European Commission

RENEWABLE ENERGY IN CITIES SOLUTION BOOKLET

Smart Cities Marketplace 2025

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ENERGY

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WHAT IS THE SMART CITIES MARKETPLACE?

The Smart Cities Marketplace is an initiative supported by the European Commission bringing together **cities, industry, SMEs, investors, banks, research and other climate-neutral and smart city actors**. It supports cities of all sizes in developing sustainable projects by providing information free of charge, technical assistance, consulting, and matchmaking financing. Services include funding calls, financing masterclasses, and tailored support.

WHAT ARE THE AIMS OF THE SMART CITIES MARKETPLACE?

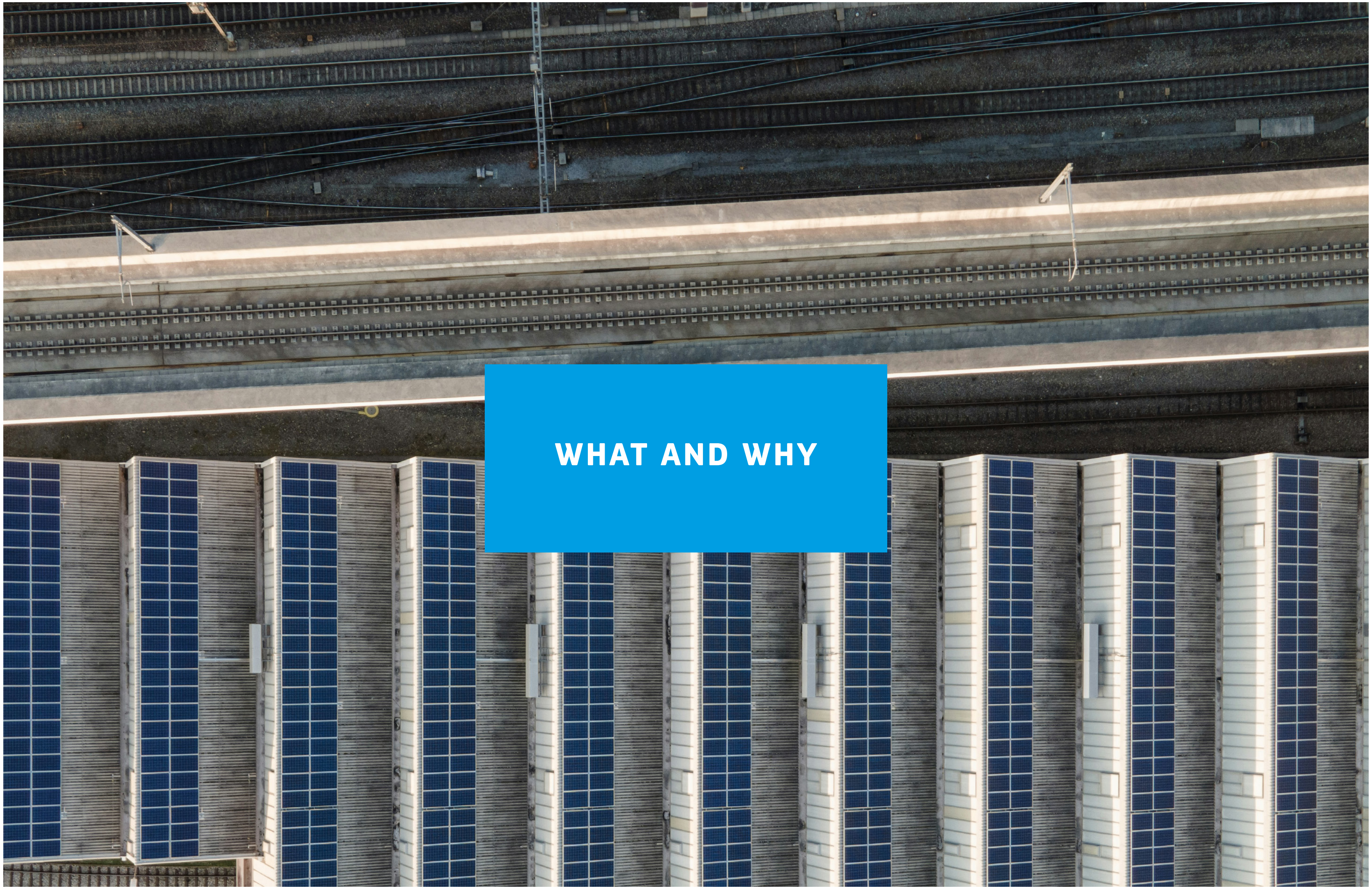
The Smart Cities Marketplace Investor Network is a growing group of investors and financial service providers who are actively looking for climate-neutral and smart city projects. The Smart Cities Marketplace has thousands of followers from all over Europe and beyond, many of which have signed up as a member. Their common aims are to **improve citizens' quality of life, increase the competitiveness of European cities and industry as well as to reach European energy and climate targets**.

WHAT CAN THE SMART CITIES MARKETPLACE DO FOR YOU?

The Smart Cities Marketplace is offering a series of over 20 solution booklets[1], short practical and example-rich guides to help city officials to address key issues related to securing a sustainable and green urban future. We hope that this solution booklet will help you focus on climate risks and solutions that are relevant to your city context.

Explore the possibilities, shape your project ideas, and close a deal for launching your smart city solution! If you want to get in touch with us, please use info@smartcitiesmarketplace.eu.

1 smart-cities-marketplace.ec.europa.eu/insights/solutions



WHAT AND WHY

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WHAT AND WHY

Cities are at the heart of Europe's energy transition. Home to over 70% of the EU population and responsible for a substantial share of energy consumption and greenhouse gas emissions, urban areas play a critical role in achieving the European Green Deal's objectives and the EU's 2050 climate neutrality target.

Renewable energy solutions in cities are not just an environmental imperative – they are an economic, social, and political opportunity. By integrating clean energy technologies into the urban fabric, cities can reduce their reliance on fossil fuels, lower emissions, improve air quality, and create resilient, decentralised energy systems. These solutions also drive innovation, unlock green jobs, and empower local communities through participation and ownership.

However, the urban energy transition is complex. It demands coordinated action across policy levels, alignment with EU frameworks such as REPowerEU, and tailored approaches that reflect diverse local contexts – from dense metropolitan areas to small and medium-sized cities. Municipalities often face barriers such as limited capacity, financing constraints, or fragmented governance structures.

This booklet explores key questions guiding the clean energy transition in cities: What solutions are available to help cities shape effective strategies and actions for renewable energy adoption? What barriers stand in the way of large-scale renewable energy projects, and what forms of governance can help overcome them? How can costs and benefits be distributed fairly through suitable business models? And who should be involved in these processes - and at what stages?

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The booklet presents a diverse set of practical, replicable renewable energy solutions from across the European Union, illustrating with compelling examples of systemic decarbonisation how cities are balancing energy security, sustainability, and innovation; while achieving real-world benefits with solar, wind, geothermal, hydropower, bioenergy, and hybrid systems.

From modernising district heating networks and deploying rooftop solar panels to fostering citizen energy communities, the featured examples reflect a broader European commitment and offer valuable insights and inspiration for policymakers, urban planners, and practitioners committed to accelerating the clean energy transition.

CITY CONTEXT

CITY CONTEXT

What is the role of renewables in delivering climate neutral cities?

Renewables play a significant role in delivering climate-neutral cities in the European Union. The EU aims to become a hub for clean energy manufacturing, with the Net Zero Industry Act setting a goal for EU manufacturing capacity to reach at least 40% of its annual clean energy deployment needs by 2030. The European Union has been a leader in clean energy, with energy-related CO2 emissions in 2023 declining due to increased electricity production from renewables, a recovery in hydro and nuclear power, and reduced emissions in industry. The share of renewables in EU electricity generation is projected to rise from 45% today to around 80% by 2030[2]. This transition is supported by the Fit for 55 package, which includes ambitious targets for retrofitting buildings and increasing the share of electric cars in new registrations to 100% by 2035[3].

The European Commission's current policy on renewable energy in cities is centred on accelerating the clean energy transition by simplifying permitting processes, empowering local authorities, and fostering innovative financing mechanisms. This approach is also designed to help urban areas, which are responsible for a sizeable portion of energy consumption and greenhouse gas emissions, to achieve climate neutrality and energy resilience.

2 iea.org/reports/global-energy-and-climate-model/stated-policies-scenario-steps
3 iea.org/reports/world-energy-outlook-2024

Clean energy momentum in the European Union: key figures at a glance[4]

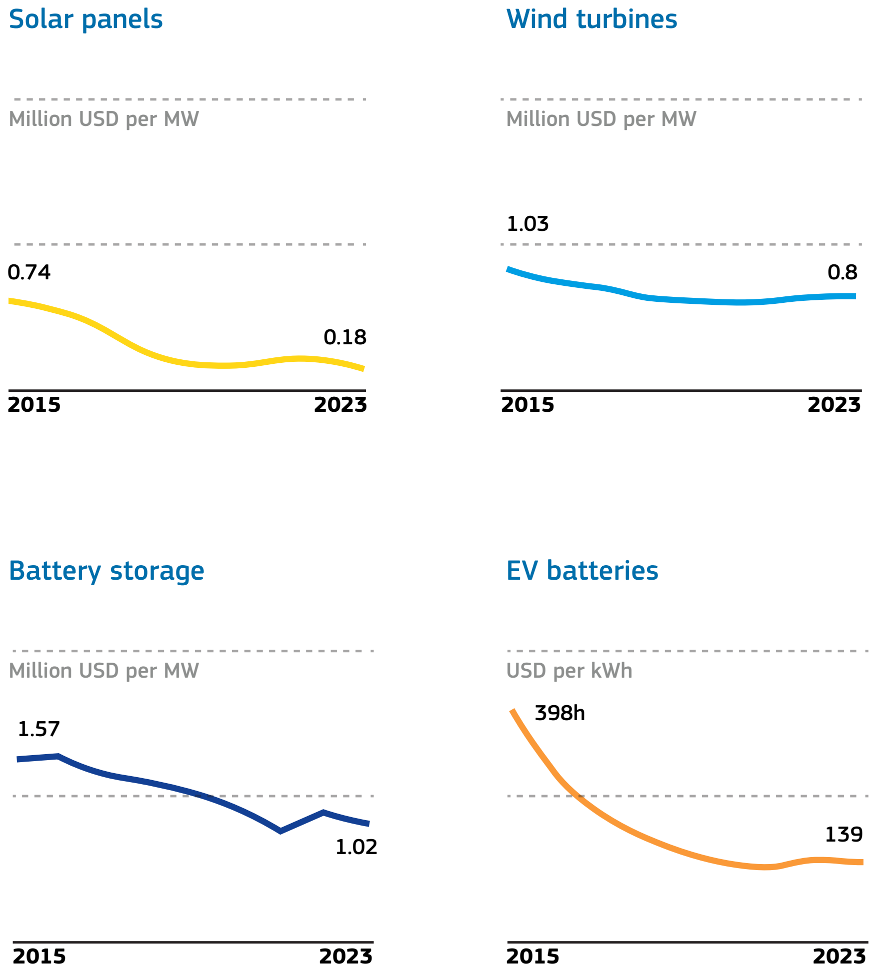
- **Solar surge:** In 2023, EU Member States added nearly 60 GW of solar PV capacity – more than 60% from rooftop installations, doubling 2021 levels. Wind growth: Over 15 GW of new wind capacity was installed in 2023 – up 40% compared to 2021.
- **Doubling capacity by 2030:** Combined installed capacity of wind and solar PV in the EU is projected to more than double by 2030.
- **Electric vehicle uptake:** Annual EV sales in the EU are expected to grow from 2.5 million today to over seven million by 2030 – nearly 20% of global EV sales.
- **Battery boom:** Battery manufacturing capacity may increase from 44GWh up to 1,200 GWh by 2030 driven by numerous gigafactory projects across the EU territory.
- **Heat pump acceleration:** Annual sales are projected to grow from 25 GW today to over 45 GW by 2030, driven by EU incentives and supportive policy.
- **Energy security shift:** The EU has cut coal reliance and significantly reduced natural gas pipeline imports from Russia. LNG now accounts for over 40% of EU gas imports.

4 europarl.europa.eu/RegData/etudes/BRIE/2025/767214/EPRS_BRI(2025)767214_EN.pdf

What are the global trends?

Electricity is at the forefront of the energy transition, with demand rising significantly faster than overall energy consumption. This acceleration is driven by both established uses – such as cooling – and emerging applications including electric mobility, heat pumps, and the rapidly growing digital sector (e.g. data centres). In response, renewable energy sources are leading the expansion of global electricity generation, already growing quickly enough to meet the net increase in electricity demand.

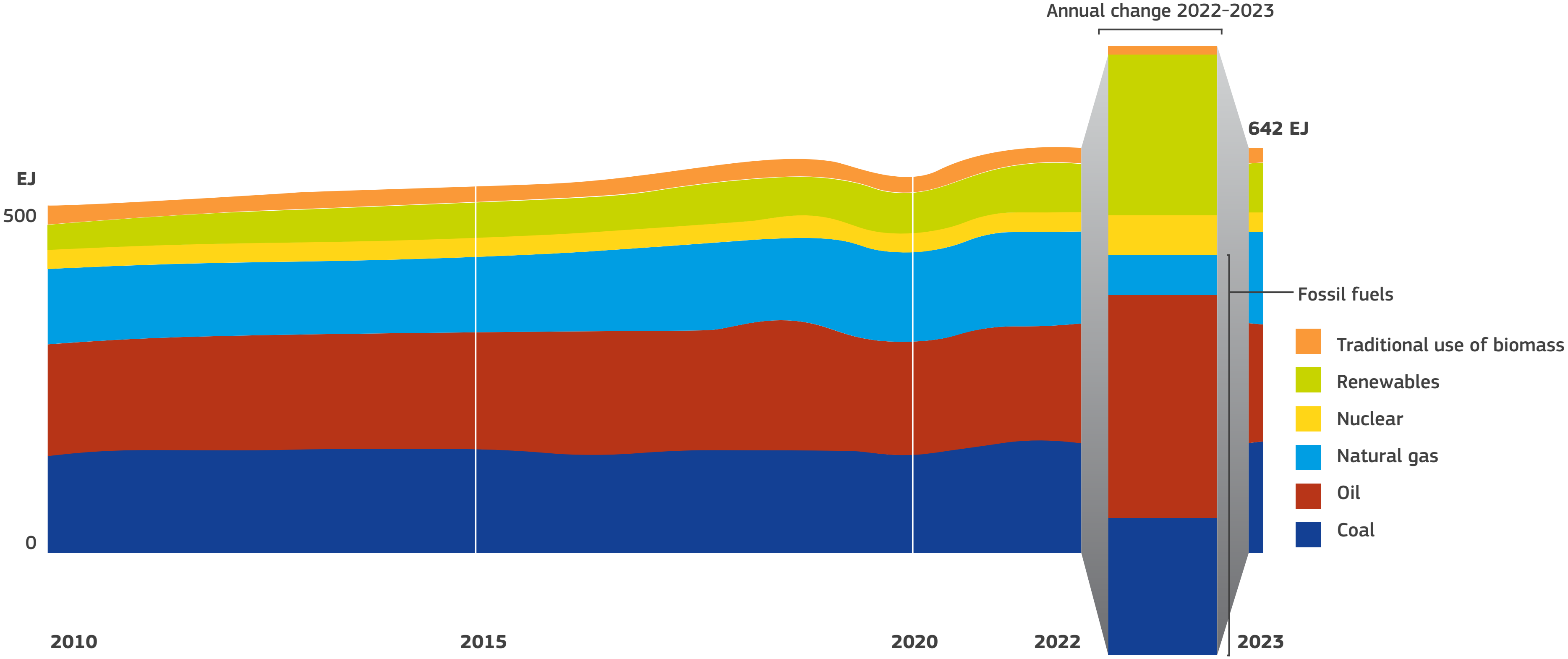
Recent technological and industrial advances are reinforcing this momentum. Clean energy technologies – particularly solar photovoltaic (PV), wind power, and electrification solutions – have seen significant price reductions in recent years, making them more accessible and cost-effective. For example, current global manufacturing capacity for solar PV modules exceeds 1,100 GW annually, enabling deployment rates nearly three times higher than those seen in 2023.



Price reductions for clean energy technologies.
Figure recreated from iea.org/reports/world-energy-outlook-2024/context-and-scenario-design#abstract

Despite record-high clean energy deployment in 2023, fossil fuels still met around two-thirds of the growth in global energy demand, highlighting the urgent need to scale up renewables even further. Nevertheless, progress in the power sector is evident: renewables accounted for 30% of global electricity supply in 2023, while the share of fossil fuels dropped to 60% – its lowest level in half a century.

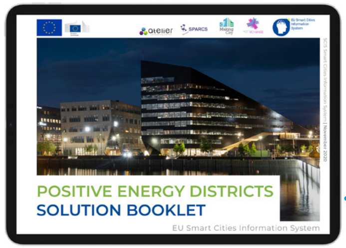
In all future scenarios, low-emission sources – especially solar PV and wind – continue to outpace electricity demand growth, pushing fossil fuel shares further down. By 2035, solar PV and wind are projected to provide over 40% of global electricity, and nearly 60% by 2050.



Global energy demand (all energy sectors). Figure recreated from https://www.iea.org/reports/world-energy-outlook-2024/context-and-scenario-design#abstract

The building and transport sectors, while far from electrified, are also crucial for decarbonisation efforts in cities. Buildings contribute significantly to greenhouse gas emissions, and the transport sector's reliance on fossil fuels makes it a major contributor to urban pollution. Electrification of these sectors, coupled with a shift towards renewable energy sources, is essential for achieving net-zero emissions and creating more sustainable urban environments. EU member states are committed to reducing the average primary energy use in residential buildings by 20-22% by 2035 compared to 2020, with a focus on renovating the worst-performing buildings[5].

Further reading to illustrate inspiring solutions regarding the decarbonisation shifts in the **building sector**:



5 Directive (EU) 2024/1275 of the European Parliament and of the Council of 24 April 2024 on the energy performance of buildings (recast)

And in the and **transport sector**:

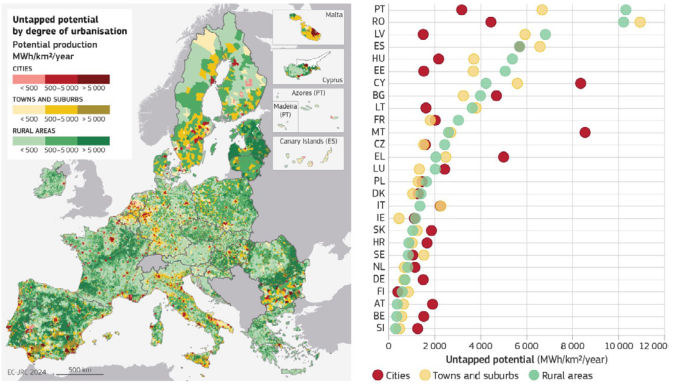
Together with the continued roll-out of renewables, this must allow to further decarbonise the building sector. Hereby the EU wants all fossil fuel boilers in buildings to be phased out by 2040. In the transport sector, particularly in cities, the shift towards renewable energy (RE) by 2035 will be heavily driven by the electrification of vehicles, with a significant increase in electric vehicle (EV) adoption. By 2030, the EU aims for at least thirty million zero-emission cars on European roads. This transition will necessitate investments in charging infrastructure and grid upgrades to support the growing demand for electricity[6]. Apart from electrifying both individual and collective transport, realising a modal shift in cities is equally important. Hereby walking, biking and using public transport must be favoured over individual motorised transport. This not only lowers the energy demand for transport but also comes with a wide range of co-benefits in terms of health, safety, congestion, noise, quality of the public domain and more. Cities should promote such shift in transport practices through their Sustainable Urban Mobility Plans (SUMPs)[7], and implement related measures through regulatory and infrastructure updates.

6 Communication From The Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions Sustainable and Smart Mobility Strategy – putting European transport on track for the future (COM/2020/789 final)
7 transport.ec.europa.eu/transport-themes/urban-transport/sustainable-urban-mobility-planning-and-monitoring_en

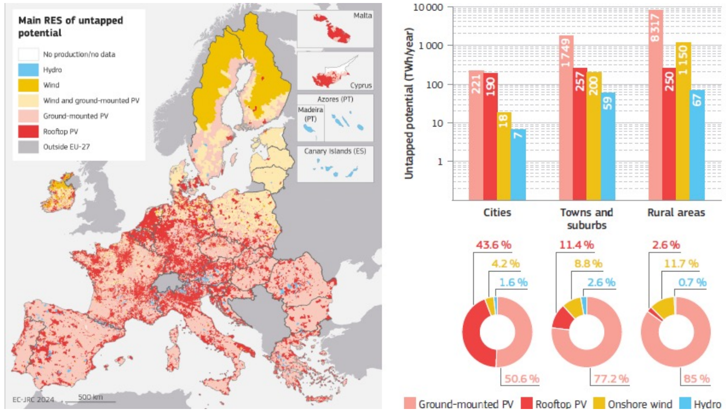
What is the unlocked renewable energy potential of European Cities?

In the EU, cities and municipalities hold a vast, still available reservoir of renewable energy potential. An estimated 12,500 TWh/year of additional electricity generation capacity – primarily from solar PV (88%), followed by onshore wind (11%) and enhanced hydropower (1%) – could be harnessed through new installations, including innovative solutions like floating solar PV on water reservoirs. Even when accounting for overlapping land use between PV and wind, the estimation of the net potential exceeds 11,200 TWh/year – more than five times the EU's total electricity consumption in 2023[8].

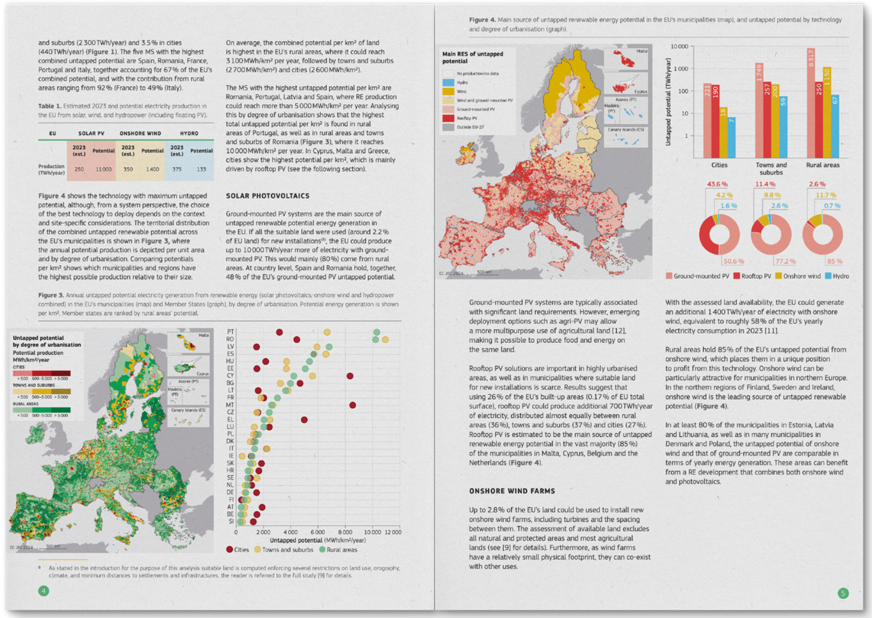
Tapping into this potential requires targeted investments, local planning capacity, and supportive regulatory frameworks. By integrating renewables more deeply into the urban fabric, European cities can become central actors in delivering the EU's climate and energy goals – boosting energy security, reducing emissions, and creating new economic opportunities at the local level.



Annual untapped potential electricity generation from renewable energy (solar photovoltaics, onshore wind and hydropower combined) in the EU's municipalities (map) and Member States (graph), by degree of urbanisation. Potential energy generation is shown per km2, Member states are ranked by rural areas' potential.



Main source of untapped renewable energy potential in the EU's municipalities (map), and untapped potential by technology and degree of urbanisation (graph). Showing only the technologies with the highest potential.



Source: Dorati C. Quaranta, E., et al. (2023). Renewable energies in rural areas. Contribution to and benefit from the energy transition. JRC Science for Policy report.

8 Dorati C. Quaranta, E., et al. (2023). Renewable energies in rural areas. Contribution to and benefit from the energy transition. JRC Science for Policy report.

SOCIETAL USER ASPECTS

SOCIETAL USER ASPECTS

Stakeholder support and citizen engagement

Empowering citizens and communities is central to the European Union's vision for a clean and inclusive energy transition. With the adoption of the Clean Energy for All Europeans Package (CEP)[9] in 2019, the EU introduced a transformative legal framework that places people at the heart of the energy system. Two key innovations under the CEP – Renewable Energy Communities (RECs) and Citizen Energy Communities (CECs) – enable individuals, households, small and medium-sized enterprises (SMEs), and local authorities to actively participate in producing, consuming, storing, and sharing renewable energy.

These community-based models are designed not only to decentralise energy systems but also to foster social inclusion, local empowerment, and economic resilience. RECs are structured to ensure broad and inclusive participation, including low-income and vulnerable households, while granting members meaningful decision-making power. CECs offer more flexible participation options but generally provide less emphasis on democratic control.

The EU has mandated all Member States to establish supportive frameworks for RECs and CECs, yet progress remains uneven. While countries such as Germany and Denmark had existing cooperative models prior to the CEP, others are still in the early stage of implementation. Bridging this gap is essential to unlocking the full potential of citizen-led renewable energy initiatives across Europe.

9 energy.ec.europa.eu/topics/energy-strategy/clean-energy-all-europeans-package_en

A key enabler of energy communities is the right to energy sharing, introduced under the Renewable Energy Directive (RED II) and the Electricity Market Directive (EMD). Recent regulatory updates in Regulation 2024/1711 provide greater clarity and flexibility for energy sharing. Individuals or legal entities can now share energy – whether jointly owning, leasing, or managing a renewable installation – even when located offsite. Energy sharing is permitted regardless of different supplier contracts, as long as it takes place within the designated imbalance settlement period. This innovation promotes efficiency, reduces grid pressure, and increases the value of local renewable production. To ensure equitable access and scale up community energy, the EU requires Member States to:

- **Remove regulatory and administrative barriers;**
- **Facilitate access to finance and technical assistance;**
- **Promote participation from vulnerable groups;**
- **Ensure transparent and non-discriminatory treatment in grid access and operation.**

Initiatives such as the RePowerEU plan further highlight the importance of simplifying permitting procedures, providing financial incentives, and building local capacity to support energy communities. Despite growing momentum, full implementation across the EU is still a work in progress. Accelerating the deployment of RECs and CECs will require sustained regulatory commitment, public investment, and collaborative engagement with local stakeholders and civil society.

Boosting Investments by Local Renewable Energy Communities (RECs) – Snowball Effect in Portugal

In Portugal, four Covenant of Mayors (CoM) signatory cities – Guimarães, Vila Real, Torres Novas, and Almada – have taken pioneering steps to boost local investments in solar photovoltaic (PV) power through the establishment and strengthening of Renewable Energy Communities (RECs) and Collective Self-Consumption (ACC) schemes. Supported by Smart Cities Marketplace (SCM) 1-to-1 Advisory Services, these cities are now setting a national example, triggering a growing "snowball effect" of local renewable energy initiatives.

These examples demonstrate how local authorities, when equipped with tailored advisory services and technical-financial tools, can successfully initiate and expand RECs. Guimarães' leadership played a catalytic role in disseminating good practice across Portugal, showcasing how local action can create a national ripple effect in renewable energy deployment and investment mobilisation.

1 Guimarães: A flagship for local energy transition

- **Goals:** Development of a REC and installation of 50 MW of PV power
- **Investment Volume:** approx. €48.3 million
- **Expected Energy Generation:** 68.5 GWh/year
- SCM Advisory Services supported Guimarães in assessing economic feasibility, structuring financing mechanisms, and preparing procurement documentation. Its successful model was showcased during a local SCM event and has since inspired similar initiatives in other municipalities.

2 Torres Novas: local financing and emission reductions

- **Goals:** Development of a REC and installation of 1.5 MW of PV power
- **Investment Volume:** approx. €1.35 million
- **Expected Energy Generation:** 1.95 GWh/year
- **Expected Emissions Reduction:** 719.6 tCO_2eq/year
- Through SCM's support on economic-financial feasibility, procurement preparation, and access to financing, Torres Novas was able to unlock local investment potential for climate action at the community level.

3 Vila Real: advancing collective self-consumption

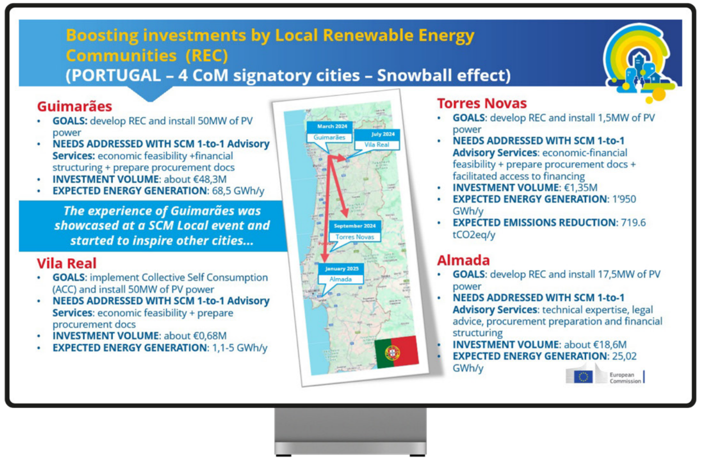
- **Goals:** Implementation of ACC scheme and installation of 50 MW of PV power
- **Investment Volume:** approx. €0.68 million
- **Expected Energy Generation:** 1.1–5 GWh/year
- Vila Real benefitted from SCM's tailored assistance to confirm economic viability and develop procurement documentation, marking an important step towards decentralised and citizen-driven energy systems.

4 Almada: A comprehensive REC strategy

- **Goals:** Development of a REC and installation of 17.5 MW of PV power
- **Investment Volume:** approx. €18.6 million
- **Expected Energy Generation:** 25.02 GWh/year
- Almada received multi-faceted advisory support from SCM, including technical expertise, legal advice, and financial structuring. The city's integrated approach is laying the foundation for a robust REC capable of sustaining long-term energy transition efforts.

One of the key challenges to the development of renewable energy in cities is the so-called “Not In My Backyard” (NIMBY) syndrome. NIMBY refers to a set of social and spatial dynamics that emerge when unwanted or disruptive projects, such as renewable energy installations, are proposed near residential areas. Importantly, residents often support the broader goals of the energy transition, but opposition arises when these developments are planned close to their homes. This resistance typically stems from concerns about potential negative impacts on health, property values, or local landscapes[10].

To overcome such a barrier, it is necessary to transform NIMBY attitudes into PIMBY “Please In My Backyard.” The PIMBY mindset reflects a shift in public perception, where local communities not only accept renewable energy projects but actively welcome and engage with them, recognising their benefits.



A successful example of shifting public attitudes toward wind energy comes from the Wądroże Wielkie commune in Lower Silesia, Poland. Initially, local residents opposed the installation of seven 2.5 MW wind turbines, even threatening to vote out councillors who supported the project. Over time, however, dialogue between local authorities, investors, and the community helped ease concerns. Residents were ultimately reassured by the positive experiences of neighbouring communes, particularly regarding minimal visual impact and significant tax revenue that supports local development and EU co-funded projects. Social acceptance was further strengthened by the investors’ active involvement in community life, such as funding churches, the fire brigade, and local events. Nevertheless, a challenge remains: the benefits of wind energy are often seen as indirect, as electricity generated feeds into the national grid rather than reducing local bills, a factor that can limit public enthusiasm [11]. As showed also further below in the example of Eeklo, Belgium, opening wind projects for direct public participation can further increase the acceptance of RE production and help to keep profits in the local community.

10 Wontorczyk A., 2016, Analiza psychologiczna syndromu NIMBY [Psychological Analysis of the NIMBY Syndrome], Czasopismo Psychologiczne, DOI: 10.14691/CPPJ.22.1.109.

11 European Commission: Directorate-General for Energy and Orłowska, J., How to turn NIMBY into PIMBY? – Key challenges and lessons learned in overcoming reluctance and promoting public acceptance of the energy transition locally, Publications Office of the European Union, 2025, data.europa.eu/doi/10.2833/1272986.

Lessons learned

Investments in renewable energy across European cities are not only technical and economic undertakings – they are deeply social processes. Successful urban energy transitions hinge on citizen engagement, social equity, and collaborative governance. The following lessons highlight the societal dimensions that must be addressed to ensure just, inclusive, and sustainable urban renewable energy development.

- **Citizen engagement and transparency are fundamental.** As permitting procedures are streamlined to accelerate project delivery, it remains essential to uphold transparency, inclusiveness, and environmental integrity. In densely populated urban environments, renewable energy projects often intersect with competing land-use priorities and community interests. Maintaining open dialogue, fostering public participation, and addressing concerns early in the planning process are key to securing broad-based support and minimising opposition.

- **Renewable projects as vehicles for social inclusion.** Urban renewable energy initiatives have the potential to deliver tangible social benefits, especially when designed to address energy poverty and promote equitable access to clean energy. Integrating affordability measures, supporting low-income households, and targeting underserved neighbourhoods can ensure that the transition is both environmentally and socially just. This reinforces public legitimacy and broadens the constituency for climate action.

- **Local participation drives ownership and long-term success.** Active involvement of residents, local businesses, and community groups is critical to building trust and a sense of shared ownership. Projects that engage citizens in co-design, co-investment, or decision-making processes are more likely to enjoy sustained public support and achieve long-term success. "Financial participation" mechanisms that share the economic benefits of new wind farms with nearby communities have proven effective in facilitating their siting. These include community benefit funds, citizen investment schemes, incentives for households closest to wind farms, and support for community ownership models[12,13].

- **Multi-stakeholder collaboration is essential.** The integration of renewables requires coordinated efforts across energy providers, local governments, technology developers, and city departments. Building shared visions, aligning timelines, and managing responsibilities are vital to navigating institutional complexity and unlocking synergies. Dedicated platforms for cross-sectoral collaboration can accelerate learning and innovation.

- **Effective governance and complaint management build trust.** New renewable projects often raise public concerns related to aesthetics, safety, or perceived disruption. Proactive community relations and grievance mechanisms are essential to address complaints, manage expectations, and foster constructive dialogue. Transparent processes for impact assessment, consultation, and mitigation can prevent resistance and demonstrate responsiveness to community needs.

- **Promoting energy citizenship requires greater public awareness.** To move from passive consumption to active participation, citizens must be informed, empowered, and motivated. Enhancing public understanding of energy systems, emissions impacts, and the role of renewables is critical. Educational campaigns, demonstration projects, and participatory tools can help cultivate a culture of "energy citizenship," in which residents see themselves as agents of change in the energy transition.

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12 Julia le Maitre, Price or public participation? Community benefits for onshore wind in Ireland, Denmark, Germany and the United Kingdom, Energy Research & Social Science, Volume 114, 2024, 103605, ISSN 2214-6296, doi.org/10.1016/j.erss.2024.103605.

13 S. Kerr, K. Johnson, S. Weir, Understanding community benefit payments from renewable energy development. Energy Policy, 105 (2017), pp. 202-211.

TECHNICAL ASPECTS

TECHNICAL ASPECTS

Non-combustible renewables

Solar power[14]

Solar energy plays a critical role in the transformation of urban energy systems across Europe. In 2024, photovoltaic (PV) electricity accounted for 11% of the EU's gross electricity production, with steady growth expected in both large-scale solar farms and building-level installations[15]. As cities strive for climate neutrality, solar technologies, in particular when integrated into urban infrastructure, offer scalable, cost-effective, and job-creating solutions.

Photovoltaics

Photovoltaic panels convert sunlight into electricity using solar cells and can be deployed across various urban settings, on rooftops, facades, parking canopies, ground mounted and even floating on water bodies. There are two main types of urban PV installations:

- **Building-Applied Photovoltaics (BAPV):** The most common method, where panels are mounted on existing building surfaces, such as rooftops or facades.
- **Building-Integrated Photovoltaics (BIPV):** These systems replace conventional building materials (e.g. glazing or cladding), serving both architectural and energy-generating functions.

BIPV offers strong potential in dense urban areas with limited rooftop space, such as high-rise residential and office buildings. It enables dual use of the building envelope, supports aesthetic integration, and can lower installation costs by substituting construction materials.

To maximise impact, PV systems are increasingly paired with energy storage, heat pumps, district heating/cooling networks, and Building Energy Management Systems (BEMS). These integrations improve self-consumption, enhance grid flexibility, and help manage peak electricity demand, especially when combined with demand-side response measures.

Deployment models include:

- Individual self-consumption, often combined with BEMS, batteries or vehicle-to-grid (V2G) systems
- Collective self-consumption and energy sharing in multi-family or public buildings
- Energy communities[16] or cooperatives, enabling citizens to co-invest in shared solar capacity
- ESCO-based models, facilitating third-party investment and operation

However, solar PV deployment may face limitations in heritage-protected areas (e.g. UNESCO sites like Bruges, BE), requiring careful architectural and regulatory coordination.

Solar Thermal

Widely used for domestic hot water and space heating, solar thermal systems are predictable, low-cost, and fuel-free. They are especially viable in Eastern and South-Eastern Europe, where they offer one of the most affordable alternatives to fossil fuels. In northern Europe solar thermal systems can be also efficiently integrated with heat storage solutions.Wind power

14 See also: smart-cities-marketplace.ec.europa.eu/insights/solutions/catching-sunlight-solar-heat-cities; and smart-cities-marketplace.ec.europa.eu/insights/solutions/discover-solar-district-heating; smart-cities-marketplace.ec.europa.eu/insights/solutions/solar; smart-cities-marketplace.ec.europa.eu/insights/solutions/thermal-energy-storage.

15 ember-energy.org/data/electricity-data-explorer

16 smart-cities-marketplace.ec.europa.eu/insights/solutions/solution-booklet-energy-communities-0

Vojens, Denmark: Seasonal Solar Heat Storage

The world's largest seasonal solar heat storage system has been in operation since 2016. This innovative project demonstrates how solar thermal energy, when integrated into an existing district heating network, can deliver substantial environmental and economic benefits.

Operated by Vojens Fjernvarme, the system supplies heat to approximately 2,000 households. Around 45% of their annual heating needs are met by solar energy stored in a vast, insulated pit filled with water and gravel. The storage facility, built in a repurposed gravel pit, holds 200,000 cubic meters of thermal energy. It measures thirteen meters deep with a circumference of 610 meters and is charged over five months using solar heat collected from 70,000 square meters of solar thermal panels. The system is supported by a mix of other energy sources, including gas engines, an electric boiler, a gas boiler, and an absorption heat pump.

The pit storage is insulated with a 60-centimeter layer of clay and a plastic liner to retain heat effectively over the seasons. Thanks to this setup, residents enjoy heating bill reductions of 10 to 15 percent, and for the solar-covered share of demand, no additional fuel is required, only amortisation of the initial investment. The system avoids approximately 6,000 tonnes of CO_2 emissions each year.

In 2020, the cost of building similar large-scale heat storage was around thirty euros per cubic meter for volumes exceeding 100,000 cubic meters. For households in Vojens, the investment per home was about 1,500 euros, including one hundred cubic meters of storage capacity and 35 square meters of solar collectors.

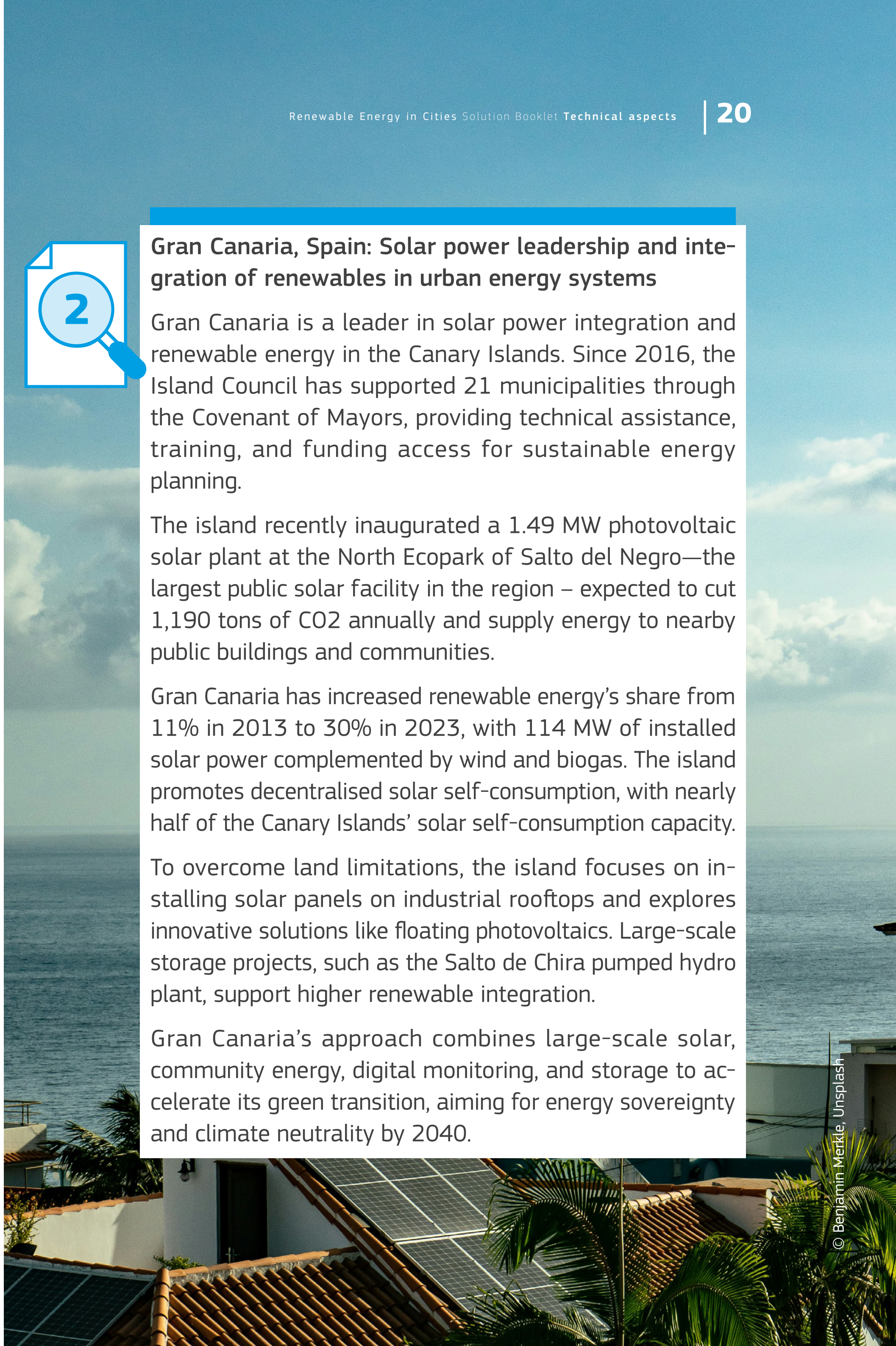
The success of the Vojens project shows that, when financing for solar thermal and seasonal storage can be secured, both environmental impact and household heating costs can be significantly reduced. Given that Denmark has relatively low solar radiation, the model holds even greater promise for sunnier regions across Europe.

Vojens district heating | Map data ©2025 Google

Concentrated Solar Power (CSP)

Although limited in Europe (approx. 2.3 GW installed since 2013), CSP, particularly when combined with thermal storage has potential for industrial heat applications and hybrid systems in sunny regions.

To meet EU climate targets, urban solar development must evolve from isolated installations to fully integrated systems that interact with buildings, grids, and thermal networks. Incentive schemes and building codes should increasingly support multifunctional solar solutions – like BIPV – to unlock the untapped potential of Europe's urban environments.



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Gran Canaria, Spain: Solar power leadership and integration of renewables in urban energy systems

Gran Canaria is a leader in solar power integration and renewable energy in the Canary Islands. Since 2016, the Island Council has supported 21 municipalities through the Covenant of Mayors, providing technical assistance, training, and funding access for sustainable energy planning.

The island recently inaugurated a 1.49 MW photovoltaic solar plant at the North Ecopark of Salto del Negro—the largest public solar facility in the region – expected to cut 1,190 tons of CO2 annually and supply energy to nearby public buildings and communities.

Gran Canaria has increased renewable energy's share from 11% in 2013 to 30% in 2023, with 114 MW of installed solar power complemented by wind and biogas. The island promotes decentralised solar self-consumption, with nearly half of the Canary Islands' solar self-consumption capacity.

To overcome land limitations, the island focuses on installing solar panels on industrial rooftops and explores innovative solutions like floating photovoltaics. Large-scale storage projects, such as the Salto de Chira pumped hydro plant, support higher renewable integration.

Gran Canaria's approach combines large-scale solar, community energy, digital monitoring, and storage to accelerate its green transition, aiming for energy sovereignty and climate neutrality by 2040.

Marseille, France: Fostering Energy Communities

The city of Marseille is following a transformative approach to renewable energy through the development of energy communities – collaborative, citizen-led initiatives that integrate solar power production within local neighbourhoods. By combining grassroots movements with strong municipal support and partnerships with local energy companies, Marseille is creating a dynamic and sustainable urban energy ecosystem.

Marseille's strategy focuses on amplifying citizen engagement and empowering local actors to produce and consume renewable energy close to home. Key projects involve installing solar panels on residential buildings, public schools, and cultural facilities, including the successful solar coverage of a local art centre. These initiatives foster local ownership of energy production and help reduce reliance on centralized fossil-fuel power.

At the heart of this approach are energy communities – groups of residents, organisations, and businesses collaborating to generate renewable energy for their neighbourhoods. Marseille aims to establish such communities with a one-kilometre radius, enabling buildings to share and consume locally produced solar energy efficiently.

Collaboration has been essential to Marseille's success. The city has partnered with citizen-led groups like Marseillia Sun Systems and cooperatives such as Enercoop, which has long promoted the development of energy communities across France. These partnerships ensure local expertise and citizen participation remain central to the city's renewable energy transition.

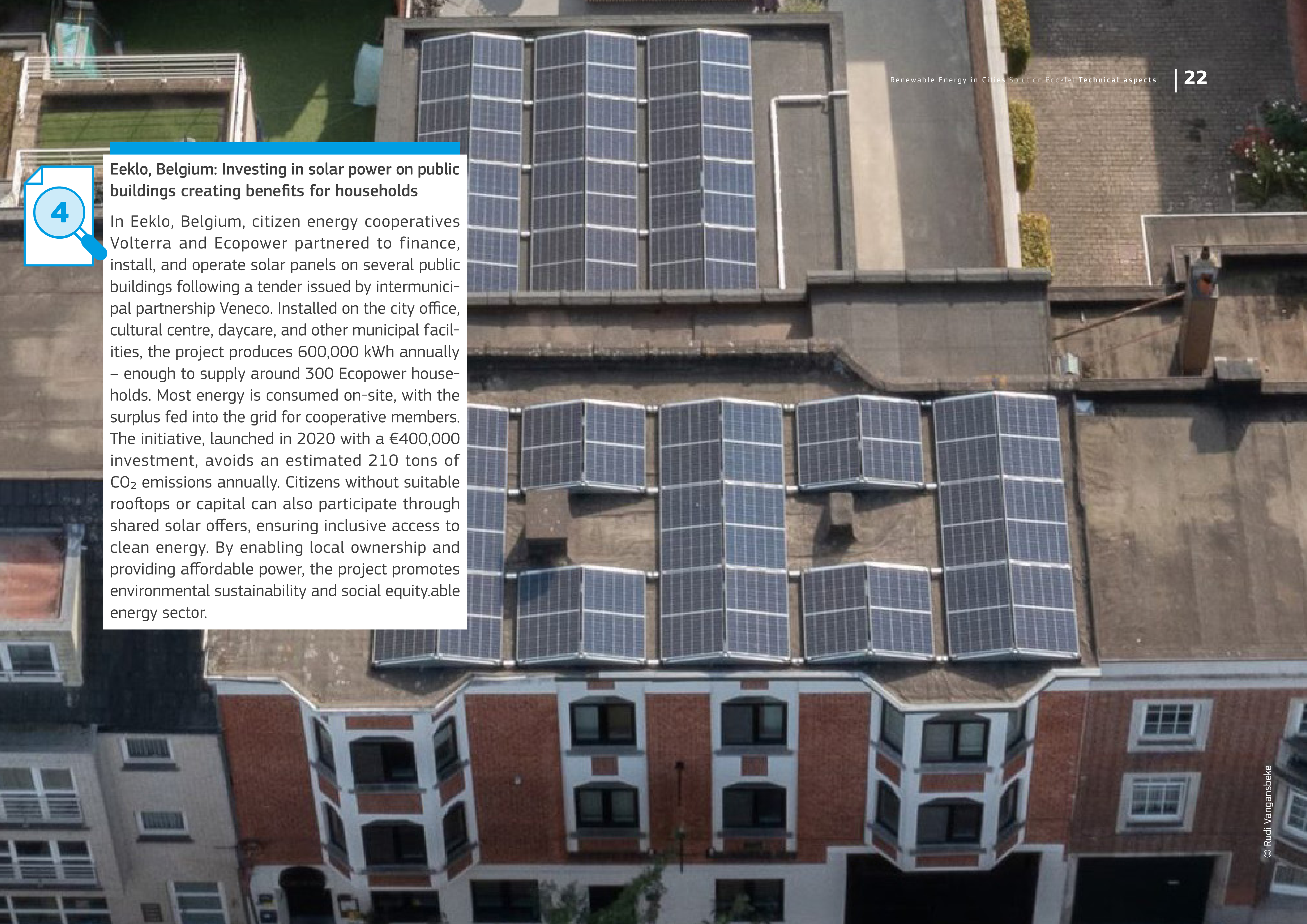
Notably, Marseille partners with citizen-led groups and cooperatives through public-private or community-based contracts. These agreements allow cooperatives like Enercoop to develop, operate, and maintain solar installations on public and residential buildings, often using public rooftops or infrastructure provided by the city. Thus, energy is produced locally by the community or cooperative, then consumed by residents or sold to the grid. Revenues are shared or reinvested, reducing energy bills and promoting community ownership.

Further strengthening this ecosystem, Marseille is launching a municipal energy company dedicated to renewable energy production. This company will serve as a catalyst, blending public investment and community initiatives to foster a self-sustaining, locally controlled energy market.

In addition, the ambitious Sirius project epitomises Marseille's integrated approach to renewable energy and energy efficiency. This large-scale renovation initiative combines extensive solar energy production with deep energy retrofits to reduce emissions by 90%, heating demand by 80%, and increase renewable energy share by 20%.

Sirius actively involves citizens, enabling local production and consumption models that offer tangible benefits such as significant cost savings for residents, including renters. While the goal to provide free electricity to renters presents regulatory and consumption management challenges, the project highlights the potential of energy communities to reshape urban energy landscapes.

Looking ahead, Marseille also plans to scale up its energy community model by involving more local businesses and encouraging corporate investment in renewable energy projects. This multi-stakeholder approach will ensure broad-based economic participation, support local jobs and foster innovation in the renewable energy sector.



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Eeklo, Belgium: Investing in solar power on public buildings creating benefits for households

In Eeklo, Belgium, citizen energy cooperatives Volterra and Ecopower partnered to finance, install, and operate solar panels on several public buildings following a tender issued by intermunicipal partnership Veneco. Installed on the city office, cultural centre, daycare, and other municipal facilities, the project produces 600,000 kWh annually – enough to supply around 300 Ecopower households. Most energy is consumed on-site, with the surplus fed into the grid for cooperative members. The initiative, launched in 2020 with a €400,000 investment, avoids an estimated 210 tons of CO_2 emissions annually. Citizens without suitable rooftops or capital can also participate through shared solar offers, ensuring inclusive access to clean energy. By enabling local ownership and providing affordable power, the project promotes environmental sustainability and social equity.able energy sector.

Wind energy is a key driver of the EU's clean energy transition, providing 39% of renewable electricity generation in 2024. Technological improvements, better site selection, and falling costs have consolidated its role in achieving EU energy and climate targets. While large-scale deployment is typically rural or offshore, wind energy is increasingly relevant to urban energy system integration, especially in industrial and port areas near cities.

In dense urban environments, large wind turbines are typically unsuitable due to noise, vibrations, and limited space. However, targeted deployment in peri-urban industrial zones and ports can support urban grids. These areas offer:

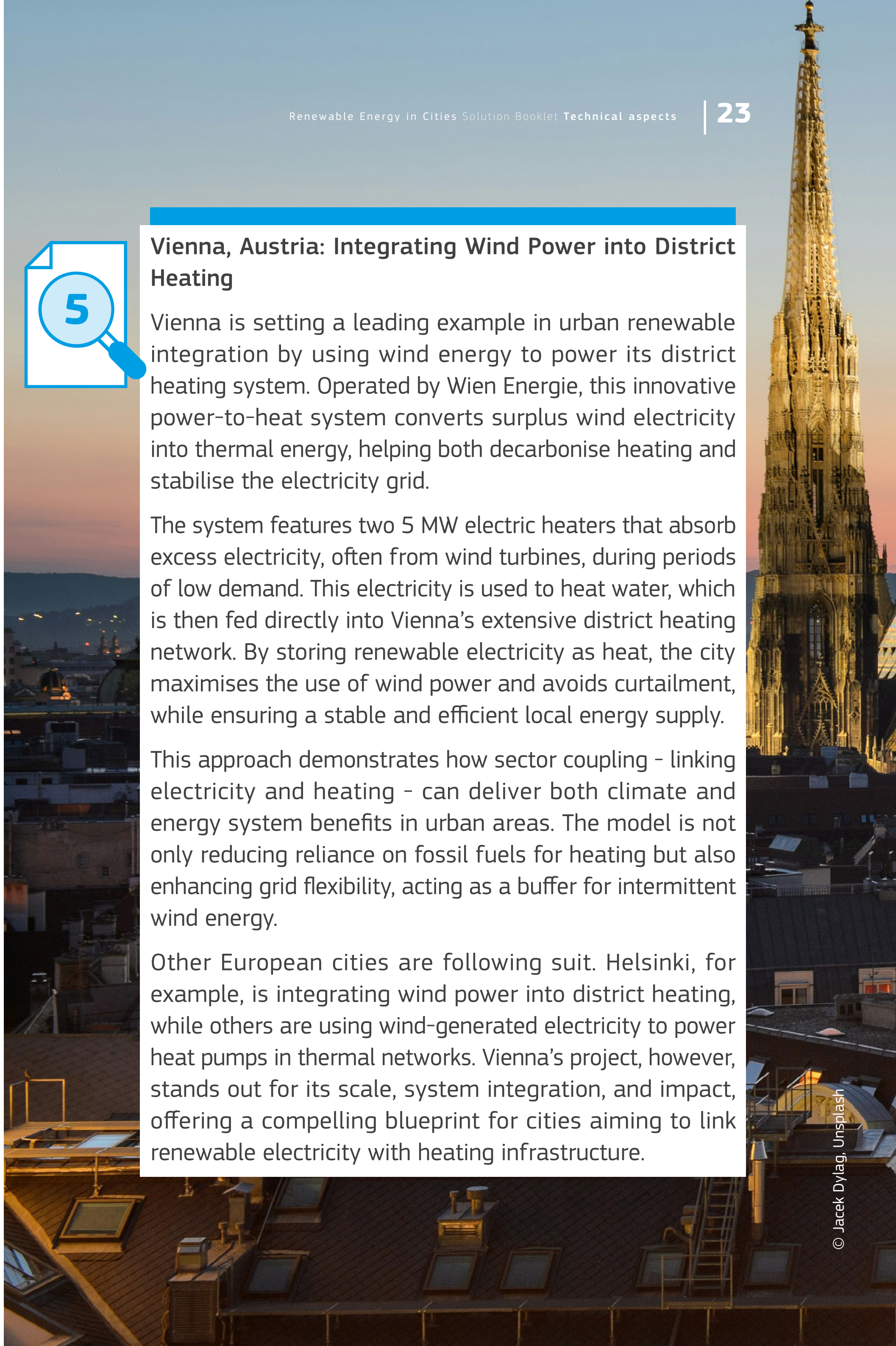
- Proximity to existing infrastructure and high electricity demand
- Easier integration with district energy systems
- Fewer land-use and social acceptability conflicts.

In select cases, building-integrated small wind turbines or vertical-axis systems may complement solar and geothermal technologies in mixed-use districts, though output remains limited.

Wind energy's variability requires integration into smart urban energy systems that combine multiple renewables[17] with storage, flexible demand, and digital controls. Urban wind contributes to this mix by:

- Feeding directly into local microgrids or district energy networks
- Reducing reliance on fossil backup during peak demand
- Enhancing resilience and decentralisation of urban energy supply

17 Wind power is quite often complementary to sun: when there is little sun there is often much wind and opposite, however with many nuances. As an example, see: nordpoolgroup.com/en/the-power-market/the-complementary-nature-of-wind-and-solar-energy-in-europes-energy-transition



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5 Vienna, Austria: Integrating Wind Power into District Heating

Vienna is setting a leading example in urban renewable integration by using wind energy to power its district heating system. Operated by Wien Energie, this innovative power-to-heat system converts surplus wind electricity into thermal energy, helping both decarbonise heating and stabilise the electricity grid.

The system features two 5 MW electric heaters that absorb excess electricity, often from wind turbines, during periods of low demand. This electricity is used to heat water, which is then fed directly into Vienna's extensive district heating network. By storing renewable electricity as heat, the city maximises the use of wind power and avoids curtailment, while ensuring a stable and efficient local energy supply.

This approach demonstrates how sector coupling - linking electricity and heating - can deliver both climate and energy system benefits in urban areas. The model is not only reducing reliance on fossil fuels for heating but also enhancing grid flexibility, acting as a buffer for intermittent wind energy.

Other European cities are following suit. Helsinki, for example, is integrating wind power into district heating, while others are using wind-generated electricity to power heat pumps in thermal networks. Vienna's project, however, stands out for its scale, system integration, and impact, offering a compelling blueprint for cities aiming to link renewable electricity with heating infrastructure.

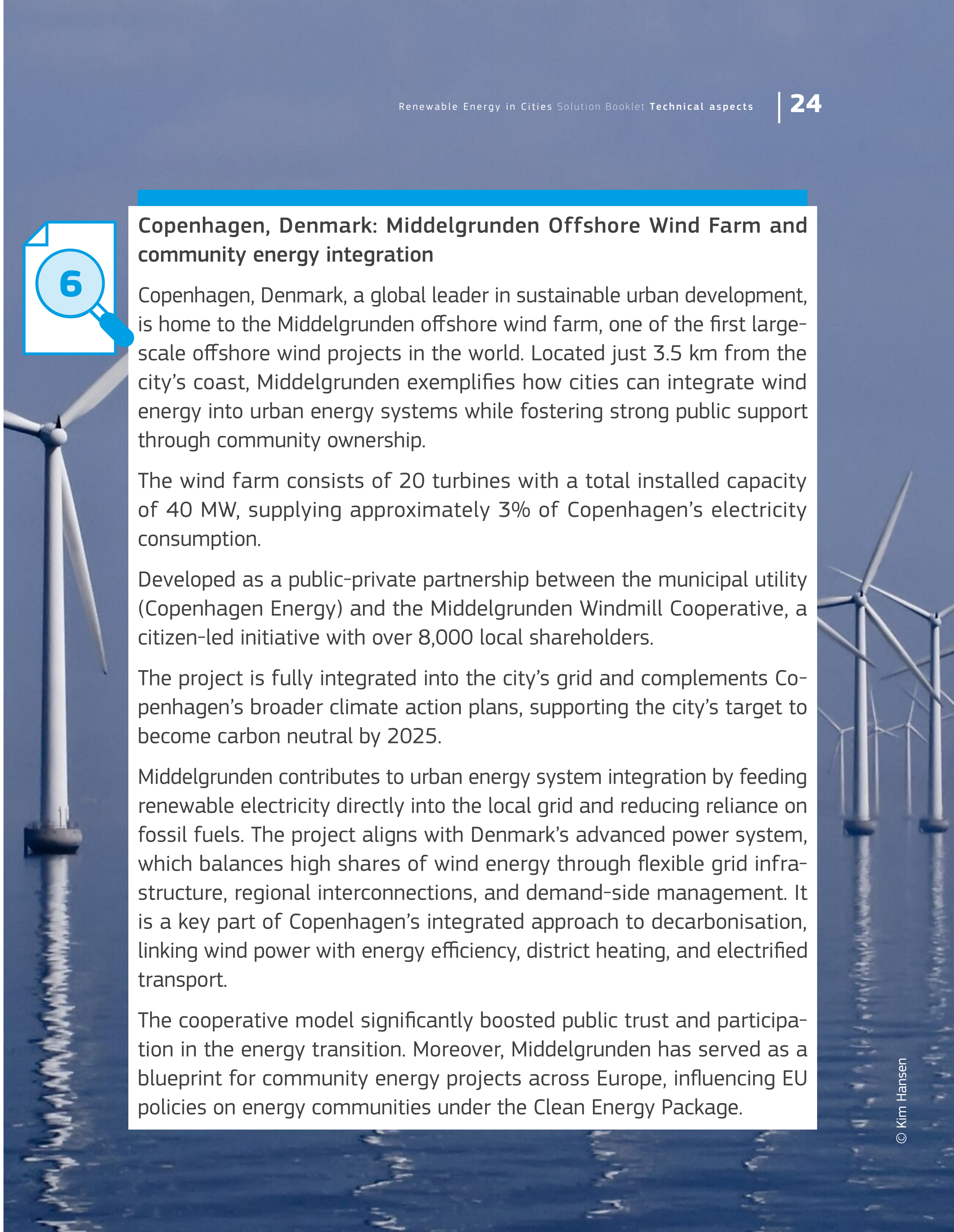
Through the EU Wind Power Package (2023), the European Commission is advancing wind energy manufacturing and deployment. Key measures include:

- Faster permitting and renewables acceleration zones
- Improved auction design with sustainability criteria[18]
- Expanded financial tools through the Innovation Fund and EIB
- Workforce development under the Blueprint Alliance for renewables

Offshore wind, including floating platforms, is rapidly scaling and offers significant potential to supply not only coastal, but also inland cities. With only 1.2 GW installed in 2022, EU ambitions target annual additions of up to 12 GW to meet climate goals. Offshore wind can deliver large volumes of renewable electricity directly to urban coastal grids, reducing dependence on imports and supporting urban electrification strategies.

While technical and spatial constraints limit large-scale wind installations inside cities, strategic integration of peri-urban, industrial, and offshore wind capacity into urban energy systems offers a powerful pathway to decarbonise cities and enhance their energy independence.

18 The Renewable Energy Auctions Platform launched in 2024 increases transparency and planning certainty for industry, including wind.



6

Copenhagen, Denmark: Middelgrunden Offshore Wind Farm and community energy integration

Copenhagen, Denmark, a global leader in sustainable urban development, is home to the Middelgrunden offshore wind farm, one of the first large-scale offshore wind projects in the world. Located just 3.5 km from the city's coast, Middelgrunden exemplifies how cities can integrate wind energy into urban energy systems while fostering strong public support through community ownership.

The wind farm consists of 20 turbines with a total installed capacity of 40 MW, supplying approximately 3% of Copenhagen's electricity consumption.

Developed as a public-private partnership between the municipal utility (Copenhagen Energy) and the Middelgrunden Windmill Cooperative, a citizen-led initiative with over 8,000 local shareholders.

The project is fully integrated into the city's grid and complements Copenhagen's broader climate action plans, supporting the city's target to become carbon neutral by 2025.

Middelgrunden contributes to urban energy system integration by feeding renewable electricity directly into the local grid and reducing reliance on fossil fuels. The project aligns with Denmark's advanced power system, which balances high shares of wind energy through flexible grid infrastructure, regional interconnections, and demand-side management. It is a key part of Copenhagen's integrated approach to decarbonisation, linking wind power with energy efficiency, district heating, and electrified transport.

The cooperative model significantly boosted public trust and participation in the energy transition. Moreover, Middelgrunden has served as a blueprint for community energy projects across Europe, influencing EU policies on energy communities under the Clean Energy Package.

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7

Valencia, Spain: Integrating regional wind energy into a climate-neutral urban strategy

Valencia is advancing an ambitious and integrated approach to achieving climate neutrality. A key component of its strategy is the integration of wind energy produced in the broader Valencian Community into the city's urban energy system.

Although most wind installations are located outside the urban core, Valencia is actively working to connect this regional renewable energy to its local grid. The city's plan includes coordinated renewable energy procurement, investment in smart and green electricity infrastructure, and the deployment of digital energy management systems to ensure efficient and flexible energy use.

This integration of regional wind power forms part of a wider urban energy system transformation, aligned with both local and European climate objectives. Valencia also benefits from EU technical support and funding instruments, including those provided through the NetZeroCities platform, to accelerate implementation and de-risk innovation.

This project demonstrates effective urban-regional collaboration for decarbonisation, highlights the role of cities in integrating off-site renewables into their local systems, and combines wind energy with smart grid infrastructure and digital tools for system-level optimisation.

8

Eeklo, Belgium: Citizen-led wind energy through an energy community

Eeklo, a small municipality in the Flanders region of Belgium, has become a leading example of how local governments can harness wind energy through citizen participation and community ownership. With a long-standing commitment to sustainability, the city actively supports renewable energy production that aligns with public interests.

Municipal partnership with Ecopower, a Belgian renewable energy cooperative, enabled the development of several wind turbines within the city boundaries.

The city uses concession contracts that prioritise public value, granting rights to install turbines only to actors who commit to local ownership, transparency, and reinvestment in the community.

Citizens co-own the wind turbines through Ecopower, receiving dividends and benefiting from lower-cost renewable electricity.

The project is part of a broader local energy system strategy, which includes integrating wind with solar PV, demand-side management, and prosumer engagement.

Eeklo's approach has significantly increased local acceptance of wind energy, even in urban or peri-urban settings where such projects can be controversial. By linking energy production to citizen empowerment, public benefit, and system integration, the city has created a model of energy democracy that is now being replicated across Flanders and studied across Europe.

Geothermal energy[19]

Geothermal energy is a renewable, sustainable, and secure energy source derived from within the earth's crust, usually in the form of hot water or steam. It can be harnessed for a wide range of applications, including electricity generation, district and water heating, industrial processes, and agricultural uses. While currently representing a small share of the EU's renewable energy mix[20], geothermal energy holds significant potential to contribute to the objectives of the European Green Deal and the EU's commitment to achieving climate neutrality by 2050.

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19 See also: smart-cities-marketplace.ec.europa.eu/insights/solutions/geothermal-heat-remnants-big-bang
20 About 2.7% of total renewable energy production in the EU. eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52023DC0650#document2

Deep High-Temperature and Shallow Low-Temperature Geothermal Systems

Geothermal energy systems are broadly divided into two fundamentally different paradigms: deep high-temperature (HT) geothermal and shallow low-temperature (LT) geothermal. These systems differ in their geological depth, energy output, infrastructure requirements, and applications, as briefly explained below.

Deep High-Temperature (HT) Geothermal

HT geothermal systems exploit heat from deep underground reservoirs, typically at depths greater than 1,500 meters, where temperatures often exceed 150°C. These systems are primarily used for electricity generation and large-scale district heating. They require advanced drilling technologies, high-pressure piping, and often involve complex geological assessments. Deep geothermal projects are capital-intensive but can deliver continuous, high-capacity energy output with extremely low emissions.

Shallow Low-Temperature (LT) Geothermal

LT geothermal systems, by contrast, extract thermal energy from near-surface ground layers, usually within 10 to 400 meters depth, where temperatures are relatively stable (8–20°C). These systems use ground-source heat pumps to provide heating and cooling for buildings. LT geothermal is scalable, widely deployable across Europe, and suitable for individual buildings or small networks, but it does not produce electricity.

Key Differences at a Glance

- **Depth:** HT > 1,500 m; LT < 400 m
- **Temperature:** HT > 150°C; LT ~10–20°C
- **Applications:** HT – electricity and large-scale heating; LT – building-level heating/cooling
- **Technology:** HT – deep drilling, turbines; LT – heat pumps
- **Investment scale:** HT – high; LT – moderate to low

Understanding this distinction is essential for targeted policy support, regulatory frameworks, and funding mechanisms tailored to the unique characteristics and use cases of each geothermal technology.

Unlike other renewable energy sources such as wind and solar, geothermal energy is not subject to weather variability. This enables a continuous and stable supply of energy, making it an asset for electricity grid stability and system resilience.

Geothermal energy is particularly efficient for heating and cooling, offering high energy yields with low transmission losses. Its direct-use applications, such as space heating can be deployed at local and regional levels, contributing to decarbonisation and improved energy security.

Moreover, the development of geothermal energy supports local economies, stimulates job creation, and fosters innovation in clean energy technologies.

Geothermal energy can be deployed across various sectors and end-uses, including:

- → **District heating and cooling systems**
- → **Heating for agriculture and food production**
- → **Domestic hot water supply**
- → **Industrial processes (e.g. drying and cooling)**
- → **Electricity generation from high-temperature geothermal resources.**

Electricity generation from geothermal resources is well established in high-enthalpy areas – typically volcanic regions such as Italy. However, technological advancements in drilling techniques, enhanced geothermal systems, and more efficient surface power plants are expanding the geographical range of geothermal development. These innovations now allow for the exploitation of geothermal energy in areas with lower natural heat flow.

Despite its promise, the expansion of geothermal energy in Europe faces several challenges:

- → **High upfront costs, particularly for exploration and drilling**
- → **Limited availability and resolution of geological data**
- → **Technical risks associated with resource development**
- → **Lack of public awareness and social acceptance**
- → **Shortage of skilled professionals in geothermal technologies.**

Momentum is growing across the EU, with several Member States adopting national geothermal strategies[21] and supporting pilot projects at city and regional levels. Geothermal energy is recognised as a key enabler for achieving EU climate and energy targets, particularly in the context of heating and cooling decarbonisation.

The EU defines geothermal energy as “energy stored in the form of heat beneath the surface of the solid Earth.” As interest in local, clean, and resilient energy solutions rises, geothermal energy is poised to play an increasingly significant role in Europe’s sustainable energy future.

Depending on the geological characteristics and temperature of the geothermal source, technologies are adapted to either direct use (e.g. thermal applications) or indirect use (e.g. electricity production). Most geothermal systems require drilling, often reaching depths of several kilometres to access geothermal fluids.

21 Ireland, the Netherlands, Poland, Croatia, France, and Germany have created national geothermal roadmaps aiming at making investment in geothermal projects more attractive and encouraging their development.

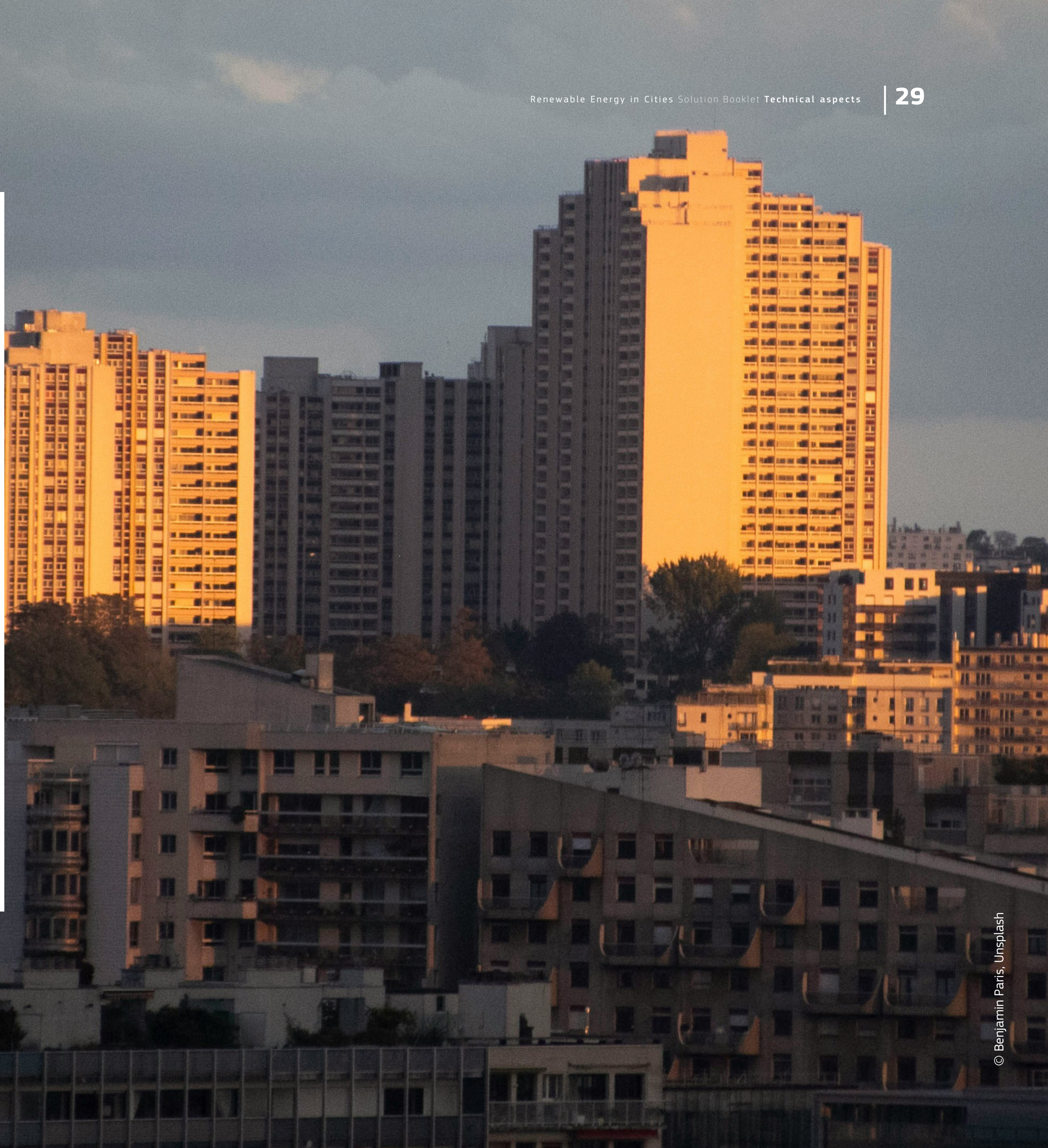
10

Issy-Les-Moulineaux, France: Shallow Low-Temperature geothermal energy powering an eco-neighbourhood

Issy Cœur de Ville is a 100,000 m^2 mixed-use, pedestrian-friendly eco-neighbourhood in Issy-les-Moulineaux, part of the Greater Paris metropolitan area. Designed for a connected, low-carbon urban lifestyle, the neighbourhood integrates deep environmental planning with cutting-edge energy infrastructure – at the heart of which is a geothermal district energy network supplying heating, cooling, and domestic hot water.

Currently, 78% of the neighbourhood's energy demand is met through low-depth geothermal energy, leading to annual savings of approximately 600 tonnes of CO_2 compared to conventional fossil-based systems.

At a depth of 35 metres, groundwater at a constant temperature of 15.8°C is extracted to serve two separate networks—a hot loop and a chilled loop—used for heating, domestic hot water, and cooling across the entire district. An innovative ice storage system enables simultaneous heat and cold production, improving efficiency and offering climate-resilient indoor comfort.



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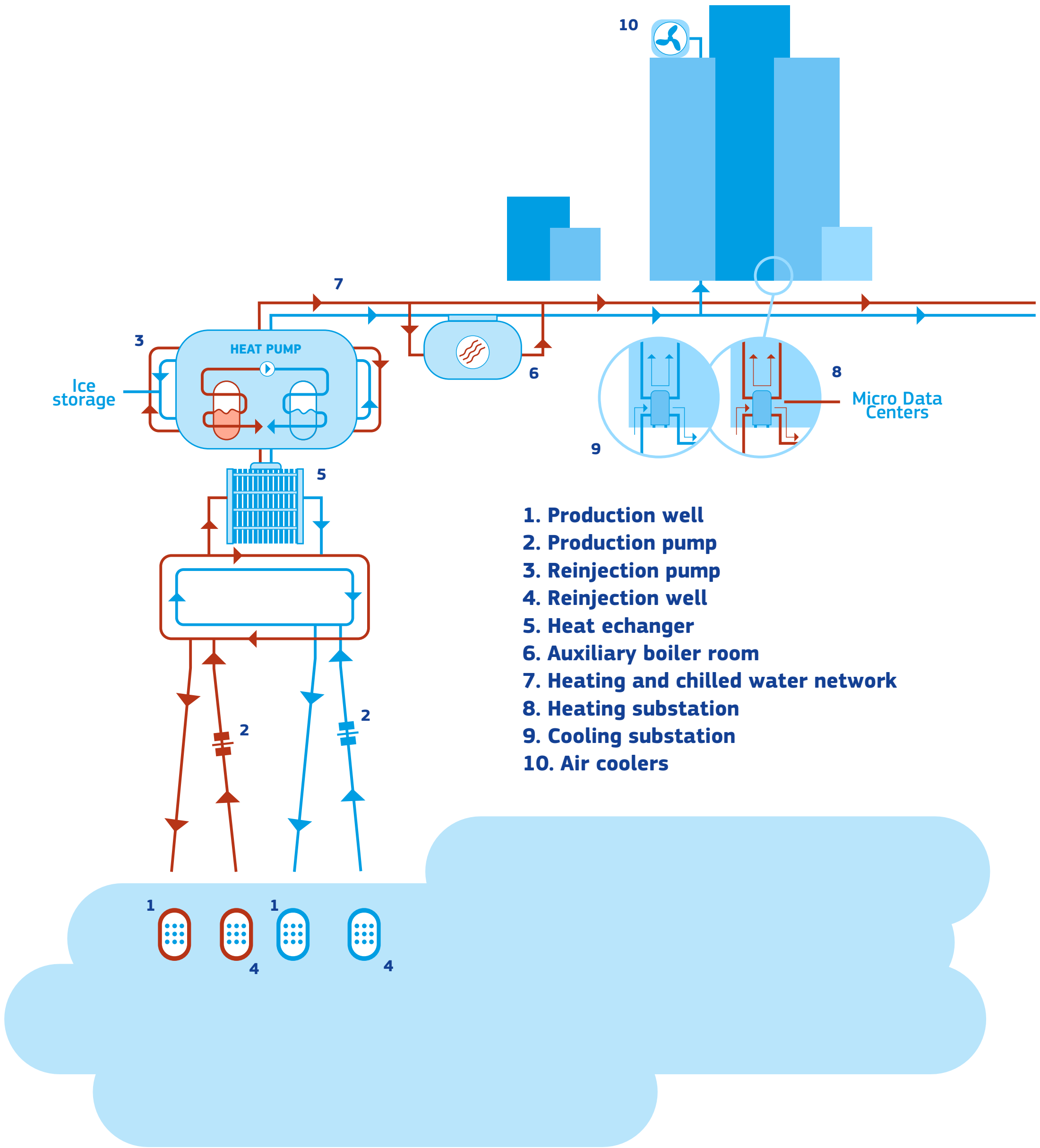

A virtuous energy mix. Figure recreated from rezomee.fr/issy-coeur-de-ville-energies/mix-energetique-issy-coeur-de-ville

The infrastructure includes:

- 627 housing units
- 40,000+ m^2 of offices including CNP Assurances HQ
- Cinema, retail, school, nursery, and community hall
- 4 geothermal wells with 180 m^3/h flow
- 8 km energy network with 18 substations
- 1,159 tonnes of CO_2 avoided to date
- 75% renewable share for heating, 70% for cooling
- CO_2 emissions 2.5x lower than conventional AC systems

A robust public-private partnership between the City of Issy-les-Moulineaux, ENGIE Solutions, and Altarea was crucial for implementation. Private developers were tasked with integrating the energy systems as part of broader urban development objectives, aligning municipal and national environmental strategies.

This case illustrates how geothermal energy can be effectively integrated into new urban developments, particularly where shallow aquifers are available. By providing centralised cooling, such systems help curb the spread of individual air conditioning units – likely to increase with more frequent heatwaves – while also reducing urban heat islands. With low greenhouse gas emissions and a primarily renewable supply, geothermal networks support local energy resilience. A key benefit is shielding residents from fossil fuel price volatility and energy tax fluctuations.

Bilbao, Spain: Geothermal energy and integrated planning in the Zorrotzaurre positive energy district

As part of the ATELIER project and Bilbao's Strategy for Sustainable and Integrated Urban Development, the Zorrotzaurre district is being transformed into a smart, climate-neutral neighbourhood powered by renewable energy. A low-temperature geothermal ring supplies space heating to buildings within the district, forming the backbone of the PED's integrated energy system.

The district features a geo-exchange loop connecting three development zones – North, Centre, and South – using geothermal and hydrothermal[22] energy to meet local heating needs. Surplus heat will be redistributed across Zorrotzaurre and potentially beyond, maximising system efficiency.

Key features:

- 5,500 new homes
- 150,000 m² of office space
- 154,000 m² of public and citizen space
- 93,500 m² of social and cultural facilities

Bilbao's approach to geothermal energy demonstrates how PEDs can serve as testing grounds for future-ready energy systems. The geo-exchange network enables flexible, decentralised energy sharing, supporting broader urban decarbonisation goals.

22 "Hydrothermal" refers to geothermal energy that is extracted from naturally occurring underground reservoirs of hot water or steam. Unlike dry rock geothermal systems, hydrothermal systems rely on the presence of both heat and groundwater. This water is typically accessed through wells and can be used directly for heating or, at higher temperatures, for electricity generation. In the context of Zorrotzaurre's district energy system, hydrothermal energy involves tapping into aquifers or other underground water sources with moderate temperatures to supply heat via a geo-exchange loop.

12

Alba Iulia, Romania: Harnessing geothermal energy for public building

In 2022, Alba Iulia launched an ambitious energy retrofit project for its Residential Home for the Elderly, transforming it into a model of integrated renewable energy use. With EEA and Norway Grants support, the project combined geothermal, solar thermal, and photovoltaic systems into a unified, intelligent energy system. The total budget of the project was more than 1.2M EUR.

The key features of the project are:

- **Geothermal system** with 80 boreholes, 4 heat exchange pumps, and 3 indoor heat pumps
- **Refurbished solar thermal system** for domestic hot water and ground energy storage
- **New heating and cooling network** with fan coil units, towel radiators, room-by-room temperature control, and ventilation with heat recovery
- **Smart energy management system (BEMS)** for optimised operation based on real-time conditions
- **Backup high-efficiency condensing boilers and thermal storage** for flexibility and reliability

This integrated approach ensures year-round indoor comfort for elderly residents while drastically reducing energy use and CO_2 emissions. The BEMS maximises renewable input and coordinates system performance, making the facility more resilient and cost-efficient.

The project shows that geothermal energy can be successfully integrated in urban public buildings, that combining energy sources through intelligent controls enhances

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Hydropower

Hydropower harnesses the potential and kinetic energy of water to generate electricity, representing one of Europe's most significant renewable energy sources. It plays a vital role not only in renewable electricity production but also in providing essential flexibility and storage services that facilitate the integration of variable renewables such as solar and wind into the grid.

In 2024, hydropower produced nearly 30% of the EU's renewable electricity (about 355 TWh), playing a key role in stabilizing the continent-wide macro-grid, a high-voltage network linking countries to balance supply and demand across borders. In contrast, local energy infrastructures like Positive Energy Districts operate at a micro-grid level, focusing on decentralised, community-based energy production and consumption using renewables such as shallow geothermal and solar. While the macro-grid ensures large-scale grid stability, local systems enhance energy autonomy and efficiency in urban areas. They complement each other: local grids reduce strain on the macro-grid, which provides backup when local supply is insufficient. Together, they form an integrated, multi-level energy system for Europe's clean energy future. Hydropower plants provide both short-term and long-term flexibility to the electricity system, helping to balance supply and demand fluctuations. This flexibility is indispensable for managing the variable nature of solar and wind energy, ensuring reliable power availability.

Pumped storage hydropower (PHS) is particularly important, representing over 90% of the EU's electricity storage capacity[23]. By pumping water to higher reservoirs during low demand periods and releasing it to generate electricity during peak demand, PHS acts as a large-scale battery that supports grid stability and renewable integration.

Hydropower plants can be broadly classified into four main types:

- → **Storage/Dam Power Plants (SPP):** These facilities store water in reservoirs behind dams, allowing modulation of water flow and electricity generation. Reservoirs may be natural lakes or artificial.
- → **Run-of-River (ROR) Plants:** Utilising the natural flow of rivers with limited or no storage, these plants generate electricity based on the continuous flow of water.
- → **Pumped Storage Hydropower (PHS):** Comprising two reservoirs at different elevations, PHS stores energy by pumping water uphill when demand is low, then generating electricity by releasing water downhill during peak demand.
- → **Hidden Hydropower in Water Infrastructure:** Innovative schemes exploit the energy available in urban water distribution, irrigation, and wastewater systems, enabling hydropower generation integrated into everyday urban infrastructure.

23 QUARANTA, E., GEORGAKAKI, A., LETOUT, S., MOUNTRAKI, A., INCE, E. and GEA BERMUDEZ, J., Clean Energy Technology Observatory: Hydropower and Pumped Storage Hydropower in the European Union - 2024 Status Report on Technology Development, Trends, Value Chains and Markets, Publications Office of the European Union, Luxembourg, 2024, doi:10.2760/8354439, JRC139225.

In urban contexts, these diverse hydropower solutions offer opportunities to integrate renewable energy generation into city energy systems, particularly by utilizing existing water infrastructure and nearby water bodies.

Hydropower plants vary widely in scale, from large-scale facilities exceeding hundreds of megawatts to small-scale, mini-, micro-, and pico-hydropower plants producing less than 10 MW, 1 MW, 100 kW, and 5 kW, respectively. Small and micro-hydropower installations, often located close to or within urban environments, can contribute to decentralised energy production and support local energy resilience.

The generation capacity of hydropower depends on two factors: the water flow rate and the hydraulic head, which is the height difference between water source and turbine. Hydropower sites are classified by hydraulic head as very low head (<5 m), low head (<50 m), middle head (50–250 m), and high head (>250 m), each suited to different technologies and applications.

13

Vienna, Austria: Integrating Small-Scale Hydropower into Urban Infrastructure

In central Vienna, a small hydroelectric power plant on the Danube Island demonstrates how renewable energy can be effectively integrated within urban infrastructure. Supported by EU funding with €251,711 from the European Regional Development Fund under the “Investments in Growth and Employment Austria” programme (2014–2020), the plant uses a 15-metre screw turbine integrated into an existing weir system to generate over 400,000 kWh of clean electricity annually—enough to power around 130 households and save approximately 175 tonnes of CO_2 per year.

Designed to blend seamlessly with the environment, most of the system is underground, ensuring no visual or acoustic disturbance. It operates safely in a public recreation area and continues to support Vienna’s flood defence system. This project exemplifies how cities can harness overlooked energy potential in existing water management infrastructure to support decarbonisation, enhance resilience, and improve urban sustainability.

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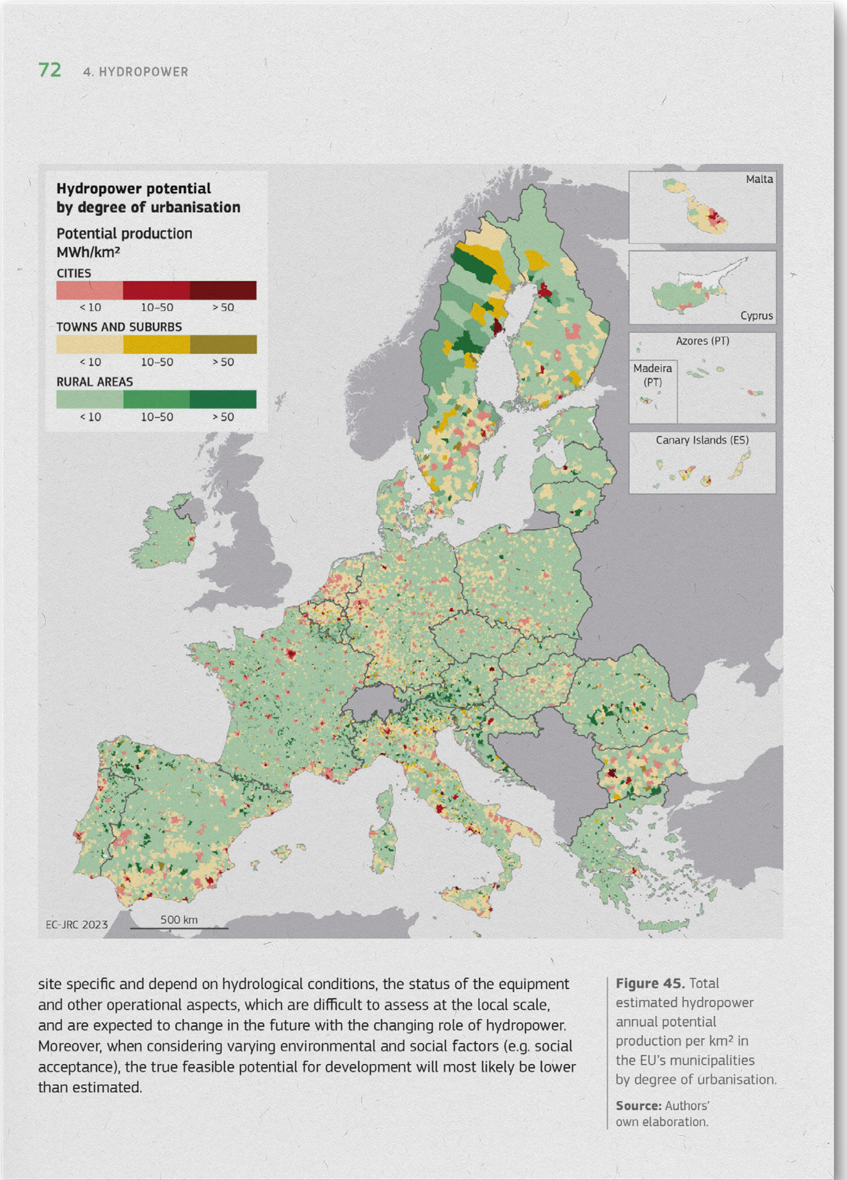
While hydropower is a clean, fuel-free renewable energy source with a long history dating back to water wheels, new installations must carefully address environmental impacts such as river ecosystem disruption and barriers to fish migration. Sustainable hydropower development balances energy benefits with ecological preservation, often incorporating fish ladders, bypass systems, and modernized infrastructure to mitigate impacts.



site specific and depend on hydrological conditions, the status of the equipment and other operational aspects, which are difficult to assess at the local scale, and are expected to change in the future with the changing role of hydropower. Moreover, when considering varying environmental and social factors (e.g. social acceptance), the true feasible potential for development will most likely be lower than estimated.

Figure 45. Total estimated hydropower annual potential production per km² in the EU's municipalities by degree of urbanisation.

Source: Authors' own elaboration.

Hydropower additional potential production in EU's municipalities estimated from modernization of aged plants, new development in water distribution networks, wastewater systems and water mills. Potential is shown by municipality unit area. Red dots represent suitable hydropower reservoirs for FPV systems. LAU is Local Administrative Unit.

Source: Quaranta, E., Georgakaki, A., Letout, S., Kuokkanen, A., Mountraki, A., Grabowska, M., Gea Bermudez, J. and Tattini, J., Clean Energy Technology Observatory: Hydropower and Pumped Hydropower Storage in the European Union - 2023 Status Report on Technology Development, Trends, Value Chains and Markets, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/841176, JRC134918; Dorati C. Quaranta, E., et al. (2023). Renewable energies in rural areas. Contribution to and benefit from the energy transition. JRC Science for Policy report.

publications.jrc.ec.europa.eu/repository/bitstream/JRC135612/JRC135612_01.pdf

14

Lappeenranta, Finland: Advanced energy storage facility enhancing renewable integration and grid stability

Lappeenranta, Finland, a city with a rich history in hydropower, is advancing its renewable energy ambitions by developing state-of-the-art energy storage solutions to support the integration of renewables into the urban energy system. A landmark project in this effort is the commissioning of one of Finland's largest energy storage facilities, delivered by Merus Power and operational since May 15, 2025.

This EUR 15 million energy storage installation, located in the Mertaniemi area, is jointly owned by Ardian's Clean Energy Evergreen Fund and the local energy provider Lappeenrannan Energia. With a capacity of approximately 38 megawatts (MW) and an energy storage capability of 43 megawatt-hours (MWh), it represents the largest energy storage facility currently in operation on the Finnish electricity market.

The facility's output corresponds to the generation capacity of a small power plant, while its nominal storage capacity can cover the electricity consumption of over 35,000 households, the size of Lappeenranta, for two hours. Such storage capacity is vital for balancing supply and demand, particularly as the share of variable renewable energy sources increases.

A key feature of this energy storage facility is its rapid response capability, adjusting to grid needs within fractions of a second. This fast-reacting flexibility is essential for maintaining the stability and reliability of Finland's power grid amidst fluctuating renewable generation from sources such as wind and solar.

The project was developed through a collaboration between Ardian Clean Energy Evergreen Fund's Finnish investment platform eNordic and Lappeenrannan Energia, ensuring alignment with regional energy strategies. The storage system operates as an integral part of the local energy infrastructure, enhancing the capacity to store renewable energy when it is abundant and release it when demand peaks.

This development underlines the critical role of energy storage in urban renewable energy systems, enabling cities like Lappeenranta to transition toward carbon-neutral energy futures by smoothing variability in renewable production and strengthening grid resilience.

15

Limerick, Ireland: integrating environmental heat and innovative hydropower in urban energy system

Limerick is at the forefront of urban renewable energy innovation, combining environmental heat recovery and small-scale hydropower to support local decarbonisation goals. As part of the EU-funded +CityxChange project, the city has pioneered the deployment of floating hydrokinetic turbines in the River Shannon, developed by Irish company GKinetic Energy.

These turbines harness the kinetic energy of low-speed river flows to generate electricity, offering a sustainable solution compatible with environmentally sensitive areas and strict urban planning regulations. Unlike traditional hydropower, the floating turbines require no dams or large-scale infrastructure, preserving river ecosystems and maintaining open access for recreational and emergency use.

Following a successful 2022 demonstration, Limerick City and County Council granted planning permission for three turbines to be installed upstream of Thomond Weir. The project has received strong community support, thanks to broad stakeholder engagement with river users and local organisations.

This initiative not only supports the city's Positive Energy Block ambitions but also lays the groundwork for establishing a Renewable Energy Community to own and operate the turbines locally. It exemplifies how small-scale hydropower can contribute to decentralised urban energy systems and enhance community participation in the clean energy transition.

Heat recovery

Ambient heat recovery[24, 25]

Ambient heat recovery refers to the process of capturing low-grade thermal energy naturally stored in the surrounding environment, such as air, water bodies, and the ground, and repurposing it for heating applications. This approach plays a key role in urban renewable energy strategies by enabling efficient and sustainable use of locally available heat sources.

The primary technology enabling ambient heat recovery is the heat pump. Heat pumps operate by extracting stored thermal energy from ambient sources and upgrading it to a higher temperature suitable for heating. Powered by electricity or other supplementary energy, heat pumps transfer this energy to heat spaces or domestic hot water. Common applications include underfloor heating systems in residential buildings, but heat pumps are also scalable for use in commercial, industrial, and public service sectors.

Importantly, this concept focuses on heat pumps used specifically for heating (including hot water production). Heat pumps can also be used for cooling purposes. Energy flows related to cooling functions, such as air conditioning, are excluded from this scope.

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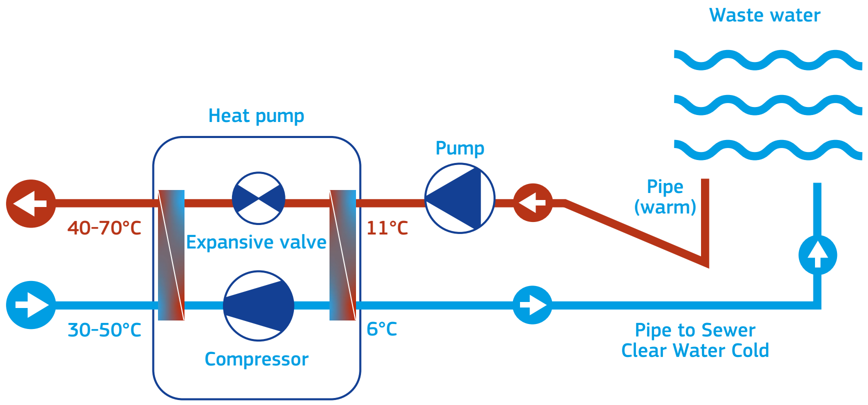
By leveraging ambient heat through heat pump technologies, cities can significantly reduce their reliance on fossil fuels for heating, improve energy efficiency, and contribute to broader climate and energy targets. This solution is adaptable for individual households as well as large-scale district heating networks, offering flexible pathways for decarbonising urban energy systems.

24 Lyons, L., Kavvadias, K. and Carlsson, J. Defining and accounting for waste heat and cold, EUR 30869 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-42588-5, doi:10.2760/73253, JRC126383.
25 See also: smart-cities-marketplace.ec.europa.eu/insights/solutions/making-use-excess-heat-assessment-methodology-urban-excess-heat-recovery



Heat recovery from waste water: Riothermia turns wastewater into a sustainable source of heat.
Figure adjusted from BOSAQ | bosaq.com/on-how-your-riddance-is-now-worth-millions

16

Leuven, Belgium: Riothermics integration

Leuven, Belgium, is a leading example of integrating innovative renewable energy technologies within urban energy systems, demonstrated through the successful application of Riothermics in its energy sector.

Riothermics is a technology that captures low temperature heat from sewage conducts and upgrades it using heat pumps for space heating and domestic hot water. By using heat exchangers embedded in the sewer system, thermal energy from sources such as shower and sink water is transferred to heat pumps, which can then be used to warm buildings and facilities like swimming pools. This approach significantly reduces reliance on fossil fuels while taking advantage of already existing infrastructure.

The City of Leuven, in collaboration with housing associations and energy partners, identified over 400 projects where the technology could be applied. The main benefits are a renewable heat supply: the system supplies renewable heat throughout the heating season, covering a substantial portion of the building's demand.

Riothermics is integrated seamlessly into the existing district heating network, complementing other renewable sources like solar thermal and biomass. This integration results in a substantial cut in greenhouse gas emissions, aligning with Leuven's commitment to climate neutrality. The project delivers affordable and sustainable heating solutions to social housing residents, improving also energy equity and quality of life.

17

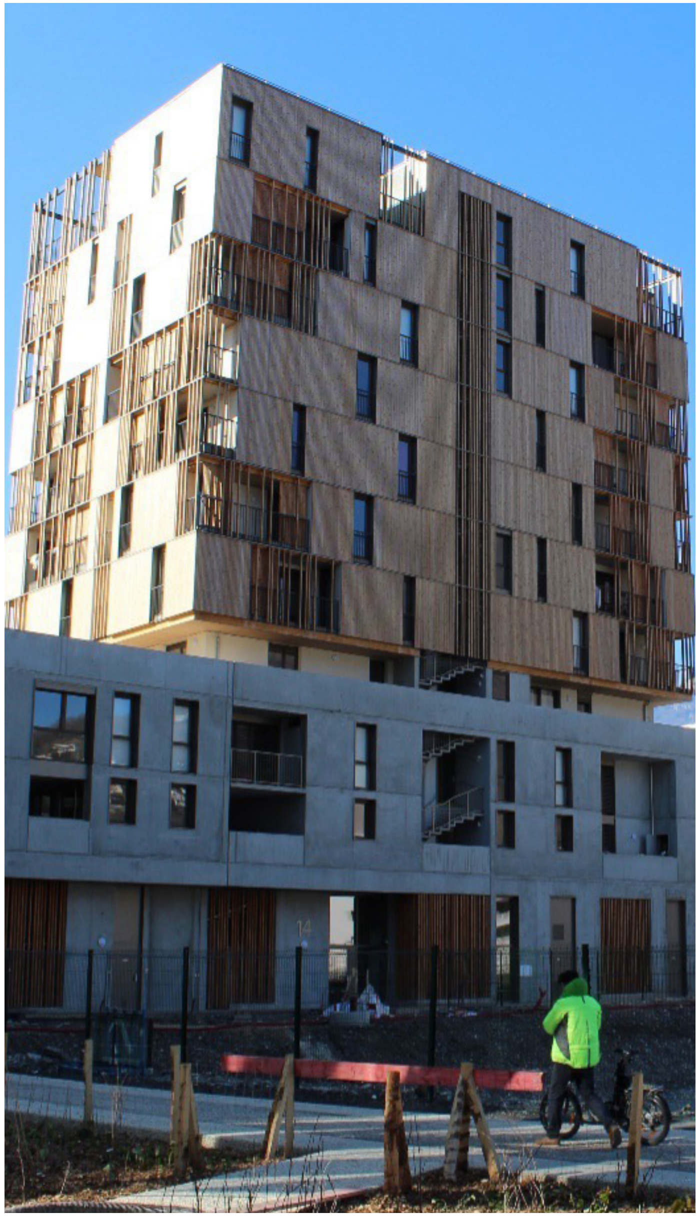
Grenoble, France: Regulatory challenges for heat sourcing from the Isère river (City-Zen Project)

The City-Zen project in Grenoble, France, illustrates the regulatory challenges and solutions involved in integrating river-sourced heat into urban energy systems. The project aimed to implement an aquathermic system extracting low-grade heat from the Isère River to supply heating for residential and commercial buildings, significantly reducing fossil fuel dependency.

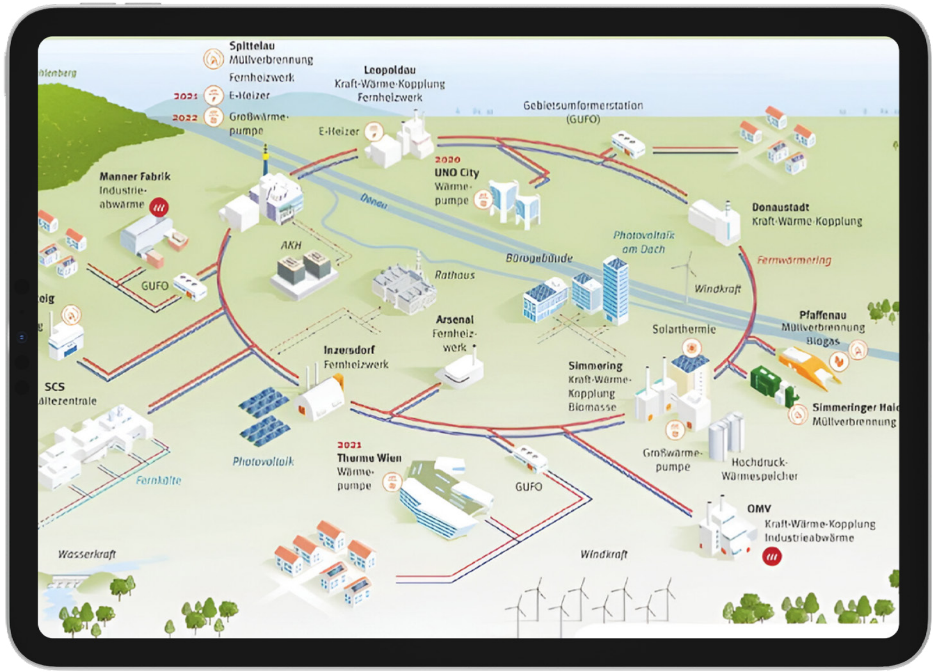
However, the use of river water as a renewable heat source required comprehensive environmental assessment and regulatory approval to prevent adverse effects on aquatic ecosystems, water quality, and existing water uses such as recreation and fisheries.

The project partners began by engaging with local environmental and water authorities to identify applicable regulations and potential environmental risks. Early studies assessed impacts on river temperature, flow, and aquatic habitats. Due to the river's ecological significance and its status under European water directives, the permit process involved multiple layers of authority, including municipal, regional, and national authorities. As questions about potential environmental impacts and permit conditions became more complex, unresolved issues were escalated to the responsible national ministry. This step was necessary to clarify regulatory interpretations, set monitoring requirements, and align the project with national environmental objectives and EU directives such as the Water Framework Directive.

The escalation process ensured that the project adhered to the highest environmental standards, securing a permit that balanced renewable energy benefits with ecosystem protection. Comprehensive environmental monitoring plans were established as permit conditions, including regular assessments of river temperature changes and aquatic biodiversity. The experience highlighted the importance of early, transparent stakeholder engagement and the need for clear regulatory guidance when pioneering innovative uses of natural resources in urban renewable projects.



Grenoble Presqu'île development with aquathermic system integration (construction phase)
© Han Vandevyvere



DBDH | dbdh.org | Article on decarbonization of the Austrian district heating systems

Vienna, Austria, Heat decarbonisation through heat recovery and electrification

As part of its commitment to achieve climate neutrality by 2040, the City of Vienna is implementing a comprehensive strategy to decarbonise its heating sector. Recognising that fossil fuels must be phased out, Vienna is prioritising the deployment of heat pumps for low-temperature heat demand, including large-scale systems using wastewater or ambient heat. For example, three heat pumps in Simmering are already supplying heat to 56,000 households, with plans to double capacity to serve 112,000 households by 2027. For high-temperature needs, Vienna is introducing direct electrical heating technologies (e.g., power-to-heat systems) where they are technically and economically feasible. This complements heat pump deployment and helps phase out fossil fuels in areas where heat pumps alone may not suffice.

A core element of Vienna's approach is the efficient use of existing energy flows, including heat recovery from industrial processes and urban infrastructure. This maximises energy efficiency and reduces the reliance on scarce renewable gases, which are expected to remain limited and costly. In this context, green gases are strategically reserved for applications where no viable alternatives exist.

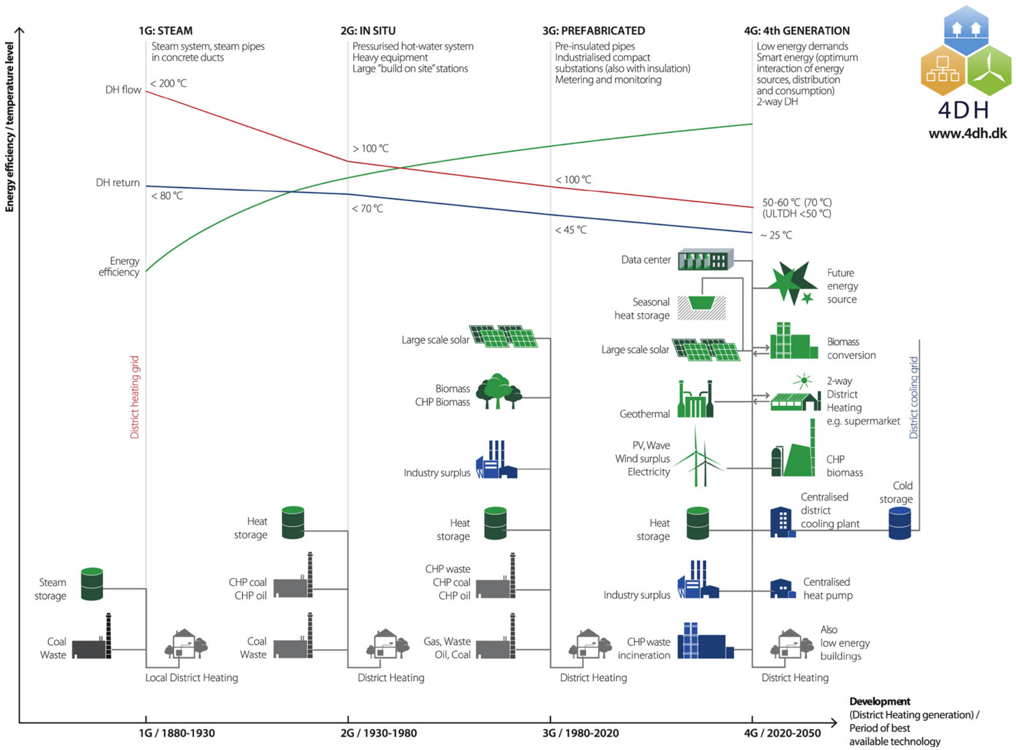
Waste heat recovery[26, 27]

Waste heat recovery harnesses heat generated as a byproduct of industrial processes or power generation installations – heat that would otherwise be lost to the environment. By capturing and repurposing this excess thermal energy, cities can improve energy efficiency and reduce greenhouse gas emissions, making it a key component of urban renewable energy strategies.

The recovered heat can be utilised in numerous ways, including:

- **Producing space heating or cooling** for residential, commercial, or public buildings
- **Preheating combustion air** to improve process efficiency
- **Generating steam** for industrial or district heating applications
- **Converting exhaust gases** from power plants into additional electricity through cogeneration systems.

26 Lyons, L., Kavvadias, K. and Carlsson, J. Defining and accounting for waste heat and cold, EUR 30869 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-42588-5, doi:10.2760/73253, JRC126383.
27 See also: smart-cities-marketplace.ec.europa.eu/insights/solutions/dont-waste-waste-water-clean-energy-sewage



Henrik Lund, Poul Alberg Østergaard, Tore Bach Nielsen, Sven Werner, Jan Eric Thorsen, Oddgeir Gudmundsson, Ahmad Arabkoohsar, Brian Vad Mathiesen, Perspectives on fourth and fifth generation district heating, Energy, Volume 227, 2021, 120520, ISSN 0360-5442, doi.org/10.1016/j.energy.2021.120520

Waste heat can originate from different processes with varying environmental impacts and conversion challenges:

- **'Black' or 'Grey' Waste Heat:** Heat derived from non-renewable, fossil-fuel-based processes. These sources often represent transitional stages in energy systems and require specific conversion strategies to mitigate emissions while maximizing heat recovery.
- **Mixed Waste Heat:** Generated from processes combining bio-based and mineral fractions, such as waste incineration plants. These mixed sources are part of evolving energy frameworks, where conversion strategies focus on balancing sustainability goals with efficient energy reuse.
- **Renewable/Sustainable Waste Heat:** Heat recovered from fully renewable or sustainable sources, including bioenergy facilities or certain industrial processes. These sources support long-term carbon neutrality and align closely with green urban energy targets.

Effectively integrating waste heat recovery into urban district heating and cooling networks offers multiple benefits: reducing fossil fuel consumption, lowering carbon footprints, and enhancing overall energy system resilience. Cities across Europe are adopting innovative approaches to capture and valorise waste heat, including from data centres, wastewater treatment plants, and manufacturing facilities, thereby contributing significantly to local renewable energy shares.

19

Espoo, Finland: Innovative waste heat utilization for carbon-neutral district heating

Espoo, Finland's second-largest and fastest-growing city, has set an ambitious target to become carbon neutral by 2030. A cornerstone of Espoo's climate strategy is its focus on decarbonising district heating, which, together with mobility, constitutes the city's largest source of CO2 emissions.

District heating in Espoo is undergoing a transformative shift by harnessing waste heat from data centres and other local sources, thus reducing reliance on fossil fuels. The city collaborates closely with Fortum, the main provider of district heating, to deploy innovative solutions such as heat pumps, heat accumulators, electric boilers, and notably, the recovery of waste heat from sewage water and data centre cooling.

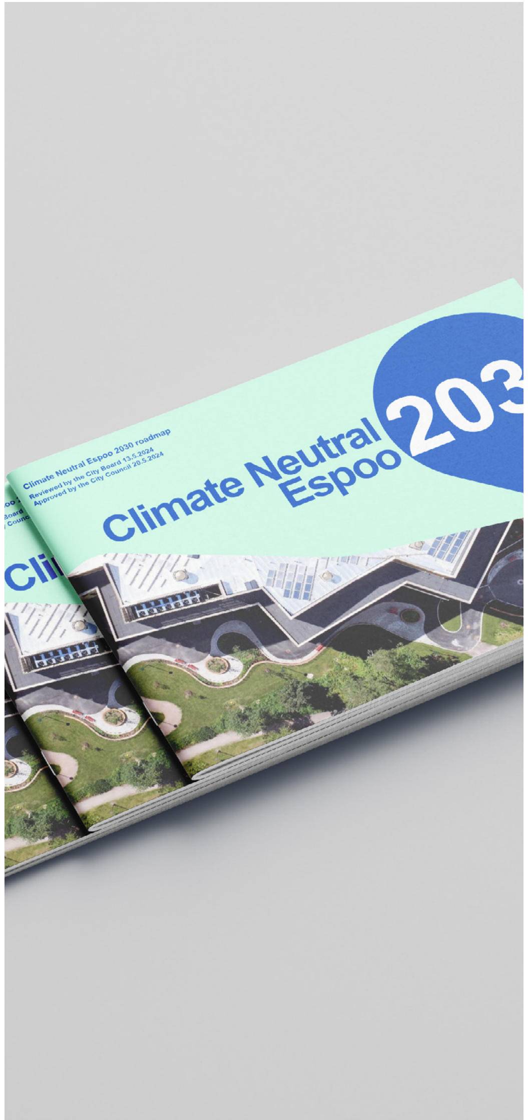
At the heart of this strategy is the Espoo Clean Heat programme, which aims to phase out coal and achieve carbon-neutral district heating before 2030. In fact, the use of coal in district heating was eliminated in April 2024. The initiative is projected to reduce CO2 emissions by approximately 400,000 tonnes annually, supplying 40% of the area's district heating demand with recovered waste heat.

The city works with six core strategic partners, including the Finnish National Technical Research Centre (VTT), Aalto University, the University of Helsinki, Caruna energy company, Microsoft, and the Forum, and actively engages twenty-five climate partners through its Climate City Contract.

A recent milestone in the partnership is Microsoft's commitment to building a new data centre in Espoo starting autumn 2024. These data centres are specifically designed to capture the heat generated by server cooling, which is then fed back into the district heating network. This synergy exemplifies how urban planning and technological innovation can combine to maximize renewable energy use.

A key enabler of Espoo's waste heat recovery is the deliberate proximity of data centres to the district heating network. Strategic land use planning has facilitated efficient integration of waste heat, minimising transmission losses and maximizing energy reuse. This illustrates the importance of matching urban and spatial planning with urban and regional energy system design, starting from the early planning phases.

By leveraging waste heat sources in a collaborative ecosystem, Espoo demonstrates a replicable model for urban areas seeking to decarbonise district heating. The city's approach not only drastically reduces carbon emissions but also strengthens energy security and fosters innovation partnerships between public and private stakeholders.



Espoo | Climate Neutral Espoo 2030 roadmap

Ocean power

Ocean power (tidal, wave) has attracted growing interest in recent years as it is one of the most promising drivers in coastal areas towards the EU ambitions to achieve net zero emission by 2050.[28] The EU offshore renewable energy strategy has set the ambitious targets of reaching 1 GW and 40 GW of installed ocean energy capacity by 2030 and 2050, respectively, and a number of European projects are already planned that could reach 600 MW of streaming tidal energy in the coming years.

Ocean energy can be of interest for waterfront cities and be extracted in two main ways illustrated in the table below.

Technology	Description
Tidal range	Takes advantage of the water level between the various times of the tidal circle. Tidal range energy has the highest installed capacity among all ocean energy sources. However, its development is limited due to the scarcity of suitable sites, high upfront costs, and potential environmental impacts. Within the EU, only a few tidal range projects are currently operational - the largest being La Rance in France - and just one new project is in the pipeline: Brouwersdam in the Netherlands with an estimated potential of 25-60MW.[29] [30]
Tidal stream	Takes advantage of the tidal currents. Tidal stream energy, driven by horizontal currents from tidal movements, is seeing growing deployment across both low and high technology readiness levels (TRL). The leading technology at commercial or near-commercial stages (TRL 8–9) is the Horizontal Axis Turbine (HAT), which uses tidal flow to rotate horizontal rotors. HATs can be seabed-fixed or floating, with capacities ranging from 100 kW to 2 MW. Several HAT designs have reached TRL 8, with key demonstration projects in Portugal, France, and the Netherlands (see example regarding the Port of Flushing in the figure below).

© Water2Energy

28 European Commission, An EU Strategy to Harness the Potential of Offshore Renewable Energy for a Climate Neutral Future, (2020). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - An EU Strategy to harness the potential of offshore renewable energy for a climate neutral future. COM/2020/741 final.
29 Tapoglou, E., Georgakaki, A., Letout, S., Kuokkanen, A., Mountraki, A., Ince, E., Shtjefni, D., Joanny Ordonez, G., Eulaerts, O. and Grabowska, M., Clean Energy Technology Observatory: Ocean Energy in the European Union – 2022 Status Report on Technology Development, Trends, Value Chains and Markets, Publications Office of the European Union, Luxembourg, 2022, doi:10.2760/162254, JRC130617.
30 energy.nl/wp-content/uploads/energy-from-water-factsheet-tidal-barrage-9.pdf

Combustible renewables

Bio energy

The European Commission defines bioenergy as energy produced from biomass - organic materials such as agricultural and forestry residues, waste, and dedicated energy crops. This energy can be converted into heat, electricity, a combination of both in biomass-based Combined Heat and Power (CHP) systems, or transport fuels.

The main elements of the EU's approach to bioenergy include:

- **Biomass-based energy:** bioenergy relies on plant- and animal-based materials as its primary source.
- **Multiple energy forms:** biomass is converted into usable energy carriers like heat, power, and fuels.
- **Renewable resource:** biomass is renewable, contributing to a more sustainable energy mix.
- **Sustainability standards:** EU policy stresses strict sustainability criteria, including minimizing land-use impacts and protecting the environment.

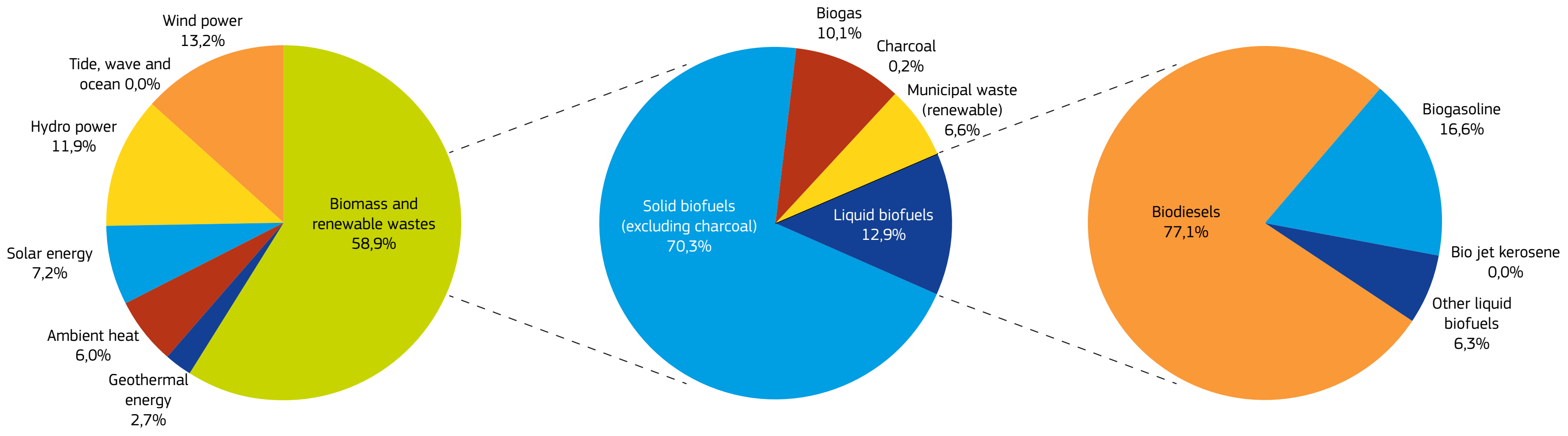


Figure recreated from the figure from Eurostat, Gross EU consumption of renewable energy per type (2021, % and Mtoe).

Solid Biomass[31]

The biomass used for energy in the EU is a mix of virgin material from forestry and agriculture and secondary sources from waste and residues, and remains the EU's largest renewable energy source, accounting for 59% of renewable energy consumption in 2021[32]. It plays a key role in heating, electricity generation, and transport fuels. However, its widespread use – particularly traditional biomass like fuelwood – raises significant concerns for urban air quality as well as the integrated sustainability score of the used biomass types.

In many European cities, residential biomass burning is a major contributor to air pollution. According to the JRC's Sherpa tool[33], household fuelwood and fossil coal combustion combined account for an average of 27% of $PM_{2.5}$ concentrations, exceeding 50% in some urban areas of Poland, Romania, Northern Italy, Croatia, and the Baltic countries. This pollution poses serious health risks due to emissions of NO_x, polycyclic aromatic hydrocarbons, volatile organic compounds, and dioxins[34].

© David Clode, Unsplash

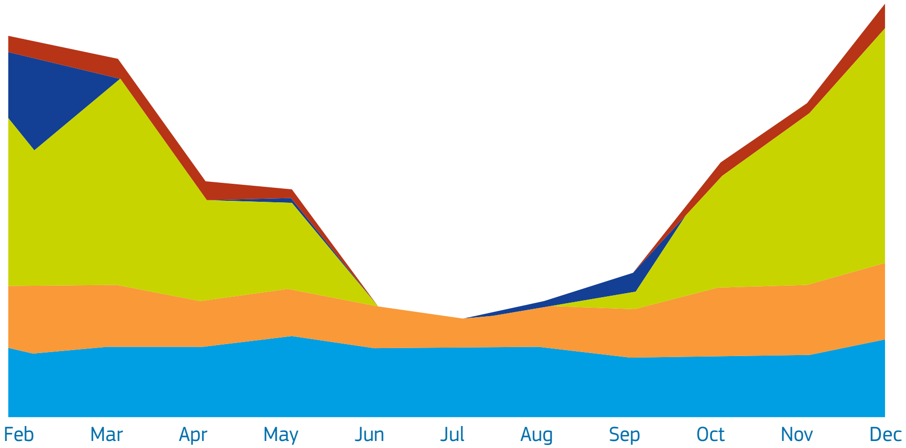
31 See also: smart-cities-marketplace.ec.europa.eu/insights/solutions/biomass-masses
32 COM(2023) 650 final; Union Bioenergy Sustainability Report, 2023.
33 jeodpp.jrc.ec.europa.eu/eu/dashboard/voila/render/SHERPA/Sherpa.ipynb
34 Zauli-Sajani, S., Thunis, P., Pisoni, E. et al. Reducing biomass burning is key to decrease PM2.5 exposure in European cities. Sci Rep 14, 10210 (2024). doi.org/10.1038/s41598-024-60946-2

Apart from phasing out coal use, to improve urban air quality and public health, reducing traditional biomass combustion in households is essential. Larger biomass boilers (e.g. in district CHP plants) can be equipped with fume cleansing. This makes them more acceptable than individual household boilers[35]. Shifting towards more efficient heating solutions – such as heat pumps, solar thermal systems, and better insulation – could significantly lower emissions while maintaining energy security. Moreover, the European Green Deal[36] and 2030 Biodiversity Strategy[37] highlight the potential environmental risks of large-scale biomass use, stressing the need for strict sustainability criteria under the recast Renewable Energy Directive[38].

For a sustainable future, biomass should be used more effectively in cities - prioritising residues and waste from agriculture, forestry, and industry rather than turning to virgin materials and inefficient household burning. Such an approach aligns with climate goals, sustainability criteria and public health priorities, ensuring that cities benefit from renewable energy without compromising air quality [39] or exhausting natural resources.

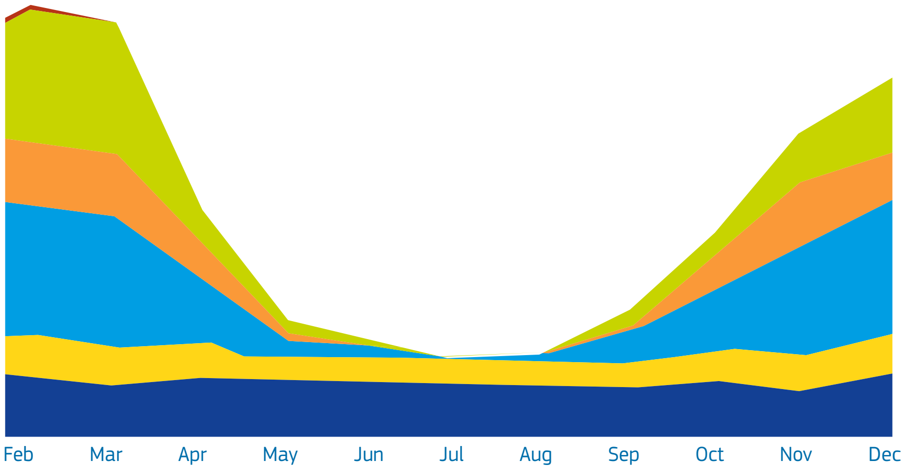
35 An example: glosfume.com/clean-energy-filtration-in-biomass-plants
36 commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en
37 environment.ec.europa.eu/strategy/biodiversity-strategy-2030_en
38 http://data.europa.eu/eli/dir/2023/2413/oj
39 Motola, V., Scarlat, N., Hurtig, O., Buffi, M., Georgakaki, A. et al., Clean Energy Technology Observatory, Bioenergy in the European Union – Status report on technology development, trends, value chains and markets – 2023, Publications Office of the European Union, 2023, data.europa.eu/doi/10.2760/327569

The heating system in Aarhus 2021



4% Electricity
5% Oil and coal
42% Wood pellets
20% Straw and wood chips
27% Waste

The green heating system of the future in Aarhus 2030



<1% Oil and gas
20% Electricity utilised in heat pumps/boilers
13% Straw and wood chips
30% Renewable ambient energy: geothermal energy, district cooling and various heat pumps
14% Surplus heat, industrial processes, including CO2 capture
23% Waste

Figure recreated from the figure from the Climate Initiative K1: The green heating system of the future | aarhus.dk/media/r0tcrowe/klimamateriale-samlet.pdf

20

Aarhus, Denmark: Green heating system of the future

The City of Aarhus, Denmark, is leading a major transition in sustainable district heating by substantially reducing biomass use and phasing out fossil fuels. This effort supports the development of a forward-looking, energy-efficient, and resilient heating system. Aarhus recently received the EU Mission Label for its ambitious goal of achieving climate neutrality by 2030, helping attract public and private investment to realise this vision[40].

Biomass is a key renewable energy source and has played a significant role in Denmark's transition away from fossil fuels. However, its climate benefits are increasingly under scrutiny due to concerns over its true carbon footprint and long-term sustainability.

The Danish Council on Climate Change's 2018 report highlights two critical reasons for reassessing biomass[41] :

- Biomass emissions may be underestimated, especially when CO_2 from combustion is not quickly or fully reabsorbed.
- Denmark's reliance on biomass is high and growing, with a significant share (43%) being imported, unlike most EU countries that use domestically sourced biomass.

Although biomass (especially woody biomass) is classified as renewable, its climate impact depends heavily on how it is sourced, burned, and replaced. Forests used for biomass take decades to regrow, delaying carbon reabsorption. Without careful regulation, this can undermine Denmark's climate goals.

Aarhus is transitioning from a biomass-heavy energy mix - currently 63% - to a future scenario where biomass accounts for just 13%. Notably, the city is modernising its district heating and cooling (DHC) system by shifting from a traditional high-temperature, biomass-dependent regime toward a next-generation, low-temperature district heating model, in line with the typology proposed by Lund et al[42].

This "generation update" involves moving from 3rd generation systems (characterised by centralised, high-temperature supply and biomass combustion) toward 4th and even 5th generation DHC, which prioritise:

- Low-temperature supply (typically below 70°C), which reduces thermal losses, improves the efficiency of renewable heat sources like heat pumps and geothermal, and enables the use of low-exergy heat recovery;
- Decentralised and flexible generation, with smart integration of large-scale heat pumps, geothermal energy (110 MW planned), and thermal and electrical storage systems;
- Sector coupling with electricity and mobility, using surplus wind and solar power for heat generation (e.g. through power-to-heat systems and batteries)

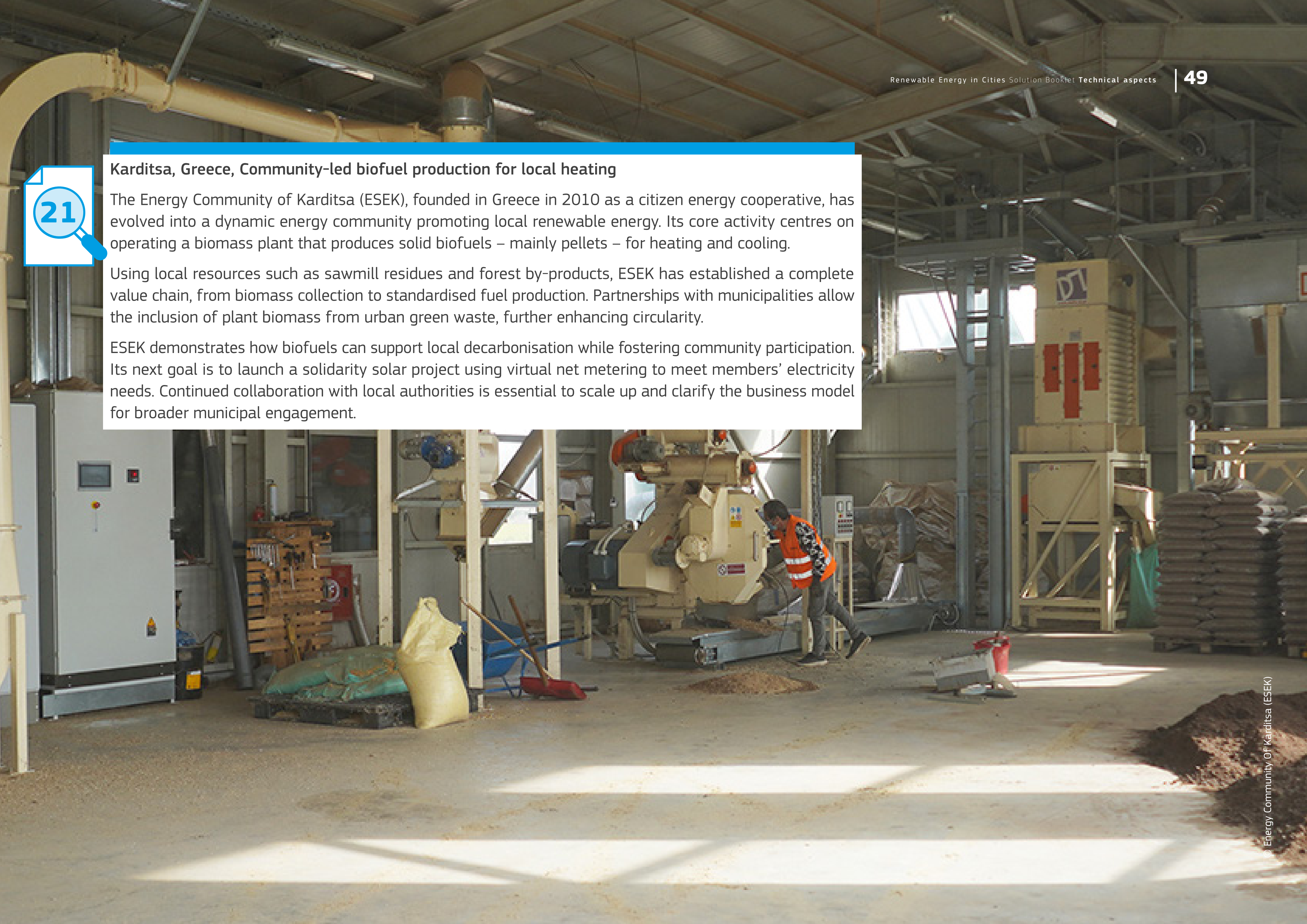
This transformation supports Aarhus' broader decarbonisation and energy efficiency goals while making the DHC system more adaptable to variable renewable energy sources. As fossil fuels and biomass are phased down, the system becomes more circular, citizen-oriented, and climate-resilient, a hallmark of 4GDH and emerging 5GDH networks. These sources will be integrated with renewable electricity from wind and solar, supported by modern storage technologies such as batteries, enabling flexible and efficient heat supply.

This strategic shift delivers a direct reduction of 27,500 tons of CO_2e annually, largely due to the phasing out of biomass (notably wood pellets accounting for 1.6 million tons CO_2 in 2021) and reducing flaring in the heat supply system.

The transition requires substantial investment. Kredsløb, the municipally-owned utility, is financing infrastructure upgrades, including electric boilers to replace oil-based peak load systems. Additionally, Aarhus Municipality has earmarked 1 million DKK annually (2025-2028) in its budget to support the Green Heating System of the Future.

Another milestone is the complete phase-out of coal at the Studstrup Power Station. Ørsted shut down Unit 4 – the last coal-fired unit – on 31 August 2024 and will cease using coal as a reserve fuel by the end of 2024. The current agreement covering plant operations with Aarhus Municipality and Kredsløb will expire in 2030.

40 research-and-innovation.ec.europa.eu/news/all-research-and-innovation-news/european-commission-awards-eu-mission-label-39-new-cities-2025-05-07_en
41 klimaraadet.dk/en/report/role-biomass-green-transition
42 About 95 % of all residents in Aarhus are served by the district heating system. The network supplies around 90 % of the overall heated building area in the municipality. Kristensen, Martin & Petersen, Steffen. (2020). District heating energy efficiency of Danish building typologies. 10.13140/RG.2.2.17578.44488.



21

Karditsa, Greece, Community-led biofuel production for local heating

The Energy Community of Karditsa (ESEK), founded in Greece in 2010 as a citizen energy cooperative, has evolved into a dynamic energy community promoting local renewable energy. Its core activity centres on operating a biomass plant that produces solid biofuels – mainly pellets – for heating and cooling.

Using local resources such as sawmill residues and forest by-products, ESEK has established a complete value chain, from biomass collection to standardised fuel production. Partnerships with municipalities allow the inclusion of plant biomass from urban green waste, further enhancing circularity.

ESEK demonstrates how biofuels can support local decarbonisation while fostering community participation. Its next goal is to launch a solidarity solar project using virtual net metering to meet members' electricity needs. Continued collaboration with local authorities is essential to scale up and clarify the business model for broader municipal engagement.

Biofuels

In the transition to climate-neutral cities, biofuels play a complementary role in reducing greenhouse gas emissions, particularly in sectors where electrification or other renewable alternatives may be limited in the short to medium term. Derived from biomass, biofuels – including biodiesel, bioethanol, and biogas – offer a renewable substitute for fossil fuels in urban transport, heating, and waste management systems.

In urban areas, biofuels are especially relevant for decarbonising public transport fleets, municipal service vehicles, and heavy-duty transport – segments that often face challenges in adopting battery-electric or hydrogen solutions. Advanced biofuels, produced from waste, residues, or non-food biomass, further enhance sustainability by supporting circular economy objectives and reducing dependency on land-intensive crops.

Biofuels can also contribute to the decarbonisation of district heating systems using bioliquids and biogas, offering flexible, dispatchable energy that complements intermittent renewable electricity sources. Additionally, biofuels generated from urban organic waste and sewage sludge can support integrated waste-to-energy solutions, reducing landfill use and promoting local energy autonomy.

To ensure their environmental integrity, the EU promotes the use of sustainable and low Indirect Land Use Change (ILUC)-risk[43] biofuels under the Renewable Energy Directive, which sets clear sustainability criteria and limits the contribution of high ILUC-risk biofuels to national targets.

While not a standalone solution, biofuels are an alternative in the broader renewable energy mix. When used strategically alongside electrification, energy efficiency, and infrastructure improvements, they help cities address complex decarbonisation challenges, while enhancing energy resilience and resource circularity.

43 Indirect land use change ('ILUC') can occur when land previously devoted to food or feed production is converted to produce biofuels, bioliquids and biomass fuels. In that case, food and feed demand still needs to be satisfied, which may lead to the extension of agricultural land into areas with high carbon stock such as forests, wetlands and peat land, causing additional greenhouse gas emissions. See EC, 2019, Commission Delegated Regulation (EU) 2019/807 of 13 March 2019 supplementing Directive (EU) 2018/2001 of the European Parliament and of the Council.

22

Stockholm, Sweden: Circular Biofuel System for Public Transport

Stockholm exemplifies innovative and sustainable urban mobility through its large-scale integration of locally produced biogas into the public transport fleet. By converting municipal organic waste and sewage sludge into biomethane, the city creates a renewable, low-carbon fuel source for buses and municipal vehicles. This system not only reduces greenhouse gas emissions but also embodies a successful circular economy approach by closing resource loops and maximising local resource utilisation.

Key Actions:

- Deployment of 300 biogas-powered buses, making biogas a major energy source within Stockholm's public transport network.
- Development of a comprehensive waste collection and treatment infrastructure to secure a continuous, sustainable supply of feedstock for biogas production.
- Significant investments in biogas upgrading and refuelling facilities to ensure operational reliability and scalability.
- Implementation of supportive policy frameworks aimed at promoting renewable fuels, aligned with Stockholm's goal to become fossil fuel free by 2040.

Replicability:

Stockholm's circular biofuel model offers a scalable and adaptable blueprint for other European cities with access to organic waste resources and ambitions for sustainable public transport. Key success factors include strong municipal leadership, integrated planning across waste and energy sectors, and close cooperation among stakeholders including local authorities, waste managers, and transport operators.

Impacts:

- Achieves up to 90% reduction in CO_2 emissions compared to traditional diesel buses, contributing to climate goals.
- Contributes to improved urban air quality and public health by lowering local pollutant emissions.
- Demonstrates an effective circular economy model, transforming organic waste streams into valuable energy, reducing landfill use and waste-related emissions.
- Strengthens energy security and stimulates local economic development through green job creation in the biogas sector.

Image by Alexander Williamson, via Wikimedia Commons, CC0 1.0. New Electric Hybrid bus, running on biodiesel, specifically HVO (Hydrotreated Vegetable Oil) or biodiesel B100)- at a Stockholm charging station.

Renewable hydrogen

When produced through electrolysis powered by renewable electricity – such as wind or solar – hydrogen becomes a fully clean and sustainable energy source. This form of production, known as renewable hydrogen, classifies as a 'renewable fuel of non-biological origin' (RFNBO) under EU legislation[44].

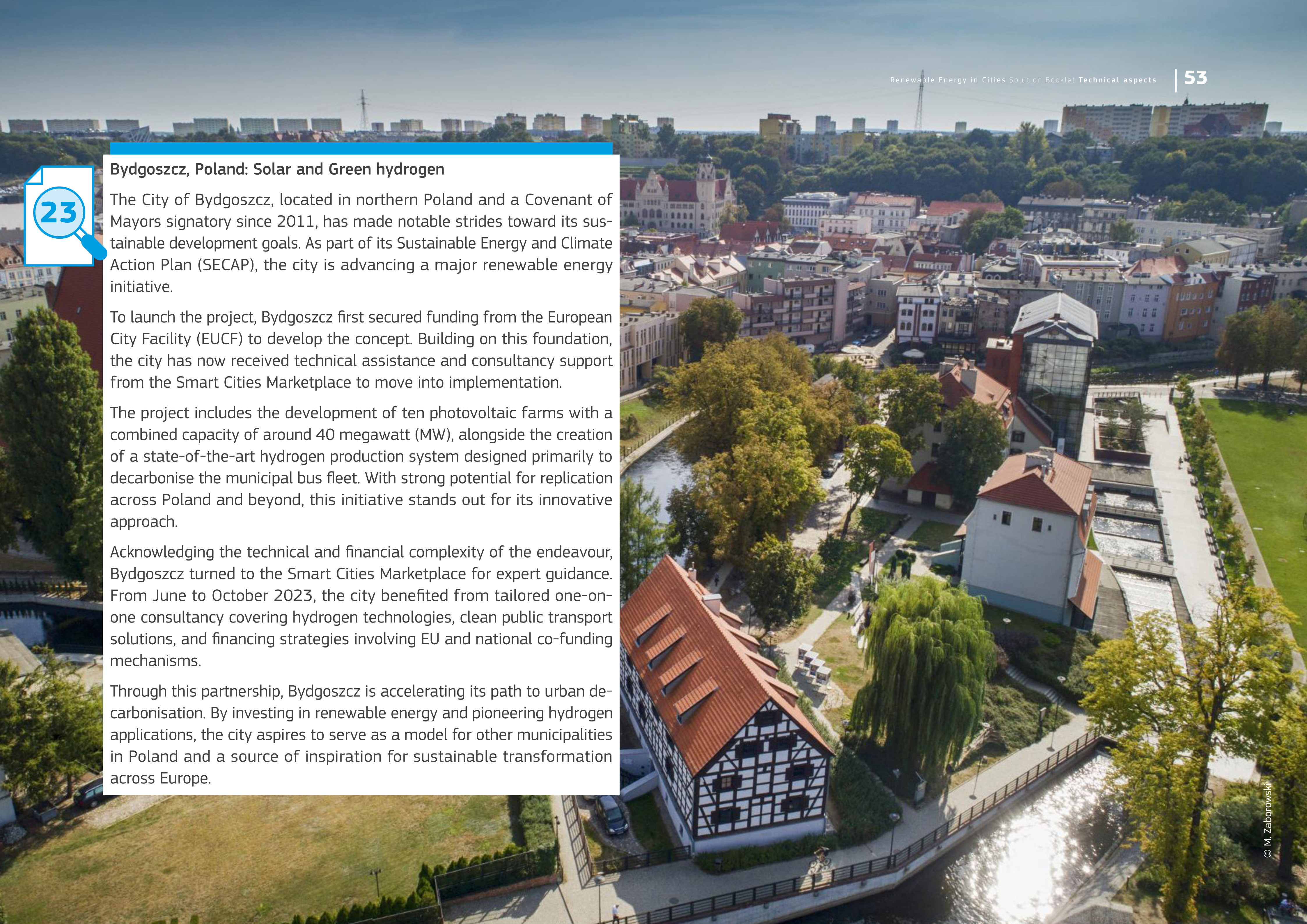
Renewable hydrogen is expected to play a complementary role in decarbonising sectors where other clean alternatives are either impractical or economically less viable. It can replace fossil-based hydrogen in transport and industrial processes, significantly reducing greenhouse gas emissions and environmental impact. In the energy sector, renewable hydrogen offers an effective solution for long-term and large-scale storage. It contributes to grid stability and supports the integration of variable renewable energy sources such as wind and solar, enhancing the flexibility and resilience of the EU's energy system. Hydrogen's potential goes beyond its production methods. In urban environments, it can serve as a clean energy carrier across multiple domains[45]. In smart cities, renewable hydrogen can be used to fuel zero-emission vehicles, and to store surplus renewable electricity to balance grids in cities. However, due to its lower energy efficiency compared to other renewable alternatives (e.g. renewable hydrogen requires five times more electricity to heat a home than a heat pump), higher infrastructure costs (including retrofitting building piping and installations), renewable hydrogen does not represent for the moment a preferable solution to decarbonise heating in cities[46].

44 eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2023.157.01.0011.01.ENG&toc=OJ%3AL%3A2023%3A157%3ATOC. The Renewable Energy Directive sets specific targets for the uptake of Renewable Fuels of Non-Biological Origin (RFNBOs): by 2030, they are expected to account for at least 1% of total energy supplied to the transport sector, and at least 42% of all hydrogen used in industry – rising to 60% by 2035.
45 transport.ec.europa.eu/transport-themes/clean-transport/clean-and-energy-efficient-vehicles/green-propulsion-transport/hydrogen-and-fuels-cells-transport_en
46 Chris Twinn, LETI, Hydrogen A decarbonisation route for heat in buildings?, Feb.2021. leti.uk/_files/ugd/252d09_54035c0c27684afca52c7634709b86ec.pdf

© Barbara Horn, Unsplash

Hydrogen mobility includes both fuel cell technology and internal combustion engines (ICE) adapted to use hydrogen. While fuel cells are currently more prevalent in zero-emission mobility solutions, exploring ICE applications broadens the scope for decarbonising urban transport. The emphasis is not on the engine type itself, but rather on replacing high-emission fuels with clean hydrogen.

The potential use of existing gas infrastructure for hydrogen must in a principle be disregarded, as future offer and demand may differ in both scale and purpose – shifting from heating to industrial uses such as replacing grey hydrogen and coal. Virtually unfeasible upgrades to pipelines, compressors, and appliances would be necessary, with blending limits and costs becoming very substantial. Consequently, hydrogen networks are expected to be localised, particularly around industrial hubs, or closely aligned with electricity infrastructure.



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Bydgoszcz, Poland: Solar and Green hydrogen

The City of Bydgoszcz, located in northern Poland and a Covenant of Mayors signatory since 2011, has made notable strides toward its sustainable development goals. As part of its Sustainable Energy and Climate Action Plan (SECAP), the city is advancing a major renewable energy initiative.

To launch the project, Bydgoszcz first secured funding from the European City Facility (EUCF) to develop the concept. Building on this foundation, the city has now received technical assistance and consultancy support from the Smart Cities Marketplace to move into implementation.

The project includes the development of ten photovoltaic farms with a combined capacity of around 40 megawatt (MW), alongside the creation of a state-of-the-art hydrogen production system designed primarily to decarbonise the municipal bus fleet. With strong potential for replication across Poland and beyond, this initiative stands out for its innovative approach.

Acknowledging the technical and financial complexity of the endeavour, Bydgoszcz turned to the Smart Cities Marketplace for expert guidance. From June to October 2023, the city benefited from tailored one-on-one consultancy covering hydrogen technologies, clean public transport solutions, and financing strategies involving EU and national co-funding mechanisms.

Through this partnership, Bydgoszcz is accelerating its path to urban decarbonisation. By investing in renewable energy and pioneering hydrogen applications, the city aspires to serve as a model for other municipalities in Poland and a source of inspiration for sustainable transformation across Europe.

Lessons learned

✓ Urban planning shapes energy system viability

Long-term energy integration is most effective when aligned with urban development from the outset, including zoning, building codes, and infrastructure corridors.

Lesson: Retrofitting energy infrastructure is costlier and less efficient than embedding it during early planning.

Tip: Use energy mapping tools and cross-sectoral coordination (e.g., between utilities and spatial planners) to guide siting and investment.

✓ Integrated energy systems unlock synergies

Combining renewable electricity, heating, cooling, and mobility systems increases overall system resilience and efficiency. Hybrid configurations – such as solar thermal + shallow geothermal + district heating – create flexible, multi-vector energy networks.

Lesson: System integration requires early-stage coordination across utilities, urban planners, and transport authorities.

Tip: Use Energy Management Systems (EMS) or Building Energy Management Systems (BEMS) to synchronise energy flows across sectors and assets.

✓ Grid capacity constraints limit renewable expansion

Urban areas often face significant grid congestion, limiting the ability to connect new renewable sources—particularly wind and solar. Differences in national grid infrastructure (e.g., Belgium vs. the Netherlands) highlight the need for tailored grid reinforcement strategies.

Lesson: Cities must engage early with Transmission and Distribution System Operators (TSOs/DSOs) to assess grid hosting capacity and co-plan infrastructure upgrades.

Tip: Promote grid-friendly project design (e.g., co-located storage, demand-side management) and support regulatory reforms to enable dynamic grid services.

✓ Environmental permitting is a strategic bottleneck

Securing permits for technologies using natural resources (e.g., rivers, aquifers, geothermal reservoirs) is often complex and time-consuming, particularly in dense urban environments.

Lesson: Understanding ecological impacts and regulatory requirements early in project development is crucial.

Tip: Allocate sufficient time and expert support for environmental impact assessments, particularly for geothermal, hydrothermal, or river-based heat extraction projects.

✓ Energy communities enhance grid flexibility and local ownership

Citizen-led energy projects can help distribute load, share surplus energy, and improve social acceptance of renewables. They also foster behavioural change through direct participation.

Lesson: Legal and regulatory frameworks must support community self-consumption and energy sharing within geographic limits (e.g., 1 km radius).

Tip: Use digital tools for smart metering, peer-to-peer trading, and real-time monitoring to optimise performance and ensure transparency.

Tip: lower financial and knowledge barriers for vulnerable users so that they can participate in energy communities.

Lessons learned

Planning positive energy districts (PEDs) enables testing and replication

Positive Energy Districts (PEDs), and the broader concept of Positive or Clean Energy Districts (PCEDs), offer a controlled and practical setting to pilot integrated energy system solutions at the district scale. These zones are designed to be highly energy-efficient and capable of generating renewable energy locally, with the ambition, where feasible, of achieving a net annual energy surplus. This surplus can support surrounding areas and inform citywide energy planning.

However, in practice, especially in the context of urban retrofitting, most districts will still require net energy imports at times or will need to rely on virtual energy balancing mechanisms, such as off-site renewable production or energy storage aggregated across systems[47]. These realities highlight the importance of flexible and context-sensitive definitions of PEDs and PCEDs, acknowledging that achieving energy positivity may involve both physical and virtual assets within a broader urban energy ecosystem.

Lesson: PEDs should be embedded in urban masterplans and designed with scalability in mind.

Tip: Combine PEDs with local mobility, storage, and digitalisation initiatives to maximise cross-sector integration.

Digitalisation is key for real-time coordination

Smart energy infrastructure, such as Energy Management System (EMS), and Supervisory Control and Data Acquisition (SCADA), and interoperable platforms, enables cities to manage decentralised energy assets and adapt to variable generation.

Lesson: Lack of digital integration hampers responsiveness and optimisation.

Tip: Invest in open, interoperable systems and standardised data protocols to future-proof city energy networks.

Geothermal can anchor urban energy systems

Geothermal energy (notably shallow geothermal) provides reliable baseload heat and cooling and, when integrated with reversible heat pumps, generally offers high year-round efficiency. However, it demands specific geological data and skilled implementation.

Lesson: Local thermal response tests are essential to avoid design mismatches and underperformance.

Tip: Involve specialised contractors and conduct pre-feasibility tests to validate geothermal potential before committing to full system design.

Hydrogen and biomass/fuel/gas shall be applied with precaution

Hydrogen and bio-based fuels (e.g., biomass, biogas, biofuel) offer potential climate benefits but come with significant technical, environmental, and economic complexities. Renewable hydrogen plays a critical role in hard-to-electrify sectors such as public transport fleets (e.g., buses), heavy-duty freight, and industrial processes. However, it requires co-location with renewable electricity, as well as tailored infrastructure for safe production, storage, and delivery.

Lesson: Renewable hydrogen is not an optimal solution for cities at the moment, and biomass and biogas projects may face feedstock supply constraints, land-use concerns, or air quality trade-offs, especially in densely populated areas.

Tip: Invest in urban-compatible renewables avoiding land-intensive options in densely built environments and base decisions on lifecycle performance and emissions, while prioritising energy efficiency and direct electrification wherever possible, using hydrogen only where it adds system value.

Expect technical complexity and manage risk proactively

Combining new renewable technologies with ageing infrastructure can lead to unexpected compatibility issues and technical delays.

Lesson: High-quality technical supervision and experienced design teams are essential for successful delivery.

Tip: Allocate contingency in budgets and timelines and prioritise interdisciplinary project teams familiar with both legacy and modern systems.

47 Vandevyvere, H.; Ahlers, D.; Wyckmans, A. The Sense and Non-Sense of PEDs-Feeding Back Practical Experiences of Positive Energy District Demonstrators into the European PED Framework Definition Development Process. Energies 2022, 15, 4491. doi.org/10.3390/en15124491.

BUSINESS MODELS AND FINANCE

BUSINESS MODELS AND FINANCE

Description – possible business models

Business models are increasingly recognised as a foundational concept in the development of smart cities across Europe. They serve as a central organising framework that cuts across urban planning, technology deployment, stakeholder engagement, and economic value creation. However, while interest in "smart city business models" is high, practical, scalable, and theory-informed frameworks remain limited.

Existing models, such as the widely adopted Business Model Canvas, often fall short in capturing the systemic complexity of smart cities. They tend to focus narrowly on value propositions and firm-level operations, neglecting broader ecosystem dynamics and strategic adaptability, offering valuable insights but remaining fragmented, context-specific, and difficult to generalise or scale[48].

This solutions booklet presents different key elements to understand business models not merely as static templates, but as approaches and dynamic tools for achieving the following:

- **Translating city-level strategies into practical implementation pathways**
- **Aligning economic and technological development objectives**
- **Recognising and acting upon emerging urban opportunities**
- **Building long-term value for citizens, businesses, and administrations.**

48 Anthopoulos, L., C. G. Reddick, I. Giannakidou, and N. Mavridis. 2016. "Why e-Government Projects Fail? An Analysis of the Healthcare. gov Website." Government Information Quarterly 33 (1): 161–173. doi.org/10.1016/j.giq.2015.07.003;
Giourka, P., M. W. Sanders, K. Angelakoglou, D. Pramangioulis, N. Nikolopoulos, D. Rakopoulos, A. Tryferidis, and D. Tzovaras. 2019. "The Smart City Business Model Canvas--A Smart City Business Modeling Framework and Practical Tool." Energies 12 (24): 4798. doi.org/10.3390/en12244798.;
Walravens, N. 2015. "Qualitative Indicators for Smart City Business Models: The Case of Mobile Services and Applications." Telecommunications Policy 39 (3–4): 218–240. https://doi.org/10.1016/j.telpol.2014.12.011.; Díaz-Díaz, R., L. Muñoz, and D. Pérez-González. 2017. "The Business Model Evaluation Tool for Smart Cities: Application to SmartSantander use Cases." Energies 10 (3): 262. doi.org/10.3390/en10030262.

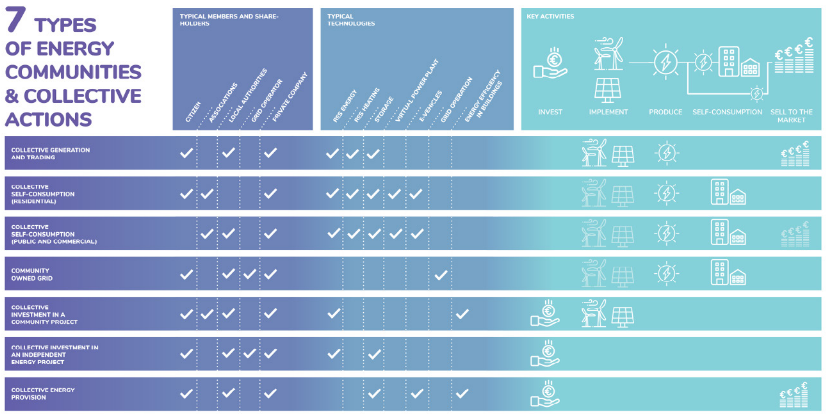
Model	Definition	Main advantages	Main disadvantages
Public–Private Partnerships (PPP)	Collaboration between public and private sectors to finance, develop, and operate smart city projects.	• Access to private funding & innovation • Shared risks • Faster project delivery • Long-term revenue opportunities	• Complex governance • Risk of cost overruns • Conflicting public-private objectives
Build-Operate-Transfer (BOT)	Private sector designs, builds, and operates infrastructure, then transfers ownership to the public sector after a concession period.	• Mobilises private capital • Transfers operational risk • Efficiency gains • Ensures eventual public ownership	• High upfront costs • Risk of low returns • Contract enforcement challenges
Performance-Based Contracts	Payments are tied to achieving specific performance metrics, promoting accountability and results-driven delivery.	• Aligns incentives with outcomes • Encourages innovation • Adaptable to evolving needs • Potential cost savings	• Difficult to define/measure metrics • Monitoring complexity • Potential contractual disputes
Community-Centric Models	Local communities are engaged in the design, governance, and implementation of projects to ensure inclusivity and local relevance.	• Builds trust and social cohesion • Integrates local knowledge • Reduces opposition • Promotes empowerment	• Time- and resource-intensive • Potential internal conflicts • Difficult to scale
Innovation Hubs & Incubators	Ecosystems that support startups and researchers developing smart city solutions, offering resources and mentorship.	• Drives technological innovation • Supports entrepreneurship • Encourages collaboration • Speeds up deployment	• Limited scalability • Funding sustainability issues • IP conflicts and competition risks
Revenue-Sharing Models	Revenue from smart city services is shared between public and private entities, encouraging investment and aligning incentives.	• Sustainable funding source • Attracts private investment • Aligns financial interests • Improves transparency	• Complex negotiations • Market volatility risks • Potential revenue disputes
Outcome-Based Financing	Repayment depends on achieving defined outcomes (e.g., energy savings), shifting risk to stakeholders and incentivizing results.	• Outcome-aligned financing • Promotes innovation • Shifts performance risk • Enhances accountability	• Complex structuring • Difficult outcome measurement • Attribution disputes
Asset Monetization	Generates funding through the strategic use or lease of public assets (e.g., land, infrastructure) for smart city development.	• Unlocks asset value • Reduces taxpayer burden • Supports ongoing funding • Stimulates investment	• Risks of long-term agreements • Public resistance to privatisation • Valuation and monetization challenges

→ **The Horizon 2020 project E-LAND** has published a study presenting a morphological analysis of 90 energy communities[49] and pioneering companies that apply business model design.

5	90	25
5 business model dimensions	90 implementation references	25 business model design options

→ **Scalable Cities** have published the report "European Smart Cities Business Models. Avoid the trap: From piloting projects to upscaling"[50]. The guidance document aims to pinpoint, comprehend, and highlight viable business cases and financing models, with a special focus on Positive Energy Districts (PEDs). The report selected thirteen business models as exemplary models that have contributed to expansion and upscaling of projects.

→ **The EU Horizon 2020 project decide4energy**[51] has developed a report that provides insights into existing and emerging business model approaches for energy communities and collective energy actions. It categorises various business models and presents concrete examples to illustrate each category in practice.



DECIDE | decide4energy.eu

49 Merla Kubli, Sanket Puranik, A typology of business models for energy communities: Current and emerging design options, Renewable and Sustainable Energy Reviews, Volume 176, 2023, 113165, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2023.113165. (sciencedirect.com/science/article/pii/S1364032123000217)
50 smart-cities-marketplace.ec.europa.eu/insights/publications/european-smart-cities-business-models
51 European Union's Horizon 2020 research and innovation programme under grant agreement No 894255. decide4energy.eu. Final report on Business Models, contractual conditions and recommendation, 31 May 2023.

Economic performance indicators

Together with social and environmental analyses, the assessment of economic impacts is one of the key elements to help policy makers build a compelling case to gain local community acceptance and implement Renewable Energy projects. Early economic assessments are key for understanding the economic benefit of renewable energy projects, particularly for the local communities in which they are located[52].

In terms of variables, economic impacts can be assessed using different indicators. Job creation, in general, is the most used, together with gross economic output (GEO), gross value added (GVA), and Income. The definition of the quantitative indicators selected to inform economic impacts are presented below.

- **Employment:** This refers to the number of jobs generated by the implementation of the renewable energy (RE) project. Employment is measured in Full-Time Equivalents (FTE), which standardizes both full-time and part-time positions into a single unit (e.g., one part-time job counts as 0.5 FTE). It can also be measured in terms of persons/year.
- **Gross Economic Output:** This represents the total monetary impact on a specific industry or the wider economy resulting from the RE project. It includes direct output—expenditures related to the construction and deployment of the project—and indirect output—additional economic activity generated among suppliers and supporting industries.
- **Gross Value Added (GVA):** GVA is a standard indicator of economic wealth creation. It reflects the value of output remaining after subtracting the cost of purchased goods and services. This remaining value is then distributed as profits, wages and salaries, and capital investments.
- **Income:** This measures employee compensation and reflects changes in earnings resulting from the RE project's implementation.

52 Marco Bianchi, Iratxe Fernandez Fernandez, A systematic methodology to assess local economic impacts of ocean renewable energy projects: Application to a tidal energy farm, Renewable Energy, Volume 221, 2024, 119853, ISSN 0960-1481, doi.org/10.1016/j.renene.2023.119853.

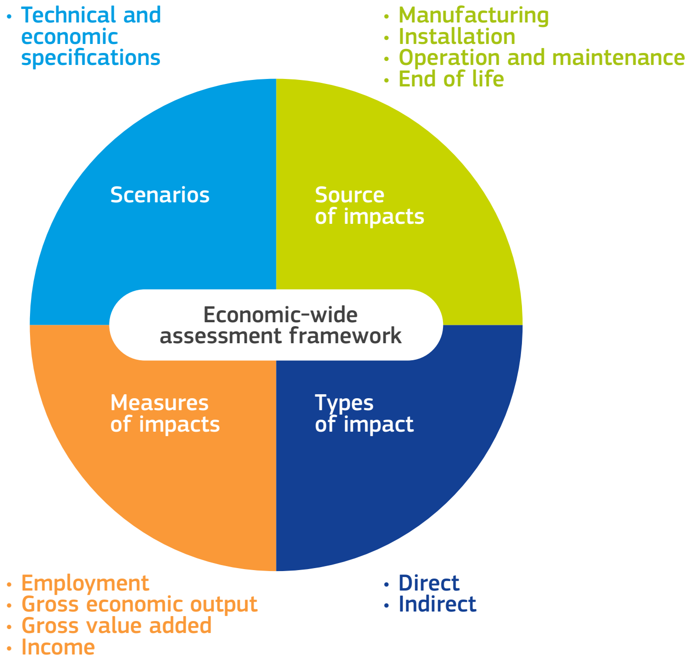


Figure recreated from Marco Bianchi, Iratxe Fernandez Fernandez, A systematic methodology to assess local economic impacts of ocean renewable energy projects: Application to a tidal energy farm, Renewable Energy, Volume 221, 2024, 119853, ISSN 0960-1481, doi.org/10.1016/j.renene.2023.119853.

Environmental performance indicators

Environmental sustainability metrics are the main area for tracking sustainability. Environmental metrics cover a wide range of activities impacting climate, waste, and energy use. Useful performance indicators that can be used include the ones presented below.

- → **Greenhouse emissions:**
  - » CO_2 equivalent emissions (CO_2e) reduction (in kilotonnes - kt): Total GHG emissions from energy, transport, agriculture, and other sectors.
  - » GHG emissions intensity of the economy: Expressed as tonnes of CO_2e per million EUR of GDP.
- → **Energy use and efficiency:**
  - » Final energy consumption (in ktoe): Energy consumed by end users, excluding energy used in transformation sectors.
  - » Energy intensity of the economy: Energy consumption per unit of GDP (kg of oil equivalent per 1,000 EUR GDP).
  - » Share of renewable energy in gross final energy consumption (%): Key EU climate and energy target.
- → **Water management and use**
  - » Total freshwater abstraction (million m^3 per year): Includes all freshwater withdrawals.
  - » Water exploitation index (WEI+): Ratio of total freshwater abstraction to renewable freshwater resources.
  - » Water reuse rate (%): Share of reused water in total water consumption.
  - » Water intensity: Water use per unit of production or per capita.
- → **Waste generation and management**
  - » Total waste generation per capita (kg per person): Includes all waste types from households and economic sectors.
  - » Recycling rate of municipal waste (%): Key EU waste management indicator.
  - » Hazardous waste generated (tonnes): Total quantity by type and treatment method.
- → **Land use and biodiversity**
  - » o Land use change: Deforestation, urban expansion, or degradation of ecosystems.
  - » o Biodiversity indicators: Species richness, habitat preservation, or threatened species count.
  - » Terrestrial protected land areas: Based on Natura 2000 and nationally protected sites.
- → **Circular economy and resource efficiency**
  - » Domestic material consumption (DMC) (tonnes per capita): Total amount of materials used in the economy.
  - » Resource productivity (EUR/kg): GDP per unit of DMC.
  - » Circular material use rate (%): Share of material recycled and fed back into the economy.
  - » Average product lifespan (proxy indicator): Relevant for material efficiency and waste reduction.
- → **Air quality**
  - » Emissions of air pollutants (NOx, SO_2, PM2.5, NH_3, NMVOCs) (tonnes/year): Tracked under the National Emission reduction Commitments Directive.
  - » Population exposure to air pollution (% exceeding WHO/EU thresholds): While health-related, this is used in environmental assessment frameworks.
- → **Ecosystem services and natural capital**
  - » Extent and condition of ecosystems (e.g., forest, wetlands): Based on Copernicus land monitoring.
  - » Soil organic carbon (tonnes per hectare): Indicator of soil health and carbon sequestration.
  - » Ecosystem services accounts (monetary and physical): Based on EU ecosystem accounting framework (INCA).

Lessons learned

- **Integrated planning is key to unlocking systemic value.**
  Renewable energy deployment in urban areas cannot be approached in isolation. Cities that succeed in scaling renewables, including wind and solar, embed them within broader integrated energy systems – linking electricity, heating and cooling, mobility, storage, and digitalisation. This requires strong institutional coordination and cross-sectoral planning to overcome silos between urban planning, utility services, and transport.

- **Flexibility and interoperability must be embedded from the start.**
  A common challenge in energy system integration is the lack of interoperability between technologies and systems. Cities that prioritise open standards, modular architecture, and grid flexibility from the design phase reduce future retrofitting costs and increase resilience. Successful projects often incorporate smart grids, demand response mechanisms, and real-time monitoring systems to manage renewable variability.

- **Decentralised systems demand decentralised governance.**
  Renewable energy integration is increasingly decentralised, involving multiple actors such as municipalities, utilities, prosumers, cooperatives, and aggregators. Business models must therefore support multi-actor governance structures with shared responsibilities and benefits. Cities that formalise collaborative governance, e.g. through local energy agencies or cooperatives, achieve higher trust, efficiency, and investment alignment.

- **Business models must be adapted to local context and ecosystem maturity.**
  While model frameworks like PPPs or BOTs provide structure, their success hinges on how well they are tailored to local socio-economic, institutional, and energy market conditions. For example, community-centric models thrive in municipalities with strong civic engagement, while performance-based contracts work best in cities with mature monitoring capabilities. Flexibility and local adaptation are more important than rigid model replication.

- **Scalability depends on ecosystem partnerships, not pilot projects alone.**
  Many renewable energy projects stall after the pilot phase due to fragmented governance, unclear revenue flows, or inadequate upskilling. Cities that succeed in scaling build ecosystem partnerships involving start-ups, academia, financiers, utilities, and civil society, moving beyond isolated demonstration projects toward co-created, investable solutions with long-term operational frameworks.

- **Data-driven decision-making enhances performance and accountability.**
  The use of digital twins, integrated energy modelling, and predictive analytics enables cities to better plan, simulate, and optimise renewable energy deployment. Where data is shared transparently across stakeholders, including energy communities, it supports performance-based business models and enhances monitoring, reporting, and verification (MRV) capacities.

- **Revenue diversification strengthens financial resilience.**
  Renewable energy projects benefit from business models that incorporate multiple revenue streams, e.g. combining electricity sales, grid balancing services, carbon credits, and circular economy synergies (e.g. heat recovery, waste-to-energy). Cities that adopt hybrid financing models, blending public funds, EU grants, private capital, and citizen investment, tend to achieve better long-term viability.

- **Energy communities offer social and financial co-benefits.**
  Cities that support citizen-led energy communities report higher levels of public acceptance, social innovation, and local value creation. However, successful implementation requires dedicated enabling frameworks -such as access to technical assistance, supportive regulation, and tailored business model templates, especially to guide emerging communities through legal, financial, and operational challenges.

- **Business model innovation is ongoing, not static.**
  As technologies evolve and regulatory environments shift, so too must the business models that underpin them. Cities are increasingly moving toward adaptive business model approaches, using iterative learning, experimentation (e.g. living labs), and performance feedback to refine models over time. Embedding this adaptability into governance processes ensures long-term project relevance and resilience.

See also: smart-cities-marketplace.ec.europa.eu/insights/solutions/find-money-next-step-funding-scaling-checklist.

GOVERNANCE AND REGULATION

GOVERNANCE AND REGULATION

Description – governance and regulatory barriers

As cities across the European Union intensify efforts to meet climate neutrality goals, a major barrier persists: slow and complex permitting procedures for renewable energy projects. Particularly for urban areas, where space is limited and energy demands are high, navigating administrative hurdles can delay or deter the deployment of clean energy solutions like rooftop solar, district heating, and wind integration.

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To address these barriers and support the clean energy transition, the Renewable Energy Directive (RED) was amended in 2023. The revision introduces key reforms aimed at streamlining permit procedures while ensuring citizen engagement and environmental protection. The reforms align with the broader ambition of the EU Green Deal and the REPowerEU Plan, positioning cities as central actors in accelerating renewables uptake.

Key measures

Simplified permitting framework

- → **The amended Renewable Energy Directive (EU/2023/2413)**[53] **and accompanying regulations** aim to significantly accelerate permitting processes for renewable energy and related infrastructure projects.
- → **Updated Recommendations (EU/2024/1343 & C/2022/3219)** provide practical guidance to Member States on how to reduce administrative burdens[54].
- → **The Council Regulation (EU/2024/223)** outlines a legal framework to accelerate project deployment and integration into the grid[55].

Guidance is tailored to include local-level examples and encourages cities to adopt fast-track permitting processes for low-impact installations like rooftop solar and small wind turbines.

Relevance for cities: Urban governments can directly benefit from these measures by establishing local one-stop-shops for permits and aligning municipal procedures with EU-level best practices.

53 energy.ec.europa.eu/topics/renewable-energy/renewable-energy-directive-targets-and-rules/renewable-energy-directive_en
54 eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022SC0149&qid=1723654491360
55 eur-lex.europa.eu/eli/reg/2024/223/oj

Supporting market-based deployment through PPAs

Power Purchase Agreements (PPAs) are long-term contracts between an electricity producer (often a renewable energy developer) and a buyer (typically a utility, large company, or public entity), under which the buyer agrees to purchase electricity at a predetermined price for a fixed period. They offer cities and local businesses a direct path to clean energy procurement via long-term contracts with renewable energy providers. Despite their potential, PPAs remain underused, especially in smaller municipalities and among local SMEs. This is mainly due to regulatory and legal complexity (uncertainty about the legal frameworks governing PPAs, which vary across EU Member States; lack of the legal and technical expertise to structure or negotiate complex energy contracts; mismatch between the structure of PPAs that is typically based around long-term commitments and the shorter planning cycles or budget limitations of SMEs or public administrations; creditworthiness concerns deterring developers from entering into agreements with smaller cities, who may struggle to guarantee payment over time; low awareness among local actors about how PPAs function or the benefits they offer; and smaller cities being often too small to participate individually in large-scale PPAs[56].

The Commission's 2022 Recommendation (C/2022/3219) offers a roadmap to promote and de-risk PPAs, including aggregation schemes and standardized contracting templates.

Relevance for cities: Municipalities can function as aggregators or facilitators for local PPAs—pooling demand from public buildings, schools, and businesses to attract investment in nearby renewable projects.

56 energy.ec.europa.eu/topics/renewable-energy/enabling-framework-renewables_en

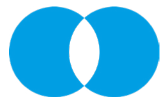
Renewables Acceleration Areas

The revised Directive requires Member States to designate Renewables Acceleration Areas by February 2026. These are zones where permitting will be particularly rapid, and where environmental risks are expected to be minimal.

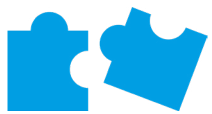
- **The Commission's 2024 Staff Working Document (SWD/2024/333)** outlines criteria and steps to identify such areas.
- **Energy and Industry Geography Lab tools** are available to help cities and Member States map suitable zones, using consolidated energy and environmental datasets.

Relevance for cities: Urban areas can pre-identify zones (e.g., industrial zones, brownfields, rooftops) as acceleration areas. This enables faster deployment of renewables with reduced bureaucratic delay and community conflict.

Efficient, flexible, and value-driven approaches: Strong governance leveraging on shared values helps minimising bureaucracy and encourages adaptable, locally tailored solutions rather than rigid models and procedures.



Inclusivity for better policies: Involving government, business, and community actors improves the quality and legitimacy of decisions, leading to more inclusive and representative outcomes.



Shared leadership and ownership: Multilevel governance works best when partners bring complementary strengths and align around a shared vision.

Trust and commitment: Trust underpins effective agreements. Long-term political and business commitments—formal or informal—help ensure sustained cross-sector cooperation.

Lessons learned

- **Integrated planning is key to unlocking systemic value.**
  Renewable energy deployment in urban areas cannot be approached in isolation. Cities that succeed in scaling renewables, including wind and solar, embed them within broader integrated energy systems – linking electricity, heating and cooling, mobility, storage, and digitalisation. This requires strong institutional coordination and cross-sectoral planning to overcome silos between urban planning, utility services, and transport.

- **Flexibility and interoperability must be embedded from the start.**
  A common challenge in energy system integration is the lack of interoperability between technologies and systems. Cities that prioritise open standards, modular architecture, and grid flexibility from the design phase reduce future retrofitting costs and increase resilience. Successful projects often incorporate smart grids, demand response mechanisms, and real-time monitoring systems to manage renewable variability.

- **Decentralised systems demand decentralised governance.**
  Renewable energy integration is increasingly decentralised, involving multiple actors such as municipalities, utilities, prosumers, cooperatives, and aggregators. Business models must therefore support multi-actor governance structures with shared responsibilities and benefits. Cities that formalise collaborative governance, e.g. through local energy agencies or cooperatives, achieve higher trust, efficiency, and investment alignment.

- **Business models must be adapted to local context and ecosystem maturity.**
  While model frameworks like PPPs or BOTs provide structure, their success hinges on how well they are tailored to local socio-economic, institutional, and energy market conditions. For example, community-centric models thrive in municipalities with strong civic engagement, while performance-based contracts work best in cities with mature monitoring capabilities. Flexibility and local adaptation are more important than rigid model replication.

- **Scalability depends on ecosystem partnerships, not pilot projects alone.**
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- **Data-driven decision-making enhances performance and accountability.**
  The use of digital twins, integrated energy modelling, and predictive analytics enables cities to better plan, simulate, and optimise renewable energy deployment. Where data is shared transparently across stakeholders, including energy communities, it supports performance-based business models and enhances monitoring, reporting, and verification (MRV) capacities.

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  Renewable energy projects benefit from business models that incorporate multiple revenue streams, e.g. combining electricity sales, grid balancing services, carbon credits, and circular economy synergies (e.g. heat recovery, waste-to-energy). Cities that adopt hybrid financing models, blending public funds, EU grants, private capital, and citizen investment, tend to achieve better long-term viability.

- **Energy communities offer social and financial co-benefits.**
  Cities that support citizen-led energy communities report higher levels of public acceptance, social innovation, and local value creation. However, successful implementation requires dedicated enabling frameworks -such as access to technical assistance, supportive regulation, and tailored business model templates, especially to guide emerging communities through legal, financial, and operational challenges.

- **Business model innovation is ongoing, not static.**
  As technologies evolve and regulatory environments shift, so too must the business models that underpin them. Cities are increasingly moving toward adaptive business model approaches, using iterative learning, experimentation (e.g. living labs), and performance feedback to refine models over time. Embedding this adaptability into governance processes ensures long-term project relevance and resilience.

BOUNDARY CONDITIONS AND REPLICATION OPPORTUNITIES

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BOUNDARY CONDITIONS AND REPLICATION OPPORTUNITIES

Barriers to replicating or scaling projects[57]

Despite growing momentum in urban energy transitions, several structural and systemic barriers continue to limit the widespread replication and scaling of renewable energy projects across Europe.

- **Financial and funding challenges.** High upfront investment costs, especially for smaller or citizen-led projects, remain a significant hurdle. Access to affordable finance is often constrained, and cities face difficulties aligning local project needs with the priorities and structures of available funding mechanisms. While EU instruments such as the ERDF and Cohesion Fund are theoretically accessible, administrative complexity and misalignment with municipal capacities hinder uptake.
- **Moreover, dependence on national strategies for allocation of EU resources further constrains flexibility.** The high minimum threshold for direct European Investment Bank (EIB) loans (€100 million) excludes most small and medium-sized cities, while smaller loans channelled through intermediaries often involve protracted approval processes.
- **Administrative burden and information gaps.** Applying for EU funding is often resource-intensive, requiring specialised expertise and internal capacity that many municipalities lack. The fragmented nature of the funding landscape, combined with the absence of a centralised platform to compare criteria, deadlines, and eligibility conditions, further complicates access. Additionally, restrictive national fiscal rules limit the ability of local authorities to use financial instruments such as Energy Performance Contracting or to blend funding from multiple sources.
- **Technical and spatial constraints.** Urban environments often present physical limitations, such as insufficient rooftop or land availability for deploying renewable infrastructure. Grid congestion and ageing energy systems inhibit the integration of decentralised generation. Delays in accessing consumption data – exacerbated by limited cooperation with distribution system operators – further complicate project planning and monitoring.
- **Institutional and governance limitations.** Municipalities frequently operate with constrained administrative capacity and lack the technical expertise necessary to design, implement, and replicate complex energy projects[58]. Fragmentation between departments – such as energy, mobility, housing, and social services – undermines holistic planning approaches.
- **Limited public engagement.** Low levels of energy literacy and trust in emerging energy-sharing models can result in limited citizen participation. This is especially pronounced among marginalised or vulnerable groups, reducing the inclusivity and reach of urban energy transitions.

57 NetZeroCities (2022). City climate finance: landscape, barriers and best practices. Deliverable 7.1

58 See also the Study on "Human capacity in Local governments: the bottleneck of the building stock transition": localstaff4climate.eu/download/study-en/?tmstv=1751236150.

Replication opportunities

Despite the challenges, a growing set of tools, policy frameworks, and real-world examples provides a solid foundation for scaling and replicating innovative urban energy solutions across Europe.

- **Policy coherence and strategic support.** The European Green Deal, REPowerEU, and the Just Transition Mechanism offer strong political and financial backing for urban renewable energy projects. Complementary initiatives such as the Covenant of Mayors, the Smart Cities Marketplace, the EU Mission on Climate-Neutral and Smart Cities, and LIFE Clean Energy Transition enhance municipal capacity through peer learning, technical assistance, and collaborative platforms.
- **Access to standardised tools and open-source models.** A wide array of replicable technical resources – such as digital toolkits, monitoring software, and governance templates – enables cities to build upon proven methodologies. Experiences from frontrunner municipalities including EU Mission Labelled cities[59] illustrate the adaptability of these models to diverse urban contexts.
- **Emerging urban leadership and collaborative ecosystems.** Many cities are embedding renewables within their Sustainable Energy and Climate Action Plans (SECAPs) and broader climate strategies. Urban innovation ecosystems – such as living labs, smart city demonstrators, and public-private co-creation platforms – offer testbeds for piloting scalable business models and technologies.
- **Digitalisation and smart infrastructure.** Technological advancements, including smart grids, digital energy platforms, and peer-to-peer trading systems, enhance the efficiency and resilience of urban energy systems. These innovations also empower local actors, including prosumers and cooperatives, to play a more active role.
- **Synergies with broader urban agendas.** Renewable energy initiatives increasingly intersect with other municipal priorities such as housing renovation, sustainable mobility, and energy poverty reduction. This integration facilitates co-financing opportunities and reinforces the socioeconomic benefits of clean energy transitions.
- **Cross-sector partnerships.** Effective collaboration among municipalities, utilities, community groups, and private investors is essential for aligning interests, mobilising investment, and delivering projects at scale. Strengthening these partnerships improves project bankability and accelerates implementation timelines.

59 research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/eu-missions-horizon-europe/climate-neutral-and-smart-cities_en#state-of-play

General lessons learned

- **Engage citizens as co-owners and active participants.**
Empowering residents to co-invest in and co-govern renewable energy (RE) systems – such as through cooperatives or local shareholding schemes – builds trust, enhances social acceptance, and ensures more equitable distribution of benefits.

- **Diversify renewable energy sources and ownership models.**
Cities should promote a mix of technologies - rooftop PV, solar parks, onshore/offshore wind, district heating, and storage – across private, public, and cooperative ownership. Diversity in both sources and actors increases resilience and accelerates deployment.

- **Embed renewable energy in integrated urban systems.**
Successful decarbonisation links electricity with heating, cooling, mobility, and digitalisation. Cities should integrate RE into holistic energy systems that leverage synergies (e.g., PV + heat pumps + EVs) to maximise efficiency and flexibility.

- **Anticipate grid and infrastructure constraints early.**
Urban grids are often congested. Cities must work with TSOs/DSOs from the outset to assess capacity, plan upgrades, and deploy smart solutions (e.g., storage, demand response) to ensure RE projects can be connected and operated efficiently.

- **Use energy communities to address energy poverty.**
Energy communities can pool resources to support low-income households – through surplus energy sharing or solidarity funds – offering a more sustainable alternative to fossil fuel subsidies while enhancing social justice. Pay special attention to lowering the entry barriers for vulnerable energy consumers when setting up energy communities.

- **Align urban planning with energy infrastructure.**
Embedding energy infrastructure into spatial planning – such as zoning for wind, heat corridors, and energy-positive districts – avoids costly retrofits and enables the long-term scalability of RE systems. Smartly situating production and consumption next to each other (e.g. data centres needing cooling next to buildings with a dominant heat demand) facilitates energy system optimization and minimizes energy losses.

- **Foster multi-stakeholder and multi-level governance.**
Effective RE deployment requires collaboration among municipalities, utilities (DSOs), mobility providers, businesses, civil society, and regional/national authorities. Shared governance models and clear coordination mechanisms help align incentives and responsibilities.

- **Prioritise digitalisation and real-time system management.**
Smart systems (e.g., EMS, digital twins, peer-to-peer platforms) allow cities to monitor, optimise, and adapt energy use dynamically – vital for managing intermittent generation and ensuring reliability.

- **Balance renewable deployment with local context and landscape.**
Respect for cultural heritage and landscapes is key. Cities should engage communities in siting decisions, design mitigation measures, and explore visually and socially acceptable solutions to prevent opposition and ensure environmental integrity.

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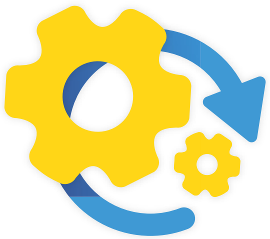
Smart Cities Marketplace

The Smart Cities Marketplace is a major market-changing initiative supported by the European Commission bringing together cities, industries, SMEs, investors, researchers and other smart city actors.

The Marketplace offers insight into European smart city good practice, allowing you to explore which approach might fit your smart city project.



Matchmaking

The Smart Cities Marketplace offers services and events for both cities and investors on creating and finding bankable smart city proposals by using our Investor Network and publishing calls for projects.

Investor network

Call for Applications – Matchmaking Services

Project finance masterclass

Focus and Discussion groups

Focus groups are collaborations actively working on a commonly identified challenge related to the transition to smart cities.
Discussion groups are fora where the participants can exchange experiences, co-operate, support, and discuss a specific theme.

Focus and Discussion groups

Community

Scalable Cities

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Scalable Cities

RENEWABLE ENERGY IN CITIES
SOLUTION BOOKLET

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