid unnecessary installation and civil works.

Sector	Asset context	Primary commercial pressure	Sector Priority	Financial impact of Circularity
Airport airfields and aprons	Apron floodlights, runway and taxiway lights and controls.	Aircraft safety; restricted work windows; high-mast access.	Protect airside operations and detect faults promptly.	Retain compatible controls; reduce equipment and maintenance requirements.
Ports, rail yards and logistics sites	High masts, lighting columns, yards and cargo areas.	Cargo or rail continuity; long hours; difficult access.	Improve visibility without interrupting operations.	Refurbish masts and reuse columns; avoid new structures and access work.
Stadiums and sports venues	High-mounted floodlights, arena lighting and event controls.	Event reliability; access; broadcast needs; varied event formats.	Meet performance requirements and adapt to each event.	Retain suitable poles; use service support to manage maintenance and risk.

Comparing project value across circular and replacement options

Three measures allow a circular scenario and a full-replacement scenario to be compared on the same basis.

- **Asset Retention Rate** – the proportion of the existing installation that remains in use.
- **Payback period** – the time required for annual savings to recover the project investment.
- **Net project cost** – the total ownership cost, including capital required after retained assets, avoided costs, and recurring savings are considered.

Retaining assets can reduce the need for new investment

The asset retention rate shows the proportion of an existing installation that remains in use after an intervention.

$$\text{Asset Retention Rate} = \frac{\text{Assets Retained (\$)}}{\text{Total Assets affected (\$)}} \times 100$$

A firm should seek to retain existing assets that remain safe, functional and suitable for the project's requirements. A higher rate means that more of the value embedded in lighting components, cabling, controls and other infrastructure is preserved. This can reduce the cost of new materials, installation work, transport and disposal. The rate does not represent a financial saving by itself, but it establishes what remains in use so that the associated purchasing, installation and disposal costs can be evaluated.

The decision to retain parts should be guided by lifecycle assessment to consider environmental and economic trade-offs, rather than maximising one of the categories for its own sake. A costly intervention that briefly extends the life of an unsuitable asset may provide less value than a new, more adaptable system with a longer useful life.

Where full replacement offers the stronger whole-life outcome or a previously unlit site requires a new installation, the current retention rate will be zero or not applicable.

The user should instead compare a conventional LED installation with products designed for circularity and future upgrades. A prospective retention rate can then estimate how much of the new installation is expected to remain in use through its next repair, upgrade, or technology change. The assessment should also consider maintenance costs required during use phase and their impacts on product useful life, and gains in its value retention potential after the use phase.

Circularity can shorten the time needed to recover an investment

The payback period is the time required for a project's annual savings to recover its initial cost. Firms generally seek a shorter payback because it recovers the investment sooner, reduces the period during which capital is exposed, and can help the project meet internal approval criteria. Chapter 1 and the case studies show how energy savings from LED technology drive the conventional calculation.

$$\text{Payback (as applied)} = \frac{\text{Annual Energy Savings (\$)}}{\text{Cost of lighting upgrade (\$)}}$$

The conventional calculation overlooks how circularity can reduce the numerator and, to a lesser extent, increase the denominator. Retaining suitable assets can reduce expenditure on new equipment, installation, removal, disposal, remedial work and business disruption. Circular options may also generate recurring savings through lower maintenance, fewer replacements, and disposal of parts. A more complete calculation is therefore:

$$\text{Payback (Circular Lighting)} = \frac{\text{Net Project Cost (\$)}}{\text{Annual Energy Savings (\$) + Annual Maintenance Savings (\$)}}$$

The main financial contribution of circularity comes from costs avoided rather than additional energy savings. Not all users value can be expressed directly through payback. Future compatibility, service reliability, warranties, contractual responsibilities, data control and end-of-contract arrangements can reduce exposure to technical obsolescence, unexpected expenditure and service failure. Although their monetary value may be difficult to establish in advance, these factors should form part of the comparison between options and the user buying guide.

A buying guide to navigating circular decisions

The measures above show the value of a circular option, but not which option to choose. This depends on how the upgrade will be financed, who will maintain the system, how much disruption the site can absorb and the value of the existing assets.

Table 4-3 compares seven visible and hidden cost factors to help users choose between Lighting as a Service, retrofit and full replacement. Hidden costs such as maintenance, downtime and disposal must be included because circular solutions can reduce them significantly.

Users are advised to gather figures from suppliers and internal teams for each factor, assess which route the answers favour, and weigh the results against organisational priorities such as capital constraints, operational continuity and ownership.

Table 4-3. Cost considerations for selecting a lighting upgrade model.

Cost parameters to consider	Questions users should ask	Financial relevance	Decision guide for the user		
			Choose LaaS if	Choose a retrofit if	Choose full replacement if
1. Upfront cost (the money required before the new lighting system is installed)	1.1 How much must the organisation pay before installation? 1.2 Does the price cover equipment only or also installation? 1.3 Can the supplier finance it?	To determine whether an organisation can proceed with a lighting upgrade even when the project offers attractive long-term savings.	The organisation has limited capital and prefers regular service payments.	Some capital is available and the existing luminaire housings remain in good condition.	Sufficient capital is available and ownership of a completely new lighting system is important.
2. Energy cost (the electricity consumed by the new system compared with the existing system)	2.1 What savings will the new system deliver compared with the current system? 2.2 How much is that in money per year?	This is the largest recurring lighting cost. Energy savings affect the project's payback period and total financial benefit.	All routes should maximise verified energy savings for the required lighting service.	All routes should maximise verified energy savings for the required lighting service.	
3. Total contract and financing cost (all payments made over the complete contract or ownership period)	3.1 How long is the contract? 3.2 What is the total paid over the full term? 3.3 How much does it cost to leave the contract early or buy the equipment at the end?	A low initial payment does not mean that an option has the lowest total cost. Contract duration, financing charges and termination conditions can substantially change the lifetime cost.	Avoiding upfront expenditure and transferring maintenance responsibility are more important than achieving the lowest total payment.		Capital is available and ownership and lower long-term financing costs are priorities.

Cost parameters to consider	Questions users should ask	Financial relevance	Decision guide for the user		
			Choose LaaS if	Choose a retrofit if	Choose full replacement if
4. Repair and maintenance cost (the cost of repairs, parts replacement and routine maintenance)	4.1 Is repair and maintenance included in the price? 4.2 How much would the maintenance cost? 4.3 What maintenance costs will the project avoid? 4.4 What is the useful life of the lighting system? 4.5 What warranty applies?	Repair and maintenance expenses continue throughout the life of the lighting system. Equipment reliability, service life, repairs and maintenance therefore affect the total operating cost.	the organisation has limited maintenance capacity or wants to avoid the high cost of repair and maintenance.		the organisation has an internal maintenance team or an affordable external maintenance arrangement.
5. Installation downtime (disruption while the lighting system is being changed)	5.1 How long will each fitting be out of service? 5.2 Is ceiling or other major construction work needed?	Installation can interrupt operations, reduce productivity and temporarily close important areas. In busy or critical facilities, the cost of disruption may exceed the direct installation cost.		closures would be expensive or operational continuity is essential.	the building is already being refurbished, the affected areas can be closed or the additional disruption can be managed.
6. Operational downtime (disruption caused by lighting failures after installation)	6.1 Is there a guaranteed repair time? 6.2 How likely are failures? 6.3 Are faults detected automatically?	Lighting failures can interrupt work, increase repair costs and create safety risks. The frequency of failures and the speed of repair therefore influence both operational performance and lifetime cost.	The organisation wants the provider to be contractually responsible for monitoring and repairs.		The organisation prefers direct control and has the internal capacity to respond quickly to failures.
7. Disposal of the existing system (removing, transporting, recycling and disposing of old lamps, ballasts and fittings)	7.1 How much will the waste disposal cost? How much material will be thrown away? 7.2 Does the chosen recovery route generate any financial return?	Removing existing equipment creates financial and environmental costs. Reusing housings and components can reduce waste, material consumption, disposal cost and the environmental impact of the upgrade.		Retaining usable fittings, reducing waste and limiting disposal are priorities.	the existing luminaires are unsuitable for reuse.





CHAPTER 5

Making circular lighting mainstream

Many technical options for circular lighting already exist, but their application at scale depends on information, incentives, capabilities, and market relationships being aligned. In this chapter, four interdependent sub-systems, namely business, policy, technology and markets, are examined, and seven intervention points are proposed. A three-phase roadmap is also presented. Readers are shown which actions can be taken immediately, which are required next, and which are needed for circularity to become standard practice.

AI

Circular lighting will remain confined to individual projects unless retaining, repairing and upgrading assets becomes easier than replacing them prematurely. Many of the technical options already exist. The challenge is to align the information, incentives, capabilities and market relationships needed to apply them at scale, across four sub-systems:

- **Businesses** determine how lighting is designed, sold, maintained and recovered.
- **Policy** sets requirements for performance, product information, waste, liability and secondary markets.
- **Technology** determines whether products, components, software and data remain compatible over time.
- **Markets** provide the finance, skills, infrastructure and demand needed to turn retained products and materials into viable assets.

Weakness in one sub-system can restrict progress in the others. A repairable luminaire has limited value if spare parts are unavailable. A technically sound refurbishment may lose to replacement if procurement considers only purchase price. Returned equipment cannot be remanufactured without information about its condition, sufficient volumes and a buyer. Service models can support maintenance, but their contracts must reward lower demand, longer asset life and responsible recovery.

Seven intervention points

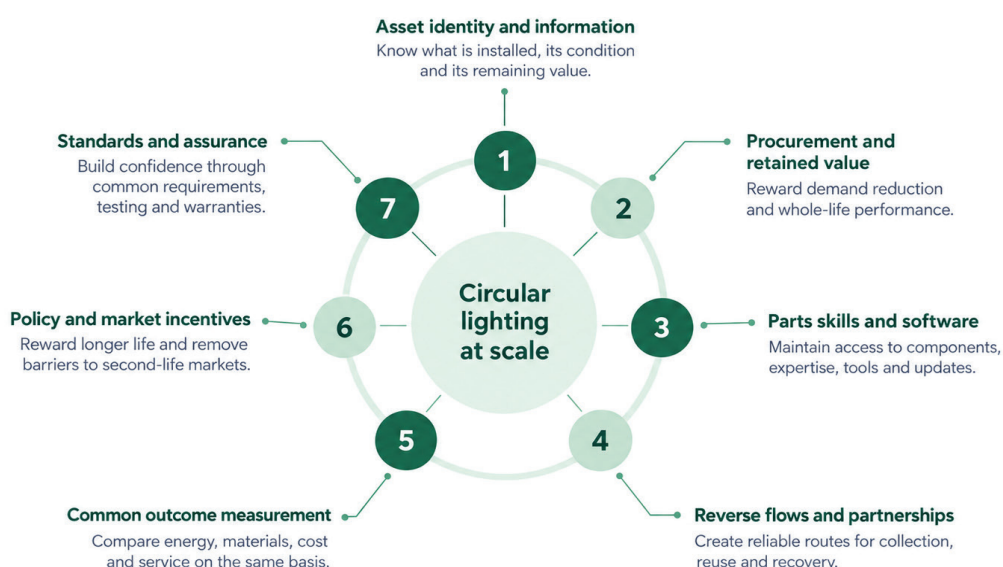
Circular lighting cannot be scaled through isolated improvements in products, policy or business models. It requires coordinated changes across the information, incentives, capabilities and market relationships that determine how lighting systems are designed, used and recovered.

The seven intervention points presented below address these interdependencies and establish the conditions for circular practices to become commercially viable and widely adopted. **Figure 5-1** illustrates how these interventions are connected and mutually reinforcing.

1. **Establish durable product identity and asset information.** Users and service providers need reliable data on condition, ownership, maintenance history, remaining life, material composition and component compatibility. Digital product passports connected systems and asset registers can support this information, provided that data remain accessible and transferable throughout the product's life.
2. **Reward demand reduction and retained value through procurement.** Users should define the lighting service they require before specifying new equipment. They should compare options using whole-life criteria, including energy use, asset retention, maintenance, disruption, future compatibility and end-of-use arrangements. Financing and Lighting as a Service can improve access to circular solutions, but responsibilities for data, upgrades, residual value and recovery must be clear.

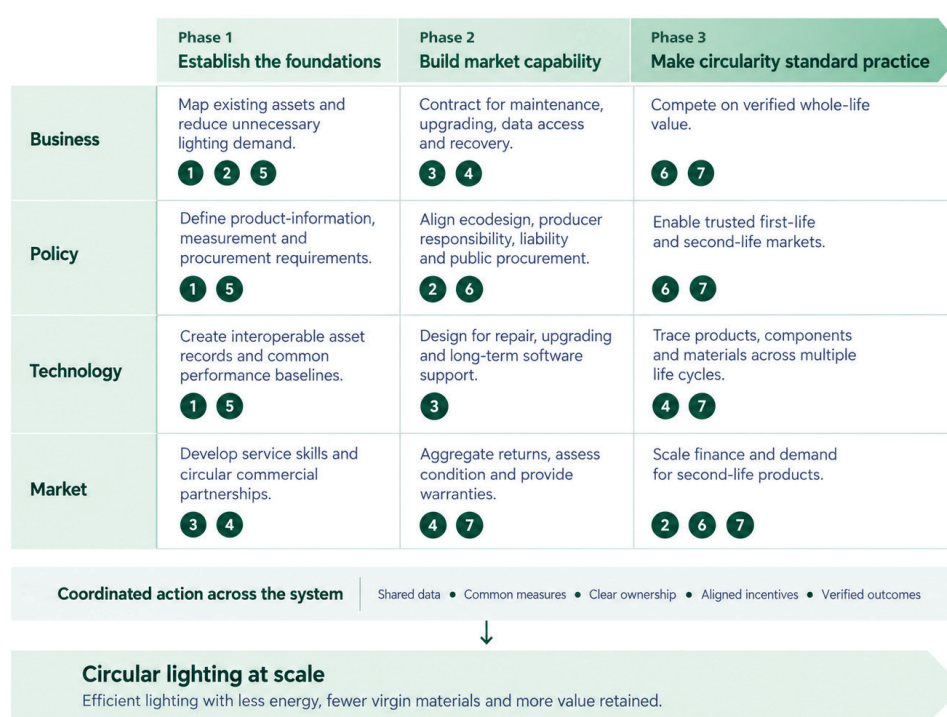
- 3. Maintain access to parts, tools, skills and software.** Modular design alone is insufficient if components, repair information or software support disappear. Manufacturers and service providers should make long-term support part of the offer, while training and recognised competence standards should expand the capacity to maintain and upgrade installations safely.
- 4. Create predictable reverse flows.** Clear ownership, condition assessment, sufficient volumes and confirmed destinations are required before refurbishment, remanufacturing or high-value recovery can operate commercially. Partnerships between users, manufacturers, contractors, logistics providers and recovery businesses can aggregate volumes and develop local capability.
- 5. Use common measures.** Options should be compared against the same lighting requirement and assessed across energy use, asset retention, expected service life, material demand, embodied emissions, cost and operational disruption. This prevents circularity from being pursued regardless of outcome and allows users to select the option with the strongest whole-life result.
- 6. Align policy incentives across the value chain.** Eco design, procurement, product-information and producer-responsibility measures should reward durability, repair, upgrading and verified recovery. Clear rules on safety, warranties, liability and the status of second-life products can reduce uncertainty and encourage investment.
- 7. Develop standards and assurance.** Common requirements for interoperability, condition assessment, testing, data quality and environmental claims can build confidence in repaired and remanufactured products. They also make it easier to compare offers, aggregate demand and finance circular projects.

Figure 5-1: Seven connected intervention points for mainstreaming circular lighting



The seven intervention points cannot be implemented independently or simultaneously at scale. **Figure 5-2** presents a roadmap showing how they progress through three phases: establishing the foundations, building market capability and making circularity standard practice. Together, these phases enable an eighth intervention: coordinated action across the system, bringing business, policy, technology and market actors together to make circular lighting mainstream.

Figure 5-2: Three-phase roadmap for coordinated action towards circular lighting at scale



From niche pilots to standard practice

The three phases of development illustrate how collaborative action between business and policy, while leveraging technology and creating market opportunities can advance the seven interventions. The immediate focus should be on establishing the foundations. Organizations can map existing assets, reduce unnecessary demand, introduce whole-life procurement criteria, and establish shared measures. The next stage is to expand service capability, secure long-term product support and build partnerships for collection and recovery. This would result in building market capability. At scale, common standards, aligned policy and dependable second-life markets can make circularity the standard practice in the lighting sector.

The next wave of LED investment will shape lighting systems for years to come. Decisions made now will determine whether that investment leads to repeated replacements or preserves the value already embedded in products, buildings, and infrastructure.



The next lighting transition: GO CIRCULAR

The first lighting transition made light substantially more energy-efficient. The second must continue improving energy efficiency while increasing the resource efficiency of materials. The task is to preserve useful infrastructure, make fast-changing technology upgradeable, prevent small failures from ending whole products, create credible second lives and recover materials only after higher-value options are exhausted.

The goal is to retain each luminaire only while it remains the best whole-life option. Users need to know what is installed, what function it must provide, what retains value, which interventions are possible, and where removed assets will go. Manufacturers and service partners need to make circular choices available. Procurers, financiers and policymakers need to value the outcomes and remove barriers to adoption, while standards bodies set minimum requirements and standardise practice. Circular lighting can scale when outcomes are measured, attributed to the actors who create them and repeated beyond isolated projects.

The opportunity is immediate. As the first wave of LED adoption gives way to a second wave of replacement and upgrading, decisions made now will determine whether the next transition simply replaces one generation of products with another or creates a lighting system that delivers the required service with less energy, fewer virgin resources, longer asset lives and more value retained throughout the lifecycle.

Endnotes & references

Research Materials

The research methodology and complete reference list underpinning this report are available at <https://doi.org/10.25446/oxford.34696374>.

The circular-lighting case-study dataset and accompanying analysis are available at <https://doi.org/10.25446/oxford.34399893>.

Selected References

Casamayor, J., Su, D., & Sarshar, M. (2015). Extending the lifespan of LED-lighting products. *Architectural Engineering and Design Management*, 11(2), 105–122. <https://doi.org/10.1080/17452007.2013.834813>

Franz, M., & Wenzl, F. P. (2017). Critical review on life cycle inventories and environmental assessments of LED lamps. *Critical Reviews in Environmental Science and Technology*, 47(21), 2017–2078. <https://doi.org/10.1080/10643389.2017.1370989>

Geissdoerfer, M., Savaget, P., Bocken, N. M., & Hultink, E. J. (2017). The circular economy—A new sustainability paradigm? *Journal of Cleaner Production*, 143, 757–768.

Grigoropoulos, C. J., Zerefos, S. C., Tsangrassoulis, A., & Doulos, L. T. (2022). Lighting products as part of the circular economy and strategies that affect it: A literature overview. *IOP Conference Series: Earth and Environmental Science*, 1123(1), 012006. <https://doi.org/10.1088/1755-1315/1123/1/012006>

International Energy Agency. (2022). Targeting 100% LED lighting sales by 2025. <https://www.iea.org/reports/targeting-100-led-lighting-sales-by-2025>

Kjaer, L. L., Pigosso, D. C. A., Niero, M., Bech, N. M., & McAlloone, T. C. (2019).

Product/service-systems for a circular economy: The route to decoupling economic growth from resource consumption? *Journal of Industrial Ecology*, 23(1), 22–35. <https://doi.org/10.1111/jiec.12747>

Liu, L., Keoleian, G., & Lewis, G. (2024). Life cycle cost analysis of LED retrofit and luminaire replacements for four-foot T8 troffers. *Lighting Research & Technology*, 56(4), 403–420. <https://doi.org/10.1177/14771535231207810>

Pavel, C. C., Marmier, A., Tzimas, E., Schleicher, T., Schöler, D., Buchert, M., & Blagoeva, D. (2016). Critical raw materials in lighting applications: Substitution opportunities and implications for demand. *Physica Status Solidi A*, 213(11), 2937–2946. <https://doi.org/10.1002/pssa.201600594> Reike, D., Vermeulen, W. J., & Witjes, S. (2018). The circular economy: New or refurbished as CE 3.0? Exploring controversies through a focus on history and resource value-retention options. *Resources, Conservation and Recycling*, 135, 246–264.

Wang, S., Su, D., & Wu, Y. (2022). Environmental and social life cycle assessments of an industrial LED lighting product. *Environmental Impact Assessment Review*, 95, 106804. <https://doi.org/10.1016/j.eiar.2022.106804>