IRENA
International Renewable Energy Agency

RENEWABLE ENERGY IN CITIES

OCTOBER
2016

ISBN 978-92-95111-31-8 (Print),

ISBN 978-92-95111-32-5 (PDF)

Report citation IRENA (2016), Renewable Energy in Cities, International Renewable Energy Agency (IRENA), Abu Dhabi, ***www.irena.org.***

About IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future and serves as the principal platform for international co-operation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity.

Acknowledgements

This report was written under the overall guidance of Rabia Ferroukhi, Dolf Gielen and Elizabeth Press. This report benefited greatly from the analysis completed by Shweta Singh and Liz Wachs (Purdue University) on energy use in cities. The report also benefited significantly from input provided by external expert review by Cécile Gracy (ADEME), Rémy Lauranson, Regis Meyer, Quentin Perret, and Sophie Viellefont (COP 21 Task Force), Jakob Baum, Robert Kirchner, and Lisa Lebershausen (GIZ), Monika Zimmermann and Ana Marques (ICLEI), Uwe Remme (IEA), and Rashmi Jawahar, Lily Riahi, and Zitouni Ould-Dada (UNEP). Kathleen Daniel, Erik Lindner-Olsson, Verena Ommer and Henning Wuester (IRENA) also provided valuable inputs and comments. Finally, a special thanks is due to Mark Turner who worked on this report as an editor.

Three stakeholder workshops held between May 2012 and June 2013 provided the initial basis for this report. These are: the "Renewables for Resilient Cities" workshop that preceded the ICLEI Resilient Cities conference in Bonn, Germany on 12 May 2012; the "Renewables for Growing Cities in Africa" workshop organised with UN Habitat preceding the World Urban Forum in Naples, Italy on 2 September 2012; and the "Renewables in Cities" workshop organised by IRENA in Bonn on 3 June 2013. In addition, the outcomes of the roundtable that IRENA hosted on "Renewable Energy Deployment in Cities" during the 8th Singapore International Energy Week from 26-30 October 2015, as well as the proceedings from the Habitat III thematic (online) discussion from 12 to 25 January 2016 and the one-day Thematic Meeting on 20 January 2016 in Abu Dhabi, UAE, both on the subject of "Sustainable Energy and Cities", were used in the preparation of this report.

Authors: Jasper Rigter, Deger Saygin, Ghislaine Kieffer (IRENA).

For further information or to provide feedback: ***publications@irena.org***

This report is available for download from ***www.irena.org/publications***

FOREWORD

Fast evolving cities will drive the transformation of the global energy system in the 21st century. Cities already account for nearly two thirds of global energy use and an even larger share of energy-related carbon-dioxide emissions. As the urban population grows to a projected two-thirds of the world's total by 2030, that demand is reaching staggering proportions.

Across the world, decision makers face an important choice. Will they meet that rising demand with conventional technologies? Or will they seek systems that are healthier, more sustainable, and offer citizens new economic opportunities?

This publication suggests the choice is clear. Renewable energy, combined with energy efficiency, is ready to power the future growth of cities.

Accelerating the deployment of renewables and energy efficiency offer the best route to meet international development targets, including Sustainable Development Goal 11, which aims to "make cities and human settlements inclusive, safe, resilient and sustainable" by 2030. This is the optimal energy strategy that gives the world a fighting chance of keeping climate change within manageable levels.

A growing number of cities have already taken the decision, adopting ambitious renewable energy targets, some of them aiming for 100% renewable energy with zero net carbon emissions. However, it is not an easy path.

Switching to renewables means rethinking the entire urban energy landscape, from buildings, to transport, to industry and power. It means integrating energy supply and demand across the board, through smart technologies, rigorous planning and holistic decision-making.

Cities vary widely by size, population density, level of development and climate. Yet in each case, the right set of solutions exists to pave the way to a sustainable urban energy system.

Renewable Energy in Cities provides a compelling view of how this has started to happen.

Cities around the planet are charting their unique paths to sustainability, deploying a wide spectrum of renewable energy technologies for power, heating, cooling, cooking, and transport. Decision-makers are taking effective action at the municipal level, through planning, regulation, public procurement, direct investment, provision of services and awareness raising.

In the run-up to the United Nations Habitat III Conference in Quito, Ecuador, such pro-active energy solutions have drawn growing attention. The time has come to put renewable energy at the heart of the "New Urban Agenda".

Adnan Z. Amin

Director-General

IRENA

CONTENTS

List of Figures

List of Tables

List of Boxes

ABBREVIATIONS

A/C	air-conditioning
BESCOM	Bangalore Electricity Supply Company
BIPV	building integrated photovoltaics
CCA	community choice aggregation
CHIC	Clean Hydrogen in European Cities
CHP	Combined heat power
CO_2	carbon dioxide
CPCU	Paris Urban Heating Company
DALY	disability-adjusted life years
DEWA	Dubai Electricity and Water Authority
DSM	demand side management
EIB	European Investment Bank
EJ	exajoule
ESMAP	Energy Sector Management Assistance Program
GBPN	Global Buildings Performance Network
GDP	gross domestic product
GEF	Global Environment Facility
GIZ	German Agency for International Cooperation
GW	gigawatt
GWh	gigawatt-hour
IBRD	International Bank for Reconstruction and Development
ICCT	International Council on Clean Transportation
ICLEI	International Council for Local Environmental Initiatives
ICT	information and communication technology
IEA	International Energy Agency
IFC	International Finance Corporation
IPCC	Intergovernmental Panel on Climate Change
IPEEC	International Partnership for Energy Efficiency Cooperation
IRENA	International Renewable Energy Agency
KERC	Karnataka Electricity Regulatory Commission
kg	kilogram
kWh	kilowatt-hour
m^2	square metres
m^3	cubic metres
MSW	municipal solid waste
MW	megawatt
MWh	megawatt-hour
MWp	megawatt-peak
MWth	megawatt-thermal
NPR	Nepalese Rupee
NREL	National Renewable Energy Laboratory
O&M	operation and maintenance
OECD	Organisation for Economic Co-operation and Development
PACE	property-assessed clean energy
PJ	petajoule
PPA	power purchase agreement
PPP	Public-Private Partnerships
PV	photovoltaic
RE	renewable energy
REEEP	Renewable Energy and Energy Efficiency Partnership
RPC	representative concentration pathways
SE4All	Sustainable Energy for All
ST	solar thermal
SVP	solar ventilation preheat
SWAC	sea water air conditioning
SWH	solar water heating
TES	thermal energy storage
TPES	total primary energy supply
UCLG	United Cities and Local Governments
UITP	International Association of Public Transport
UNEP	United Nations Environment Programme
USD	United States Dollar
VAT	value added tax
VPP	virtual power plant
VRE	variable renewable energy
W	Watt
WBCSD	World Business Council for Sustainable Development
WHO	World Health Organization
WRI	World Resources Institute
WWF	World Wildlife Fund
WWI	Worldwatch Institute

EXECUTIVE SUMMARY

The transition to renewables cuts across the entire urban energy landscape, from buildings, to transport, to industry and power. It means integrating energy supply and demand between different sectors, through smart technologies, rigorous planning and holistic decision-making.

Cities today have the opportunity and the means to provide sustainable services and quality of life to their citizens. Urban areas account for more than half the world's population, as well as 65% of global energy demand and 70% of energy-related carbon dioxide (CO_2) emissions. Cities, therefore, need to take action to meet the rising needs of their populations while maintaining a healthy living environment, combatting poverty and avoiding catastrophic climate change.

Abundant renewable energy sources have the potential to meet these goals. Increasingly cost competitive with conventional power sources, renewables offer the lowest-cost supply of power in a growing number of places, without any financial support. Renewable solutions can transform and are transforming lives, communities and economies. This transition is creating jobs and new economic activities, democratising energy sources and ensuring energy independence for a wide range of countries and economies.

Cities are playing an increasing role in this crucial transition. Faced with the realities of fast urbanisation, they are embracing new and innovative solutions to meet development and climate objectives. *Renewable Energy in Cities* presents analyses the role cities can play in the transformation of the energy system. Built on real-life data of the energy use in 3 649 cities that account for 60% of global energy demand, the report charts pathways to greater deployment of renewables and explores the implications of renewable energy strategies between now and 2030. It also highlights best practices and provides an overview of policy and technology options.

While the potential for renewables is high, it varies greatly depending on each city's characteristics. Population density, growth prospects and demand profiles in cold versus hot climates all shape the opportunities to introduce renewables, including the vast growth potential for uses in urban buildings and transport. Accordingly, deployment strategies must be tailored to technology options and enabling policy frameworks for each city.

For example, average urban energy use in buildings and for transport ranges from about 5 000 kilowatt-hours (kWh) to nearly 30 000 kWh per capita, simply due to differences in climatic conditions, population density, and each city's level of establishment (Figure ES1). As a result, sustainable and low-carbon energy roadmaps must address specific challenges and formulate specific policies to support particular cities. As the report indicates, no single solution exits to scale up renewable energy in cities.

Transforming the urban energy system is not a question of simply replacing one form of energy with another, but of rethinking the entire energy system with all the related interactions and uses. This involves considering the main end users, including buildings, transport and industry. It requires designing smart, integrated urban energy systems that can manage variable power produced by solar panels and wind turbines, and that can take advantage of sector synergies where energy is produced and consumed. It also means taking all policy areas and governance levels into consideration.

Cities in emerging economies with population growth above 2% per year, for example, will account for 70% of global growth in energy use up to 2030. These cities will be best positioned to deploy energy efficiency and renewable energy technologies in new buildings and can adopt more compact urbanisation models that ensure efficient and sustainable transportation. In urban and peri-urban areas, where extending energy access is a top priority, decentralised power generation and clean cooking solutions are crucial for sustainable development. There, renewable energy technologies can be deployed quickly, incrementally and cost-effectively.

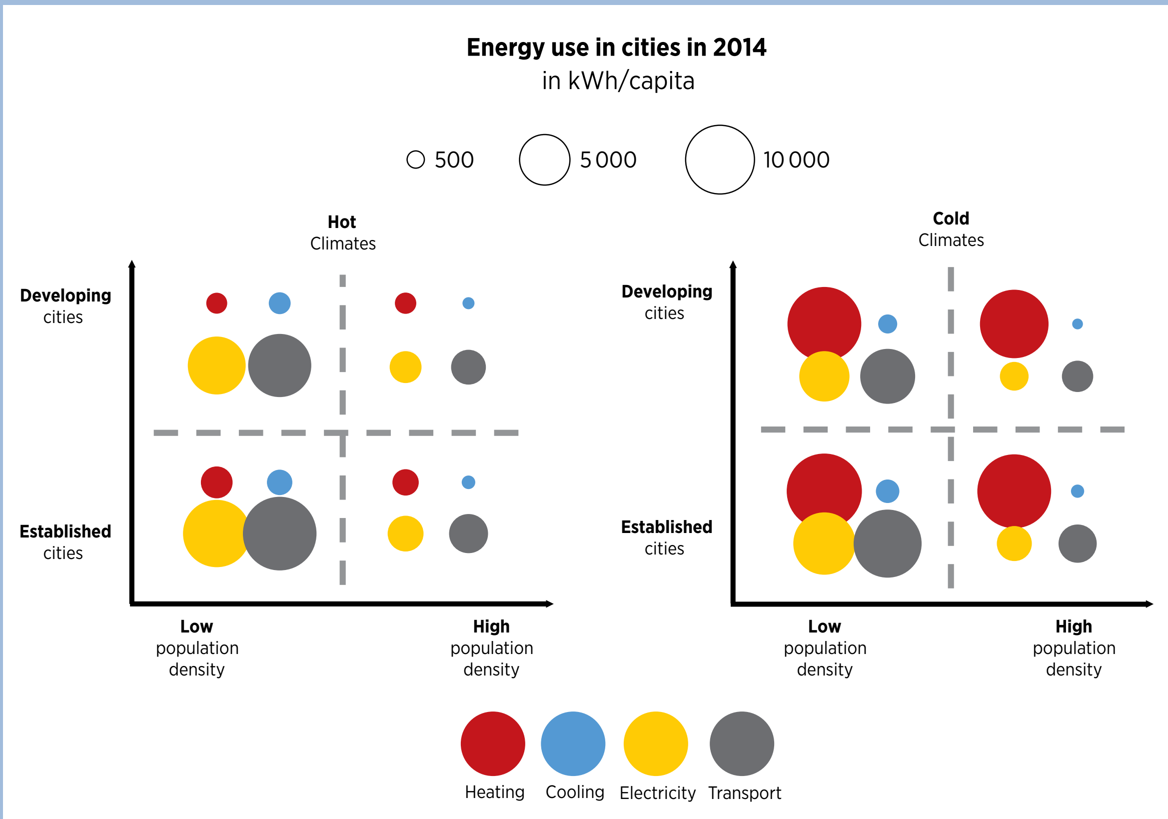
Priority action areas for renewable energy in cities:

1) Renewable energy in buildings
2) Sustainable options for transport
3) Creating smart integrated urban energy systems

Established cities, on the other hand, have lower building turnover rates and will largely rely on retrofits and technologies that can be added relatively easily to existing buildings, such as heat pumps and rooftop solar equipment.

Cities with **high population density** can benefit from renewable-powered electric public transit systems and cost-effective district heating and cooling systems. **Low-density cities**, with larger rooftop areas, could benefit from highly distributed renewable energy technologies and the growth of electric cars.

Figure ES1: Energy use by application in different city types, 2014



Note: to distinguish city types, the city database was split into upper and lower groups (lowest/highest 50% of values) based on population growth 2014-2030, population density in 2014, and heating degree days in 2014. Heating degree days are a metric used to measure the demand for heating relative to a reference/base temperature (typically outdoor temperature). Electricity use excludes energy use for heating and cooling.

Renewable Energy in Cities presents proven and emerging renewable energy technology solutions, examines the growing linkages between the heat, transport and power sectors, and considers the build-out of smart grids and demand-side management. Featured solutions include renewable heating, cooling and cooking in residential and commercial buildings as well as renewable energy for transport, including biofuels and electric mobility based on renewable power sources.

City planners and policy makers possess several available levers to steer urban energy systems towards renewables and reap their benefits. As growing evidence confirms, sustainable energy can be promoted at the municipal level through planning, regulation, public procurement, direct investment, provision of services and awareness raising.

Cities are largely bound by national frameworks and infrastructure systems. Yet effective cooperation and coordination of policies and initiatives between different levels of governance can enable change at the local level. It can unlock finance, capacity building and technical support, data, and can create new mandates to accelerate the transition to a sustainable energy future.

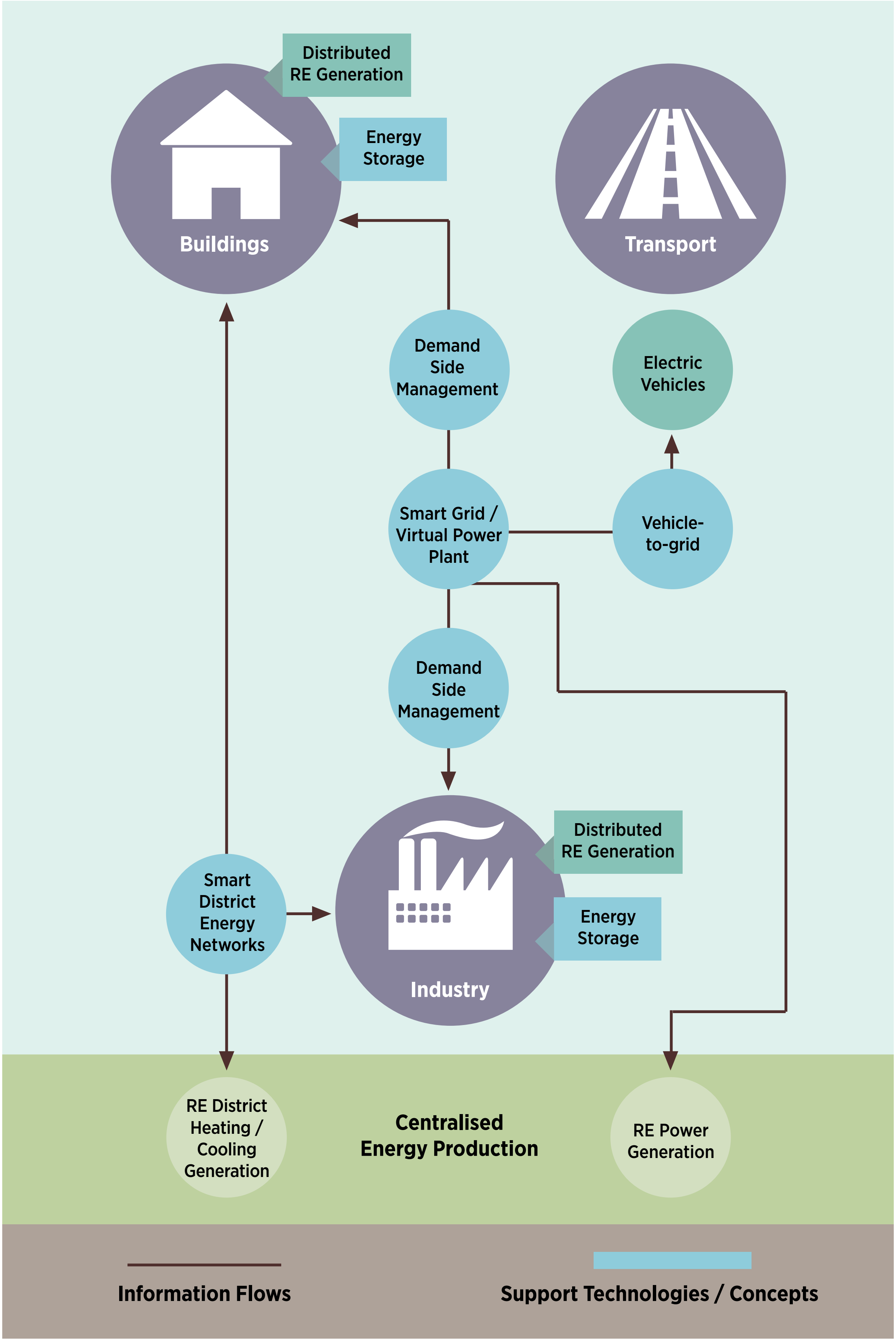
Renewable Energy in Cities presents examples of city experiences, challenges and success stories to highlight viable and carbon-effective options for renewable energy deployment. It also underlines the compelling business case for the transition, stressing that the time is ripe for cities to switch to renewable solutions.

Mayors and municipal governments are playing an increasingly central role in accelerating the switch to renewable energy. While many policies are still enacted at the national or regional level, this report examines the many ways in which cities are taking control of their own renewable futures, with encouraging results.

- **Target setting.** Cities can set their own renewable energy targets to align stakeholders behind common goals. A small but growing number of cities are planning to switch to 100% renewable energy, with zero net carbon emissions.
- **Regulation.** Based on their legal competence, cities have a powerful regulatory role to unlock renewable energy potential whether through building codes, grid connection rules, technical standards, land-use planning, public housing programmes, and through specific measures such as solar ordinances.
- **Operation.** In some cases, cities are owners and operators of municipal utilities including energy utilities. As such, they may influence the energy mix as well as develop and invest in renewable power plants, district heating/cooling networks and sustainable transportation infrastructure.
- **Consumption.** Cities without utility ownership remain large energy consumers in their own right, and can demand that the power they use for hospitals, schools, offices, street lighting and public transportation comes from renewable sources. They can act as aggregators of demand, procuring electricity in large quantities to cover the combined needs of residents and businesses, thereby increasing competition and reducing risk and prices.
- **Financing.** Cities act as financiers, influence taxation and can offer incentives or low-interest loans to promote the uptake of renewable energy solutions. In some countries, municipal energy companies are among the most important investors in renewable energy projects.
- **Advocacy.** Cities serve as powerful advocates, able to influence the behavioural choices of citizens and businesses by raising awareness about the benefits of renewables. Municipal authorities can also strengthen local capacities and skills through dedicated training programmes on renewable energy.

The transition to renewables in cities also entails a shift in mindset that considers energy as a driver for economic and environmental sustainability across the urban landscape. In such an interconnected system, every citizen sits at the centre of a web of decision-making, from electricity supply to consumption and transportation choices.

Figure ES2: Overview of required support technologies and concepts for an integrated urban energy system



Cities operate through a vast web of interconnected networks. While many of these are treated, traditionally, in policy-making silos, the switch to renewables offers a wealth of opportunities to create synergies between sectors.

Technologies such as rooftop solar photovoltaic power generation, distributed energy storage and electric mobility are becoming an integral part of city power systems, with a key role in balancing the demand and supply of electricity. Buildings are now both consumers and producers, switching between these functions at different times of the day. An electric car is both a user of renewable power and a storage centre that can provide essential backup at periods of lower power generation.

Linkages are also growing between the electricity and heat sectors, through the expanding use of heat pumps, as well as renewable-based district heating and cooling networks. Many other innovative technologies, such as demand-side management, virtual power plants, vehicle-to-grid, and smart power and district energy networks, are similarly reshaping the systems and infrastructure of the past.

Renewable energy solutions are part of the broader sustainable development agenda of cities. For the key role of renewables to be fully realised, cities will need to break down their internal barriers and forge new links between decision makers in urban planning, power, transport, waste management, and multiple other areas. The rewards for an effective sustainable energy strategy in cities are immense, affordable and achievable.

1. ENERGY USE IN CITIES AND THE ROLE OF RENEWABLES

1.1 Recent trends in urban energy use

The share of global energy used by cities is rising fast. In the early 1990s, cities used less than half of the global energy supply. Today, it is nearly two-thirds (Figure 1).

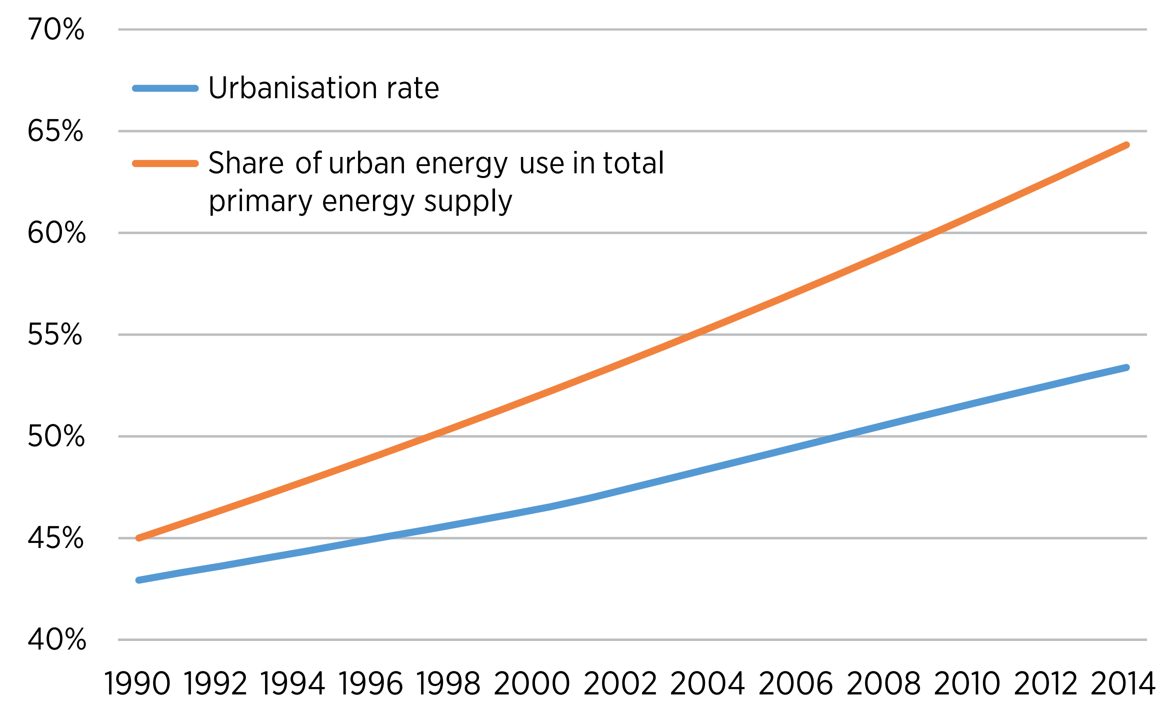
Because of this growth, any decisions made for the future of energy and climate need to build on a robust understanding of urban energy systems. As we learn more, we are better able to categorise different urban energy system types, and design policies specific to them.

Until recently, these breakdowns of energy usage have typically not been available, or only available for a limited number of cities.

Figure 2 provides estimates by sector in selected cities. They show significant differences between cities. High- and middle-income country cities, for example, use most of their energy in transport and buildings. In cities in Asia and some Latin American countries, energy use is dominated by industry.

These shares change depending on how city boundaries are defined, and where industrial plants are located

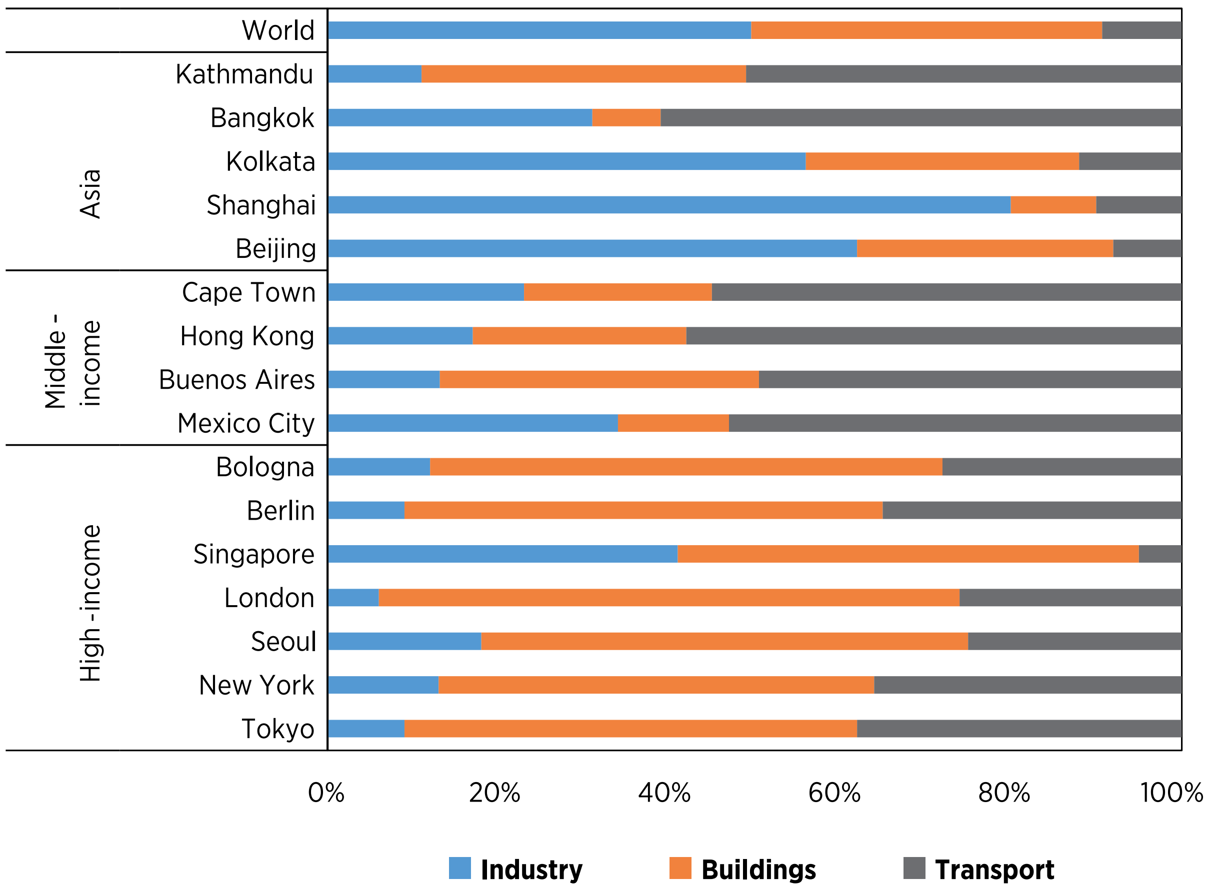
Figure 1: Global urbanisation rate and share of urban energy use in total primary energy supply, 1990-2014



Based on IRENA estimates

The share of urban energy use in the global energy mix is increasing faster than the global share of urban population.

Figure 2: Estimates of the breakdown of energy use by sector in selected cities



Note: data refers to a year between 1998 and 2005

Source: UN Habitat (2008)

(Box 1 and 2). For clarity's sake, this analysis will focus on buildings and transport, as well as efforts to integrate currently disparate sectors into one coherent urban energy system. It builds on previous IRENA analysis of the potential for renewable energy in the manufacturing industry (IRENA, 2014a, 2015a). Analysis is complemented by IRENA's ongoing work on renewable energy in district heating and cooling.

Box 1: What is a city?

For this analysis, IRENA included all named metropolitan agglomerations and cities with populations exceeding 100 000 in the year 2000, as per the city level data from the Lincoln Institute of Land Policy (Schlomo *et al.*, 2010). In total, the database covers 3 649 cities with an aggregate population of about 2.6 billion in 2014; *i.e.* about 36% of the global population. The United Nations estimated a higher global urbanisation rate of 53% in 2014, by including cities with less than 100 000 inhabitants (UN Statistics, n.d.).

Box 2: Potential of renewable energy in industry in the urban context

The manufacturing industry represents a third of global energy use today. However, at a city level, there are disputes about its scale, and it differs significantly between cities. This report focuses on buildings and transport. However, for the transition to a more sustainable urban energy system, some cities will also need to consider the industry sector.

For example, Rotterdam in the Netherlands hosts a large industrial area in its seaport, which includes activities from food processing to chemicals production. In China, it is not unusual for a large iron and steel plant to be part of the urban panorama. Small and medium-scale industries, such as ceramics production and foundries, are scattered across cities in India.

1.2 The role of renewable energy in cities

Negative impacts of rising energy use

Rising energy use in cities has lifted billions of people out of poverty. However, it has also come at a cost due to the increased use of fossil fuels.

Cities account for 70% of man-made CO_2 emissions, making them a major contributor to climate change. Cities are also likely to suffer the brunt of climate change effects. An estimated 70% of all cities are dealing already with the effects of climate change (C40, n.d.). As 90% of all urban areas are coastal, the damage from rising sea levels and severe storms will only increase. Some cities in developing countries are particularly vulnerable due to relatively high rates of population growth. They also lack infrastructure and planning capacity, and have limited financial resources (Birkmann *et al.*, 2016).

Increasing energy use has also led to skyrocketing urban air pollution. Of people living in urban areas, more than 90% cope with air quality levels exceeding the World Health Organization limits (WHO, 2016). In low and middle-income countries, this rises to 98%. IRENA estimates the cost of outdoor air pollution at USD 1.8-6.0 trillion in 2010, or about 3-10% of global gross domestic product (GDP) (IRENA, 2016a). Under a business as usual scenario, this will rise to USD 2.4-8.8 trillion per year by 2030.

Fuel-driven transport creates high levels of noise pollution. An estimated 65% of EU citizens living in major urban areas are exposed to high noise levels, with 1-2 million disability-adjusted life years (DALYs)[1] lost to environmental noise in the EU each year (European Commission, 2015). In developing world cities with high population densities, the effects are likely to be more severe.

Energy efficiency and conservation

Energy efficiency is one major route to reducing projected energy use by 2030.

The largest potential for savings exists in **buildings**. New buildings in growing cities can be designed with the latest technology, which follows minimum energy use standards. Modernising the existing building stock in established cities is more challenging. It is important to avoid investment in marginally more efficient technologies, so as not to create a "technology lock-in". For example, replacing an old oil-fired boiler with one that is slightly more efficient (instead of a significantly more efficient heat pump) can inhibit efficiency improvements for many years, given the long lifetime of the equipment. Similarly, the renovation of shells of buildings that were constructed with energy-inefficient building materials can be costly.

While most developed countries have ambitious targets for achieving low energy use in buildings, and already have mandatory building energy efficiency codes in place, this is not the case in many developing countries. These often suffer from a lack of information

1 One DALY represents the loss of one year of living in full health

and knowledge on energy efficiency options, poor enforcement of building codes and standards, and misalignment between national and local governments in implementing and enforcing policies (IBRD and World Bank, 2010). Given that they account for a majority of new building stock in the coming decades, developing countries have a critical role to play in reducing energy use in buildings at a global level. Inefficiently designed buildings constructed today risk becoming stranded assets tomorrow, and significant funds may need to be spent on renovation.

According to the International Energy Agency (IEA), far more investment is needed in building energy efficiency to meet international climate change targets, and keep average global temperatures within 2°C of pre-industrial levels. Total investment will have to increase from USD 80-100 billion in 2014 to about USD 215 billion per year in 2020 (IEA, 2015a).

Many international organisations have launched initiatives to support the required focus on energy efficiency improvement in buildings (Table 1). For example, the Building Efficiency Accelerator partnership works directly with 23 cities to implement policies, programs and projects to improve building efficiency (WRI, 2016). Numerous other initiatives exist for specific countries or regions, or with a focus on the residential or commercial sectors.

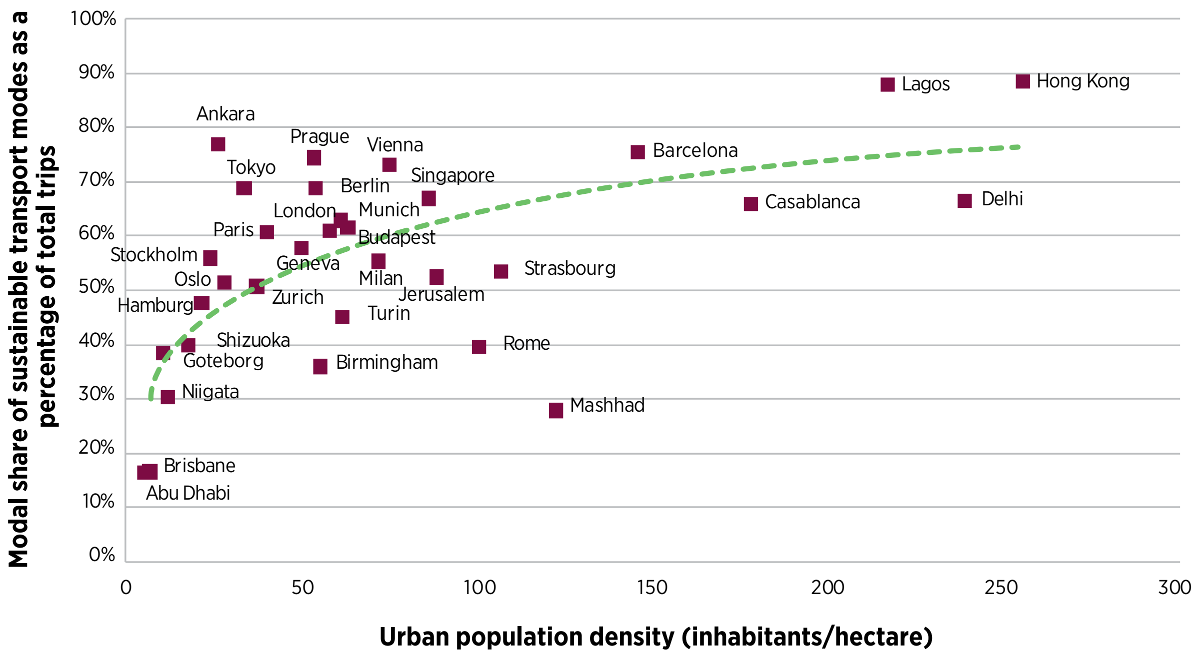
Efforts to conserve energy in the **transport sector** include technological innovation and modal shift. Such innovations include more fuel-efficient internal combustion engines, smaller and lighter cars, and zero-emission electric vehicles. More important is the move towards electrified transport that, in turn, can drive a higher share of renewables in the energy supply mix. Modal shift includes the promotion of more sustainable transport modes, such as public transport but also walking and cycling. Generally, the share of sustainable transport is higher in cities with high population density (UITP, 2015a) (Figure 3). Cities can pro-actively encourage behavioural change. In Copenhagen, large parts of the city are no longer accessible to cars. In New Delhi, the government recently experimented with alternately banning cars with odd and even number plates to support car-pooling, cycling, and walking.

Many cities have understood their crucial role in transforming urban mobility systems. Almada (Portugal), Boulder (US), and Kochi (India) are some examples of cities that have developed comprehensive plans to improve the sustainability of their urban transport systems (ICLEI, 2016b).

Table 1: Overview of selected international initiatives that include a focus on energy efficiency in buildings

Initiative	Key stakeholders	Geographic focus
Building Efficiency Accelerator	WRI Ross Center	Global (cities)
Global Buildings Performance Network	GBPN	Global
Global Energy Efficiency Accelerator Platform	SE4All	Global
Building Energy Efficiency Task Group	IPEEC	IPEEC member countries
Sustainable Buildings and Climate Initiative	UNEP	Global
City Energy Efficiency Transformation Initiative	World Bank, ESMAP	Global (cities)
Affordable Efficient Housing	REEEP	Developing countries
Energy Efficiency in Buildings	WBCSD	BRIC, Japan, US, Europe
Energy Efficiency Program	Clinton Foundation	Global
Private Building Efficiency Network	C40	Global (large cities)
Global Alliance for Buildings and Construction	UNEP, France, *et al.*	Global
Global District Energy in Cities Initiative	UNEP	Global (cities)

Figure 3: Share of sustainable transport modes versus population density in cities



Source: UITP (2015b)

Note: sustainable transport modes includes walking, cycling, and public transport trips.

Energy efficiency in buildings, modal shift in transport and electric mobility offer significant potential to reduce energy use in cities.

Renewables as a key solution

While many cities have so far focused primarily on energy efficiency, the next step towards a sustainable energy system will require a significant increase in the use of renewable energy.

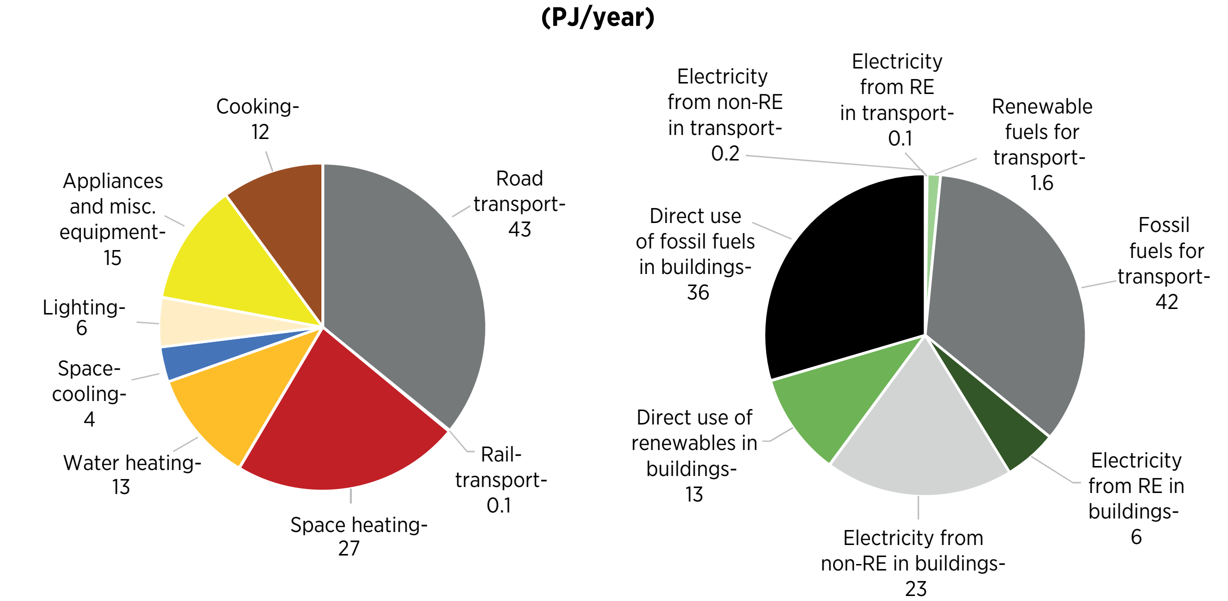
This offers many advantages. Renewable energy is clean, reducing CO_2 emissions and air pollution. It is affordable, meaning it is cost competitive with non-renewable alternatives. It is sustainable, offering greater energy security and resilience to external shocks. Moreover, it is empowering, providing a wealth of new jobs, and greater economic opportunities in cities. IRENA estimates that doubling the share of renewables in the global energy mix by 2030 can create millions of new jobs, improve health and boost the global economy by up to USD 1.3 trillion (IRENA, 2016a).

In 2013, about 20% of all buildings and transport energy use in cities was supplied by renewable energy (Figure 4). This mainly consisted of direct and indirect uses of renewable energy in buildings, which supplied nearly a quarter of the energy they used. The share of renewable energy used in transport remains more limited at about 4%, primarily from liquid biofuels.

Falling costs, and growing awareness of renewable technologies (*i.e.* easier access to finance) implies there is an opportunity to increase this share significantly.

At a global level, installations of wind power plants and solar photovoltaic (PV) power plants and rooftop systems have reached record highs. In heating, cooling and transport, however, progress has been slower. Investments in liquid biofuels – renewable gasoline and diesel substitutes produced from biomass feedstocks

Figure 4: Breakdown of urban energy use in buildings and transport by application and carrier, 2013



Source: IEA (2016)

Renewables currently supply about 20% of energy for transport and buildings in cities. There is an opportunity to significantly increase this share.

– have slowed down significantly, and countries are refining their plans to utilise bioenergy for heating. The uptake of heat pumps and solar water heating is progressing relatively well.

Promoting renewables at the city level depends on several factors, including whether targets and policies are set at the national or local level, as well as the level of control that cities have over utilities. Winning over citizen support is also essential. The roles that cities can play in accelerating renewable energy deployment are detailed in section 3.2.

2. PRIORITY AREAS FOR A TRANSITION TO RENEWABLE ENERGY USE IN CITIES

Cities can accelerate the uptake of renewable energy in three priority areas:

1. Renewable energy in buildings;
2. Sustainable options in transport;
3. Creating smart integrated urban energy systems

Buildings and transport are the two largest energy consumers in cities, and what happens in these sectors will determine the sustainability of energy use. City governments can play a pivotal role by implementing supportive policies, demonstrating innovative technologies, and providing the right infrastructure for these sectors. As energy supply and demand become increasingly interconnected, systemic, long term and integrated planning for urban energy systems will become more important.

The sections in this chapter each conclude with tables that provide an overview of the key solutions identified for each of the action areas, as well as numerous examples of where they are implemented at the city level. Clearly, many cities around the world are already embracing the solutions that renewable energy can provide.

2.1 Renewable energy in buildings

Most of a city's energy use takes place in its residential, commercial, and public buildings – through heating, cooling, and the powering of appliances. Figure 5 shows how cities can make use of a wide range of renewable sources to supply energy for consumption within buildings, and Table 2 at the end of this section presents selected examples of cities using renewable energy technologies and policies to meet energy needs in commercial and residential buildings.

Options range from decentralised renewable energy production, supplying energy within the direct vicinity of buildings, to centralised renewable energy production, in which energy is generated elsewhere and then distributed to buildings via energy networks.

Decentralised options include solar thermal collectors, solar PV panels, biomass boilers, and modern cookstoves using bioenergy (mainly in developing countries).

Centralised options include using renewable energy applications to generate heat or cold supplied to buildings through district energy networks, and renewable power, which can be used for cooking, lighting and appliances, and heating or cooling.

Urban policy makers can promote the production of renewable energy in buildings through a range of policies and regulations, such as building codes, permits, zoning regulations and building performance ratings (WWI, 2016). More specific examples include incentivising rooftop solar photovoltaic panels, and solar water heating (SWH).

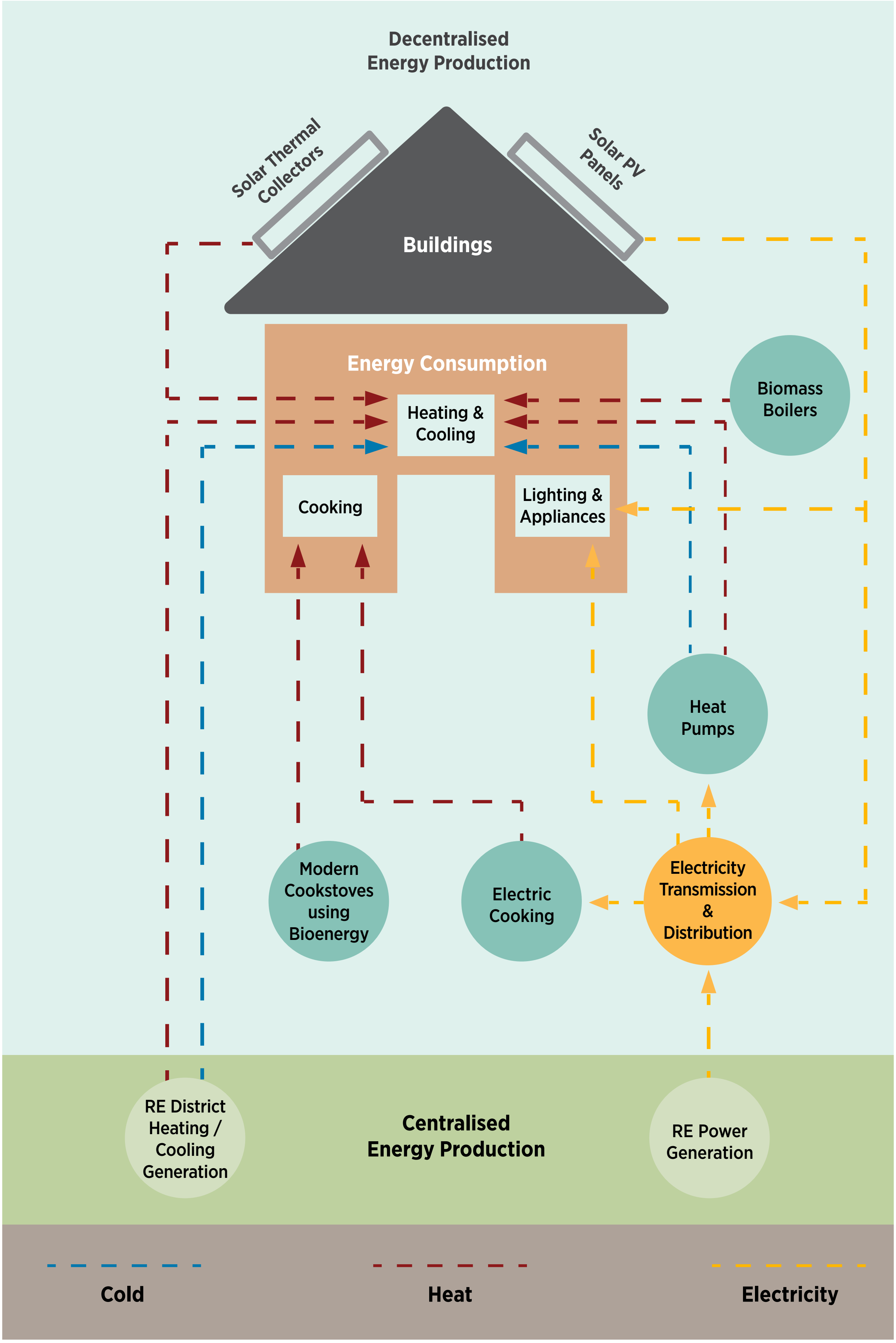
There are more than 600 building codes and standards worldwide, which vary widely in how broadly and how strictly they apply (WWI, 2016). **Building standards** provide technical guidelines and minimum requirements for a building's performance; **building codes** are standards transposed into law by local, regional or national governments. Most codes are legally binding, although their enforcement tends to be lagging (IEA, 2013), while some codes exist purely as voluntary green certification schemes (Heinsdorf, 2015; C40 and ARUP, 2015).

Heating

Renewable energy options for heating (space and water) consist of decentralised equipment in buildings and centralised generation.

Decentralised **solid biofuel-fired boilers** (*e.g.* wood pellets and chips) are a mainstream technology. For cities the implementation of codes and standards to minimise the negative health impact of such boilers is important, given they can contribute to air pollution. **Solar thermal systems** have been used for decades for water heating, and to some extent also for space heating. IRENA estimates a potential of more than

Figure 5: Overview of renewable energy options in urban commercial and residential buildings



City trends: solar thermal systems

China is home to 70% of the global installed capacity of SWH, and Chinese cities have played an important role in accelerating its deployment. Between 2009 and 2011, a central government policy supported demonstration cities for renewable energy use in buildings (IEA-SHC, n.d.). 72 cities and 146 counties took part in the programme. By 2011, about 45% of solar thermal systems in China were based in cities, up from 40% just one year earlier (Tao, 2011). At the same time, over 80 cities had issued compulsory and favourable policies for installing solar water heating systems, which often included the compulsory installation of SWH in new public, residential, and commercial buildings. The Chinese city of Rizhao, for example, has promoted SWH in residential buildings for the past 20 years through regulations, information campaigns and subsidies. The Shandong provincial government helped finance solar research and development resulting in competitive pricing of SWH systems compared to electric heaters. As a result, by 2015, 90% of households in Rizhao had access to SWH (Rizhao Government, 2015).

Today, water heating accounts for about 26% of household energy use in cities in Spain (WWI, 2016). Barcelona was the first city in Europe to introduce a Solar Ordinance in 1999. It mandated that 60% of hot water be provided through solar energy in new and renovated buildings (C40, 2011). The area of installed solar thermal panels expanded from 1650 m2 to 87600 m2 within a decade (2000-2010). Barcelona's efforts prompted more than 70 Spanish cities to introduce similar ordinances, and in 2007, the Spanish national government adopted a new technical building code requiring mandatory solar thermal installations (ICLEI, 2014a; WWI, 2016). Since then, many other cities and countries around the world have followed this example.

3200 million m^2 of rooftop space to be used for solar thermal collectors worldwide by 2030; a near six-fold increase from the installed capacity in 2014. Historically, cities have played an important role in promoting the use of solar thermal energy systems, in particular for water heating.

Large quantities of heat are lost every year from power generation and industrial processes. Co-generation is one of the most efficient ways of reusing this heat, but accounts for less than 10% of global power generation, and its use is declining (IEA, 2016). **District heating and cooling networks** are another way to provide more cost-effective energy (UNEP, 2015a; OECD, 2013). District energy systems consist of a network of underground, insulated pipes that pump hot or cold water to multiple buildings in a district, neighborhood or city. Some systems just connect a few buildings, while others connect thousands of buildings and homes across a city.

Despite the benefits, however, the use of district energy is quite limited, accounting for only one tenth of demand for heat in the commercial and residential sectors (IEA, 2016). This creates significant opportunities to further scale up the use of renewables to generate heat for distribution through district heating systems. The potential varies between cities though, not only because of the difference in the availability of renewable resources but also because generally a minimum level of heating density is required for district heating to be viable.

District heating networks using bioenergy have been in operation for a long time in many cities, mainly in Nordic countries and other parts of Europe. The heat is typically produced in large boilers known as heat plants, which is then transported across the cities to households, commercial buildings and industrial plants. Other renewable energy resources are also used, such as geothermal in Iceland and industrial excess waste heat in various cities in Europe. The use of renewable energy is growing in certain cities, such as geothermal in Munich and Paris, and solar collectors in Denmark. District energy has become a cornerstone of Denmark's goal of sourcing 100% of its energy needs from renewables.

Cooling

As people in hot climates grow more prosperous, their demand for cooling is increasing rapidly.

City trends: seawater district cooling

District cooling networks using seawater cooling have been used in cities in cold climates such as Copenhagen and Stockholm for quite some time, but recently the technology has gained traction in hot climates as well. In Port Louis, Mauritius, the first seawater-based district-cooling network in Africa is under development. When completed, it will offset about 26 MW in power supply, or about 6% of 2014 peak electricity demand in the country (UNEP, 2015a). In Honolulu, Hawaii, a USD 250 million seawater cooling project is under development, which would avoid imports of 178 000 barrels of oil per year (Honolulu SWAC, n.d.).

Almost all cooling is currently provided by air-conditioning (A/C) systems using electricity. While more of this electricity can be generated by renewable energy, cooling can also be supplied by renewable options integrated in the building infrastructure.

This includes solar cooling systems, such as absorption chillers, adsorption chillers, and desiccant cooling systems. Absorption chillers use a refrigerant to cool the environment, and account for over 70% of installed systems today (IRENA and IEA-ETSAP, 2015).

Some households connect their A/C systems to a solar panel mounted on the rooftop. This is becoming popular in cities, especially with decreasing battery storage prices.

The global market for renewable energy-based cooling is still in a nascent stage, however, and cities could do more to promote its uptake. Renewable energy-sourced district cooling is also an option, using cold water from rivers, lakes or the sea, waste heat for absorption chillers, and solar energy.

Cooking

60% of renewable energy use in buildings today consists of traditional uses of bioenergy, mainly in the

City trends: clean cooking

Modern bioenergy cookstoves can run on biogas, solid biofuels or ethanol, and reduce indoor air pollution significantly compared to cooking on an open fire. Biogas digesters for cooking have been used for some time in the south of India. The biogas is produced from organic waste in plants ranging in size from household (1-5 kg per day) to large-scale (up to 100 tonnes/day) (Vögeli and Zurbrügg, 2008). In Nepal biogas has been used in cooking for more than 60 years, mainly in rural settings. The country now aims to build 2 500 biogas plants in urban locations between 2012 and 2017 (Government of Nepal, 2012). These plants will use biodegradable waste to produce cooking gas and electricity (The Kathmandu Post, 2015).

For solid biomass, programmes to provide cleaner and more efficient charcoal and wood cookstoves are underway in Ghana, Kenya and Mali. Ethanol cooking is also prevalent in selected urban areas in Africa. 200 000 cookstoves have been sold in Ghana and Nigeria using cellulosic ethanol made from sawdust (Green Energy BioFuels, n.d.).

Electric cooking is also growing in popularity. In South Africa, 85% of urban households now use electricity for cooking, 73% in Zimbabwe, and 40% in Mongolia (ESMAP, 2015). In Ecuador, the government decided in 2014 to promote induction cooking through financing support and free electricity during the first month. It aims to reach 3.5 million systems by the end of 2017 (Scherffius, 2015). As solar and wind power capacity is set to expand in most of these countries, indirectly more of the energy used for cooking will be supplied by renewable energy.

City trends: rooftop solar PV

In April 2016, San Francisco became the first major US city to require all new buildings to install rooftop solar PV. The ordinance builds on a California requirement for new buildings to set aside 15% of the roof area to be "solar ready", meaning the space should be clear and unshaded (City and County of San Francisco, 2016).

The City of Adelaide has launched a solar leasing initiative to reduce the upfront cost of installing solar systems, targeted at lower income households (Vorrath, 2016).

Tokyo plans to install 1 gigawatts (GW) of rooftop systems by 2024, including 22 megawatts (MW) of PV on metropolis-owned buildings and facilities by 2020. It aims to increase the share of renewables to 20% of total power generation by the time of the Summer Olympics in 2020 (Movellan, 2015b).

form of cooking on open fires in the developing world. While this is mainly a rural practice, urban households are also using solid cooking fuels in inefficient stoves. This is harmful to human health, due to indoor air pollution. In developing countries, urban dwellers tend to have higher levels of access to commercial energy sources than rural populations. Yet, about 18% of urban populations in developing countries still use fuelwood and charcoal for cooking, and in the least developed countries, this share reaches close to 70% (UN DESA, 2013).

Modern cookstoves, using bioenergy or electricity, are therefore a key solution being actively promoted. The electricity used for cooking can in turn be generated by renewable power.

From consumption to production

One of the defining features of renewable energy is that consumers can now become producers at the same time. Commercial and residential buildings are amongst the largest energy consumers in cities, but in a renewable energy system, they are also the most widely available urban resource (WRI, 2016) (WWI, 2016). This is mainly due to the dramatic growth of rooftop solar PV.

Between 2010 and 2014, rooftop solar power capacity more than tripled worldwide, from 30 GW to 100 GW, enough to cover the electricity demand of about 30 million households[2]. By 2030, IRENA estimates installed rooftop PV could rise to 580 GW (IRENA, 2016b). This paradigm shift gives households the option

2 Estimated based on global averages for the capacity factor of solar PV (10%) and electricity use (3 000 kWh per household).

Table 2: City examples of the use of renewable energy technologies and policies to meet energy consumption in commercial and residential buildings

Energy use	Technology/ resource		Area	Example
Space and water heating	**District heating**	Residual heat	Rotterdam, the Netherlands	Use of residual heat from the port is being increasingly used in the city's district heating network
		Waste	Vienna, Austria	District heating provides heat to 270 000 people in the city; waste incinerators are a main source of energy
		Bioenergy	Stockholm, Sweden	87% of district heat is provided by renewables, which include excess heat and combustible waste but also solid biomass
		Geothermal	Munich, Germany	5 additional geothermal locations planned for 2025 and a target of 100% renewables in district heat by 2040
		Solar	Crailsheim, Germany	7 300 m² of solar thermal flat plate collectors provide 50% of the heat to 260 housing units
			Cities in Denmark	Solar district heating in Denmark increased from 100 000 m² installed in 2010 to 800 000 m² installed by 2015
	De-centralised boilers	Solid biofuels	Aberdeen, UK	Biomass boilers installed in various public buildings, including the City Council building, a hospital, and a primary school
	Solar thermal heating	Solar	Cities in China	Over 80 cities with compulsory and favourable policies for installing solar water heating systems by 2011
			Sao Paulo, Brazil	A Solar Ordinance requires new residential, commercial and industrial buildings to install SWH to cover at least 40% of energy used for heating water
			Barcelona, Spain	Barcelona was the first city in Europe to introduce a solar thermal ordinance, requiring 60% of the total hot water to be provided by Solar Thermal
	Heat pumps	Renewable power	Cities in Europe	The European Heat Pump Association has annual awards for cities with innovative heat pump projects. Past winners include Amstetten (Austria), Etten-Leur (the Netherlands), Viborg (Denmark), and Olot (Spain)
Cooling	**District cooling**	Water (sea)	Port Louis, Mauritius	The first seawater district cooling network in Africa is under development for 26 MW of power
			Honolulu, Hawaii	A USD 250 million project is under development to avoid oil imports to the island by 178 000 barrels per year
		Water (river)	Bonn, Germany	The Post Tower uses water flows from the Rhine river through 210 kilometres of piping for heating and cooling
		Geothermal	Paris, France	80% of France's geothermal capacity is in Paris, with plans to double geothermal capacity to 100 MW_{th} to supply energy for heating and cooling
		Solar	Geneva, Switzerland	1 139 m² of rooftop solar collectors at Geneva Airport provide heating and cooling to the airport's terminals
	Solar cooling	Solar	Barcelona, Spain	A 35 kilowatt (kW) system was installed on one of the city's public health agency buildings in 2007
			Singapore	A 1 500 kW system using 3 900 m² of collector surface at the United World College was commissioned in 2011
Electricity (production)	**Rooftop solar PV**	Solar	Tokyo, Japan	A target for 1 GW of on-site systems solar PV in the city by 2024
			Bangalore, India	Local and state entities leading net metering policy resulting in 14 MW of cumulative installations between 2014 and 2016
			Cape Town, South Africa	Through net metering programme city has commissioned more than 4.5 MW of grid-connected small-scale solar PV capacity
			San Francisco, US	An ordinance requires solar PV to be installed on new buildings up to 10 stories tall, the first major city in the US to do so
	Building integrated PV		Denver, US	Denver provides streamlined, same-day permit review for solar panel projects, including Electrical, Plumbing, and Zoning Permits for PV systems
			Uppsala, Sweden	Building integrated PV was integrated with a residential building housing 70 apartments in 2014
Cooking	**Electric cooking**	Renewable power	Cities in Ecuador	Financing support and free electricity for one month were used by the government to support induction electric cooking
			Peri-urban Bolivia and Paraguay	Solar cookstoves programme in peri-urban areas including local production, installation and maintenance, aiming to install more than 50 000 stoves in Bolivia and Paraguay. Stoves reduce fuel-wood consumption by more than 60% and generate emission reductions
	Improved cook-stoves using bioenergy	Solid biomass	Cities across Africa	Various clean cookstove programmes to support scaling up access to finance and the dissemination of clean cookstoves, such as improved cookstoves in Mali, Ghana, Urganda and Kenya, among others
		Ethanol	Maputo, Mozambique	CleanStar Mozambique, a food, energy and forest protection business, seeks to leverage carbon finance to disseminate up to 30 000 improved cookstoves in urban and periurban Maputo
		Biogas	Ibadan, Nigeria	A scheme is using slaughter-house waste to produce biogas (1,800 cm methane daily) and 1 MW power generation capacity at lower than market price. as well as fertiliser for low-income farmers, creating local jobs and boosting local industry
			Cities across Nepal	Nationally subsidised domestic biogas plants use daily organic wastes to produce biogas for cooking purposes in urban households since 2012

to produce their own electricity, and reduce risks related to shortages, blackouts and volatility in electricity prices.

2.2 Sustainable options for transport

Transport accounts for just over a third of global energy use in cities today, and IRENA's Roadmap for a Renewable Energy Future (REmap), suggests this could grow by nearly 50% by 2030 (IRENA, 2016b). If the resulting energy demand is met by fossil fuels, it will have major adverse consequences for air and noise pollution in cities, as well as global warming. Figure 6 shows the range of options in which renewable energy can power urban transport, and Table 3 at the end of this section presents selected city examples for each of these options.

For rail transport, the main options are electric-powered trains, light rail and metro systems. For road, the main options are electric vehicles, biofuels (both liquid and gaseous) and hydrogen (when produced from renewable power).

As with buildings, electrification in transport can drive the uptake of renewable energy.

Biofuels

Internal combustion engines will continue to play an indispensable role in the transport system for the foreseeable future.

To decrease their carbon footprint, these can be powered by biofuels, a form of renewable energy that comes either in liquid or gaseous form. Biofuels are generally classified as first and second generation, according to the feedstocks employed for their production. First-generation or conventional biofuels, made from agricultural crops such as corn or sugarcane, among others, predominate in the current global biofuels market.

By blending liquid biofuels with gasoline, diesel, and kerosene, and biogas with natural gas, these biofuels could account for 10% of energy consumption in the transport sector energy by 2030, more than triple today's share (IRENA, 2016b). However, given stagnant investment levels in liquid biofuel capacity, significant market development would be required to make this happen.

Most biofuel blending mandates form part of national policies, although some cities have launched their own initiatives. For example, in Brazil the city of Curitiba is implementing at a sub-national level a 100% biodiesel mandate for in its municipal bus fleet, as part of its Biocidade programme (IRENA, 2015b).

Second-generation biofuels, also known as advanced biofuels, which are primarily made of non-edible feedstocks such as waste and lignocellulosic material, have started to be marketed at commercial level. They have the potential to reduce GHG emissions by 50-70% compared to diesel and gasoline. For conventional biofuels (*e.g.* ethanol from corn or biodiesel from palm oil) this reduction potential is lower, at 30-50% (IRENA, 2016 forthcoming).

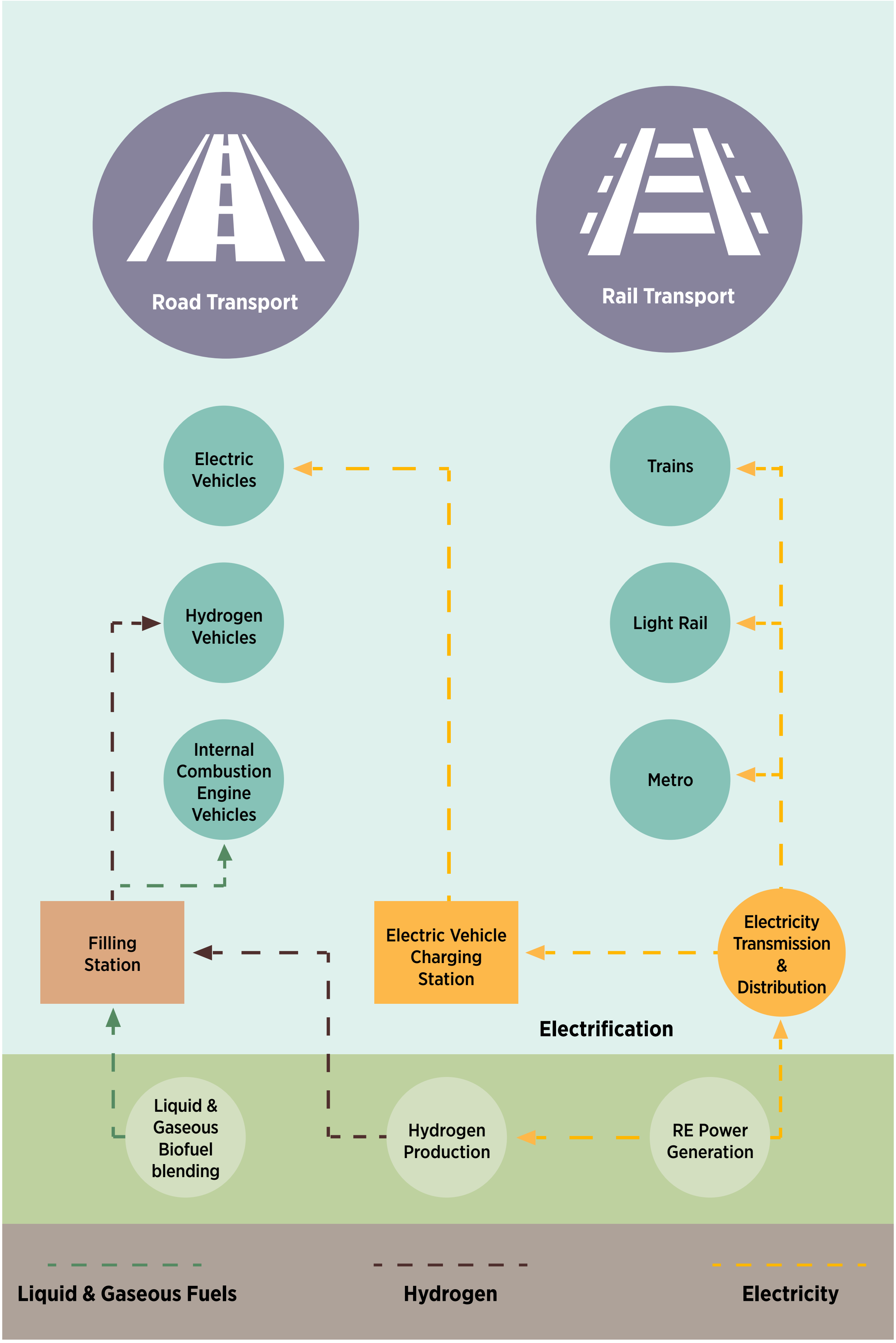
Biomethane is a cleaner alternative to liquid biofuels that can be used for a wide variety of road transport options, from passenger cars to trucks. It is produced by upgrading biogas and it has a higher content of methane.

In Sweden, biomethane is transported from production to distribution sites as compressed natural gas for distances below 200 km, while liquefied gas is preferred for longer distances. In the country's capital, Stockholm, 250 biogas-based public buses are in operation as part of the long-term vision of the Stockholm Public Transport Agency's fossil-free bus fleet (Jonerholm, 2012). Since 1994, the metropolitan region of Lille in France has used half of the city's bio-waste to produce biomethane for use in public buses (ICLEI, 2014b).

Hydrogen

Although still in early stages of deployment, hydrogen presents another promising technology. Some countries are considering using excess renewable electricity to produce hydrogen. The hydrogen can be blended in natural gas grids, but can also be stored and used in fuel-cell vehicles. A number of cities have deployed buses using hydrogen, albeit at a limited scale due to high vehicle costs. In London, eight buses have been successfully in operation since 2011, and reliability is reported to have improved significantly since their trial period between 2007 and 2009 (CHIC, 2013). In Munich, the first car sharing operator offers 50 hydrogen-powered cars to private customers (H_2-international, 2016).

Figure 6: Renewable energy options for road and rail transport in cities



Electric mobility

Electric mobility is seen as one of the most promising ways to reduce pollution and greenhouse gas emissions, and will be crucial to promoting renewable energy worldwide.

In 2010, electricity supplied 1.3% of global energy use in transport energy. IRENA estimates it could increase to around 4% by 2030 (IRENA, 2016b). Public transport would account for 60% of total electricity use in transport, with the remaining 40% coming from various forms of electric vehicles, including 2, 3, and 4-wheelers. Electric mobility is considered renewable when it is powered by renewable energy sources.

Electric public transport

Electric-powered public transport usually consists of trains, trams, and metro systems. Electric buses are becoming increasingly popular, driven by improvements in battery performance, falling technology costs and the ease of charging in bus stations. The stock of electric buses was estimated at 173 000 by the end of 2015, a nearly six-fold increase from one year before (IEA, 2016). The rapid increase is partly explained by the relatively favourable economics of electric buses. As electric vehicles generally have higher purchase costs but lower operational cost than conventional vehicles, their usage cost goes down the more they are used. Buses are typically used for multiple hours per day, which is longer than private vehicles.

Electric light rail transit and metro systems are also expanding, and are especially viable in larger cities with high population density. Nearly 160 cities worldwide had a metro system in place in 2014, carrying over 160 million passengers per day (UITP, 2015b). In 2014 alone, 513 km of new metro infrastructure (bringing the total to 11 300 km) and 355 new metro stations were put into service worldwide (UITP, 2015c). Light rail transit systems (including tramway systems) now operate in 388 cities (up from 355 in 2010) and carry about 45 million passengers daily.

Electric vehicles

Global sales of electric vehicles totalled more than half a million in 2015, with the total stock at the end of 2015 at 1.3 million units (IEA, 2016). That could increase to 160 million – or about 10% of the total vehicle stock – by 2030 (IRENA, 2016b).

Currently the average driving distance of electric vehicles is still relatively short and therefore their use is almost exclusively in the urban context. Cities also have a crucial role to play in promoting the use of electric vehicles, through the installation of charging infrastructure, city fleet purchasing, and procurement schemes or by providing vehicle purchase subsidies, parking benefits, or exclusive access to carpool lanes (ICCT, 2015).

Charging stations are an essential part of encouraging people to buy electric cars. Cities can promote the quick

City trends: electric public transport

20% of all city buses in China are now electric. Already a majority of electric buses on the road globally are in China, and many Chinese cities want to go even further. Beijing is aiming for 80% of buses to be electric by 2019, and is piloting the use of solar panels on selected metro stations (Junmian, 2013).

The direct use of renewable power for metro systems is gaining traction in other cities. New Delhi, India, opened a new metro system in 2012 (GIZ, n.d.), consuming electricity equivalent to the consumption of 100 000 Indian households. To meet part of this demand, and alleviate issues caused by power outages, solar PV was installed on some station roofs. With plans to expand this to more stations, combined with utility-scale solar plants outside the city, solar PV should eventually serve all of the metro's electricity demand.

In Riyadh, Saudi Arabia, new metro stations will also incorporate solar panels, to power 20% of their air-conditioning and lighting (ADA, n.d.). The Metro de Santiago in Chile, South America's second largest subway system in terms of length, will be powered 42% by solar and 18% by wind by 2018 (Cooke, 2016).

City trends: electric vehicles

Oslo, Norway, currently has the highest density of electric vehicles in the world. Across the country, nearly one in every four cars sold is electric, with hydropower delivering close to all electricity.

A number of pro-electric policies drove this trend, including no-purchase taxes and reduced value added tax, no charges for using toll roads, access to free parking within cities, and free access to bus lanes. A recent study found that purchase tax and VAT exemptions are critical instruments at the national level (Bjerkan, Nørbech and Nordtømme, 2016).

In the United States, Portland, Oregon, was recently ranked the most favourable city for electric vehicles, mainly due to a generous network of charging stations (with specific parking spaces) and a streamlined process for installing home charging stations (Clark-Sutton *et al.*, 2016).

rollout of charging stations through building codes and urban planning, while through zoning regulation they can influence the location and the number of EV charging stations. This highly affects the future availability of charging infrastructure.

The city of Oslo took an active role in addressing the lack of local public infrastructure and charging stations. Electric vehicles were in high demand due to national-level incentives. Between 2008 and 2011, the City Council through its Climate and Energy Fund supported the installation of 400 public on-street charging points, fully supplied by hydropower, as part of a "10-point plan to reduce emissions"(C40, 2014). This strategy worked to complement the national policy, which focused mostly on value added tax (VAT) exemptions for EV (compared with 25% on fossil fuel cars).

Electric two- to three wheelers

Electric two- to three wheelers – like scooters and bikes – are a fast way for citizens to travel within large high-density cities. They dominate markets in Asia, which account for two-thirds of global sales. They are particularly good for areas suffering from high traffic congestion, and their small battery size means they are much quicker to charge than 4-wheelers.

IRENA estimates there could be 900 million electric two- to three wheelers on the road by 2030, up from 235 million units in 2014 (Figure 7). Most of them will be in China, where the electricity to supply them increasingly comes from renewables.

City trends: electric two- to three wheelers

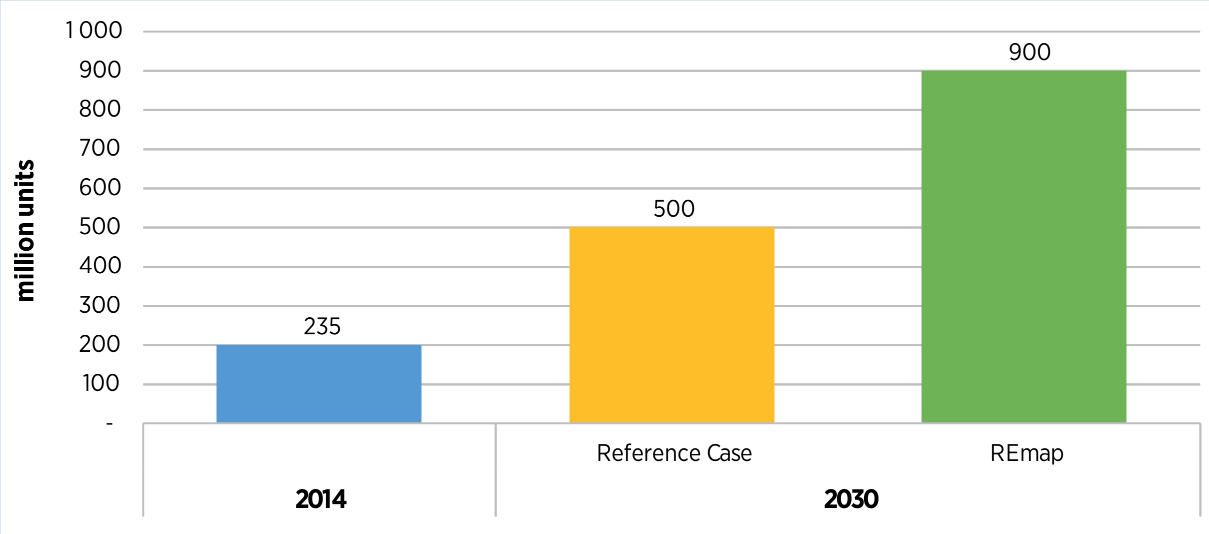
China is the largest two- to three wheeler market in the world. Of global annual sales of between 20 and 30 million, more than 90% are in China. These numbers continue to grow; by 2018 an estimated 355 million electric two- to three wheelers will be on the road (IRENA, 2014b).

Cities play a crucial role in promoting this growth. By 2007, electric two-wheelers represented more than half of all two-wheelers in Chengdu, but less than 10% in Beijing (Weinert, Ma and Cherry, 2007). This was due to Chengdu's favourable attitude towards electric two-wheelers early on (gasoline scooters have been banned since 2006). In Beijing, on the other hand, electric two-wheelers were initially banned due to the fear that they would reduce traffic speeds, create safety hazards, and cause lead-pollution from poor battery recycling infrastructure.

Table 3: City examples of the implementation of sustainable energy transport options

	Technology/ resource	Area	Example
Electric mobility	**Electric public transport**	Delhi, India	Solar panels were installed on stations of the metro system with plans for solar power to eventually supply all of the system's electricity
		Santiago, Chile	The Metro de Santiago, South America's second largest subway system, will be powered by 42% from solar power and 18% from wind power by 2018
		Riyadh, Saudi Arabia	Stations of the new metro system will incorporate solar panels, to reduce power consumed for cooling and lighting at stations by 20%
		Cities in China	In 2015 more than 100 000 electric buses were on the road in China; 20% of all city buses in the country
		Calgary, Canada	Calgary's light rail transit network is 100 % powered by wind energy
		Medellin, Colombia	Metro de Medellín is the only rail-based public transportation in Colombia largely powered by hydroelectricity
		Monterrey, Mexico	The city uses a biogas plant, which runs on waste, to power its metro system
	Electric vehicles (four wheelers)	Oslo, Norway	Oslo is the city with the highest density of electric vehicles in the world. Across Norway nearly one in every four cars sold is electric, with hydropower delivering 100% of electricity
		Portland, US	The city was recently ranked the most favourable city for electric vehicles in the US, with the most extensive charging network, planning, and outreach, and three times the average US battery electric vehicle sales
		Amsterdam, the Netherlands	Amsterdam has the highest density private charging stations in the world. The city aims to expand its network to 4 000 charging points by 2018
		Barcelona, Spain	Since October 2013, the city hosts the world's first electric vehicle charging station powered by a wind turbine
	Electric two- to three-wheelers	Cities in China	China is the largest two-wheeler market in the world with more more than 90% of global sales. Cities have played an important role for their uptake. Due to favorable city-level policies, by 2007 more than half of all two wheelers were electric in Chengdu, compared to less than 10% in Beijing
Bioenergy and hydrogen	**Liquid biofuels**	Cities in China	Several Chinese cities have worked together to reverse a national corn-based ethanol ban, resulting in the approval of new maize-based ethanol production plants and 10 percent ethanol blends in some provinces
		Curitiba, Brazil	Curitiba through its Biocidade Programme aims to convert all of its Bus Rapid Transit fleet to run exclusively on biodiesel (B100)
	Biomethane	Cities in Sweden	Organic waste is used for the production of bio-methane to fuel 89 buses of the city of Linköping; in Stockholm 250 biogases buses are in operation as part of a long term vision towards a fossil fuel free bus fleet
	Hydrogen	Cities in Europe	As part of the Clean Hydrogen in European Cities project, 26 fuel cell hydrogen powered buses are integrated in cities such as Aargau (Switzerland), Bolzano and Milan (Italy), London (UK), and Oslo (Norway). In Munich, Germany, the first hydrogen carsharing program was introduced with 50 hydrogen cars available in the city center

Figure 7: Global stock of electric two- to three wheelers, 2014 and 2030



Source: IEA (2015b), IRENA (2016b)

2.3 Creating smart integrated urban energy systems

Cities not only consume energy, but also produce it. This energy needs to be supplied via distribution networks. As an increasing share of electricity is generated by variable renewable energy (VRE), in particular wind and solar power, this brings with it specific challenges. Figure 8 provides an overview of technologies that can help build smart, integrated cities, and Table 4 at the end of this section presents examples of the use of support technologies, and concepts for sustainable and integrated urban energy systems.

Today variable renewables account for 5% of global power generation. By 2030, this will reach 20% with REmap, and many countries, especially in Europe, will see VRE exceed one-third (IRENA, 2016b). With increasing shares of VRE, there is a need to synchronise supply and demand, as the output of these resources cannot be fully determined in advance. In order to balance demand and supply, grids need to become smarter and more flexible. Cities will play an important role in enabling this.

As energy generation becomes more distributed (in industry and buildings), and energy storage more prevalent (in all sectors), demand side management (DSM) is becoming a major area of focus. This can take place through technical measures, or through flexible pricing (for example, solar power is cheaper during the day). Information and communication technology (ICT) are essential for synchronising demand and supply.

Integrating transport and power

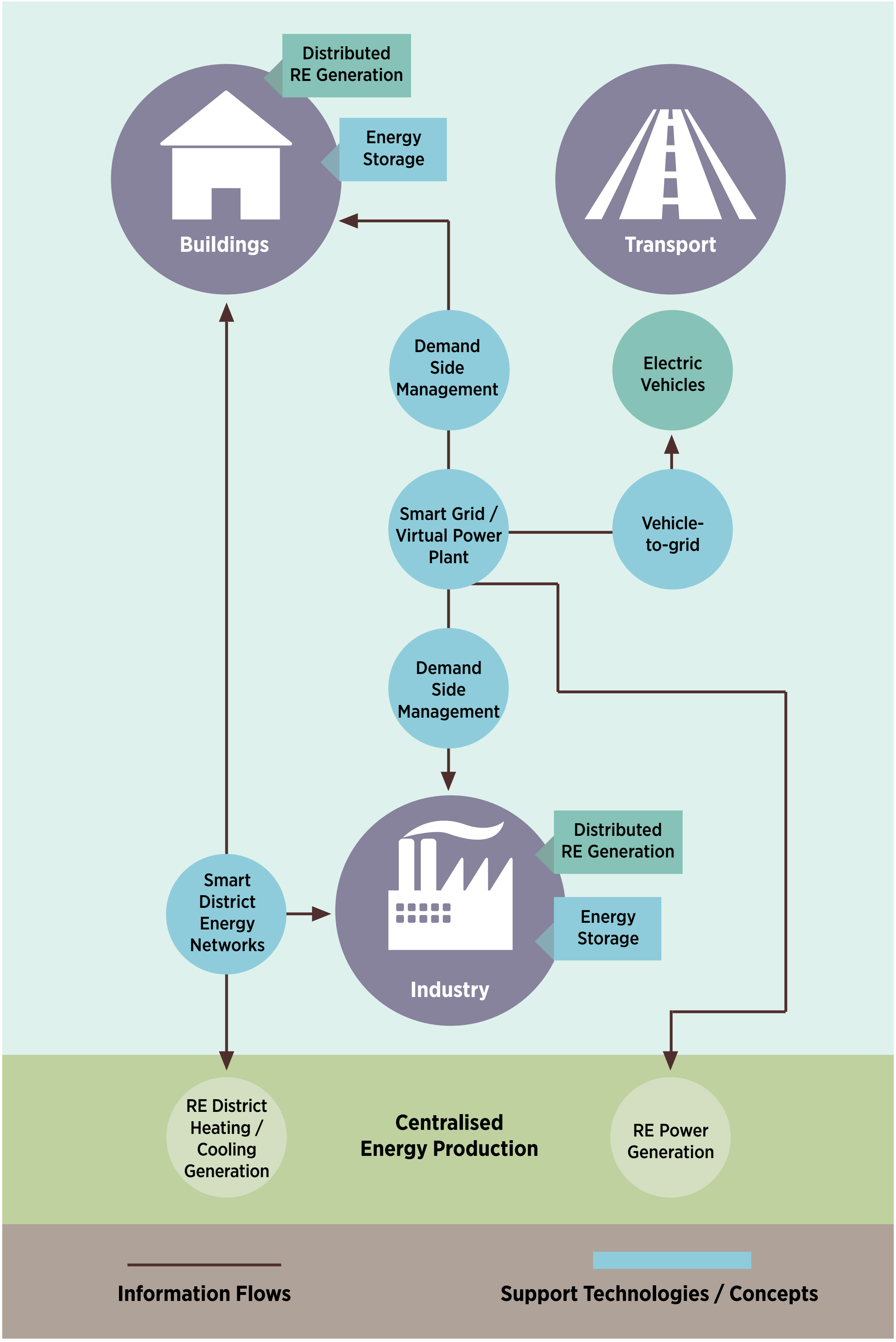
Transport and power will become increasingly interconnected. Electric vehicles are often charged at home, or take power from the grid through charging stations. With the increasing penetration of electric vehicles, their batteries can play a significant role in balancing electricity loads, either by shifting when vehicle batteries are charged ("smart charging"), or by discharging batteries in times of electricity supply shortages ("vehicle-to-grid").

Integrating heat and power

Linkages between power and heating/cooling will also become more prevalent.

Heat pumps provide a direct way of using electricity to supply heat. DSM allows them to adjust their output to accommodate more VRE. One study based on German data on air-sourced heat pumps showed that 20-30% of electricity demand for space heating could be shifted in wintertime, 65% of domestic hot water electricity demand could be shifted throughout the year, and

Figure 8: Overview of required support technologies and concepts for an integrated urban energy system



40-90% of cooling electricity demand could be shifted depending on the time of year (Fischer *et al.*, 2014).

Thermal energy storage (TES) may be needed to allow buildings and industry to adjust consumption over time. Charging a heat or cold storage system during high solar irradiation periods or wind peaks avoids curtailment in times when variable renewable electricity generation exceeds demand.

At present, distributed TES in buildings mainly consists of buffer storage systems to accumulate heat from electric heaters, but also solar heat, such as in hot water tanks. Building in daily heat buffers allows for domestic hot-water production at night. Various other options for TES exist, such as underground storage (*e.g.* in boreholes or caverns), using phase change materials (*e.g.* freezing/melting ice), or via chemical reactions (IRENA and IEA-ETSAP, 2013).

Building smarter grids

Transmission and distribution networks play an important role in increasing the share of renewable energy in cities. Electricity grids are becoming interconnected within countries and across borders, allowing for greater flexibility in managing variable renewable energy. At the same time, smaller and autonomous grids are growing in popularity, as a means of providing access to communities previously left behind.

Cities, or districts within cities, are increasingly implementing micro-grid architecture. This allows for islanding; distributed generation (*e.g.* from rooftop solar PV or small hydropower) can provide electricity within the autonomous grid in times of a blackout at the central utility.

A more advanced concept, virtual power plants (VPP), is also gaining traction in various cities. A VPP includes one or multiple micro-grids and combines this with DSM and advanced control and forecasting systems (*e.g.* on the availability of wind) to form an integrated network, and provide a reliable overall power supply. These concepts are important for cities as they provide direct solutions they can implement to allow for high shares of VRE.

To maximise potential, significant ICT upgrades will be needed for existing grid systems. This includes two-way digital communication devices connected to the grid, such as power meters, fault detectors, and voltage

City trends: waste-to-energy

In Belo Horizonte, Brazil, a large landfill biogas plant became operational in 2010, capturing methane from a 30 year-old site. It generates enough electricity to meet the needs of 35 000 people. The average city in a medium/high income country generates around 400-500 kg of solid waste per capita per year. In a city with a population of 1 million, waste can produce enough energy to power an average-size cement plant (IRENA and ICLEI, 2013a).

Smarter waste collection is also creating new opportunities. Rio de Janeiro collected 5.5 million litres of used cooking oil in 2011, which was used for energy (biodiesel) and non-energy purposes (*e.g.* soap production).

In 2006, the city of Monterrey, Mexico, adopted the project “Monterrey Cinco” (Monterrey Five), to supply several urban services with biogas produced from the decomposition of the municipal landfills. Currently, the facilities generate 20.8 megawatt-hours (MWh) and serve the public lighting of the Metropolitan Area of Monterrey, governmental offices as well as the transport system Metrorrey (Tecnologico de Monterrey, 2013).

In 2012, the city of Johannesburg developed the Northern Works Biogas project, a combined heat and power biogas power plant, which covers about 50% of the power requirement of the municipal wastewater treatment plant. The heat produced will also improve sludge management and increase biogas production (SALGA and SAGEN, 2012).

sensors. Smart grids allow a utility to increase its level of control over millions of connected devices, and to manage demand and power flows in real time.

Similarly, smart district energy networks can improve the management of heating and cooling by using smart heat meters and substations. Accounting for the availability of waste heat from industry, stored energy, and heat from solar and combined heat and power (CHP) plants, such systems can more optimally balance the demand and supply for heat and cold (European Commission, 2014). By adjusting the mode of operation and regulating heat and electricity output, CHP plants can introduce more flexibility to the power system.

The potential of waste-to-energy and excess industrial heat

The sustainable use of energy in cities involves creative thinking, and finding synergies not available during the fossil fuel era. This means going beyond the energy sector, and including other important areas of operation.

Cities are large producers of waste. Depending on the city context, availability of infrastructure and the regulatory framework, waste can take different routes: it can be sorted, recycled and reused, combusted for recovery of energy, or landfilled. There is potential to use far more waste for energy.

If waste is combusted efficiently, the generated energy can be used for heat and electricity. After several recycling trips, materials lose their quality, and it becomes more cost-effective and environmentally friendly to combust them for energy recovery.

By 2025, global urban municipal solid waste (MSW) is projected to increase to 2.2 billion tonnes per year, from 1.3 billion in 2012 (The World Bank, 2012). MSW often gets disposed in landfill sites, which leads to the release of methane, a greenhouse gas that significantly contributes to global warming. However, this methane can be captured for the production of biogas.

Municipalities can coordinate district-heating schemes with other municipal functions, such as waste management and sewage. Burning MSW simultaneously provides a solution to waste management and district heating (Ericsson, 2009; IRENA and ICLEI, 2013a).

Besides being a large consumer of energy, the industry sector also produces energy as a by-product of its processes. There are several examples of cases where this creates significant benefits for cities.

One typical example is biogas, which is a by-product of the food processing industry. It has many uses, of which the most common is the cogeneration of power and heat. Biogas can also be upgraded to biomethane and injected to the natural gas grid, or used as a transport fuel.

Excess and waste heat from industry (including heat recovery from wastewater plants) can be used to generate electricity in turbines, or reused for space heating through district energy networks. Such potential is particularly high in cities with large iron, steel and chemical plants. The port of Rotterdam in the Netherlands is home to many chemical plants, and their excess heat is increasingly being used to serve the city's district heating network.

Table 4: City examples of the use of support technologies and concepts for sustainable and integrated urban energy systems

Category	Technology/ application	Area	Example
Demand side management	Vehicle-to-grid	San Francisco, US	In 2015, a trial programme for the smart charging vehicle concept started. In times of high electricity demand, the utility alerts the car maker who can then delay charging vehicles that are not scheduled to be used
	DSM for buildings / industry	Cities in the US	Transmission organization PJM runs a program that compensates customers for reducing their electricity loads during periods of high power prices or when the reliability of the grid is threatened. By May 2016, nearly 20 000 industrial, commercial, and residential users were part of the programme
		Cities in Germany	A study in Germany showed that air-sourced heat pumps can play a major role in shifting the demand for electricity; *e.g.* 20-30% of electricity space heating could be shifted in wintertime
Energy storage	Stationary battery storage	Cities in Germany	In Germany 20 000 privately owned battery storage systems were installed in 2015
	Thermal storage	Cities in the Netherlands	Across urban areas, around 2 000 aquifer thermal energy storage systems - combined with heat pumps - have been installed to date. In the next 10 years, it is estimated that this could grow to 20 000 units.
Grids and networks	Smart power grids	Jeju, Republic of Korea	A large scale smart grid test bed started operation in 2009 towards the objective for a national smart grid for the country by 2030. Technologies tested include smart meters, intelligent power transmissions and distribution equipment, a real-time electricity pricing system and integrated electric vehicle charging stations.
	Virtual power plants	Hamburg, Germany	A VPP development and demonstration project includes DSM for buildings, CHP plants, and thermal storage systems operated by an advanced management system
	Smart district energy networks	Reykjavik, Iceland	The city of Reykjavik supplies 100% electricity and heat demand from geothermal energy sources including district heating
		Kalmar, Sweden	10 buildings are part of a smart heat grid - including intelligent control systems to coordinate interaction between production, distribution, and consumption - with plans for linking another 40 premises
Integrated urban planning	Building design and regulation	London, UK	A study shows that the solar irradiation of roofs could be increased by around 9%, while that of façades could grow by up to 45% with certain measures to utilise the morphology of London's neighbourhoods
		Santa Monica, US	The Municipal Green Building Ordinance demands new family homes and hotels to install solar PV systems with specific minimum total wattage dependent on the building surface (1.5 watts per squarefoot)
	Street lighting	Nairobi, Kenya	Kenyan Urban Roads Authority and lighting manufacturer have jointly installed solar-powered LED street lighting in Nairobi with possible expansion across the country starting in 2012
		Kathmandu, Nepal	8 000 solar lamps to be installed through a funding scheme shared between government, the city and local community funds
		Nagpur, India	As the first Model Solar City in India in 2007 Nagpur installed approximately 72 000 city-wide street lights
	Landscape planning	Melbourne, Australia	Melbourne targets a tree canopy cover of 40% by 2040 - up from 22% today - to reduce air-conditioning energy consumption as well as lost business during heatwaves
	Urban agriculture	Vancouver, Canada	Vancouver promotes urban agriculture to enhance the city's food security and reduce "distance to fork"
	Waste-to-energy	Ruhr region, Germany	The interconnection between two transregional networks would allow for more industrial waste heat to be used in serving district heat to 500 000 homes
		Vienna, Austria	District heating provides heat to 270 000 people in the city; waste incinerators are a main source of energy
		New York, US	The city has run a pilot program since 2013 to produce methane from food waste
		Belo Horizonte, Brazil	In 2010 a large landfill biogas plant became operational in the city producing 28 000 MWh per year, representing the power consumption of approximately 30 000 consumers

3. THE ROAD TO RENEWABLE CITIES

3.1 Energy use in cities: a view to 2030

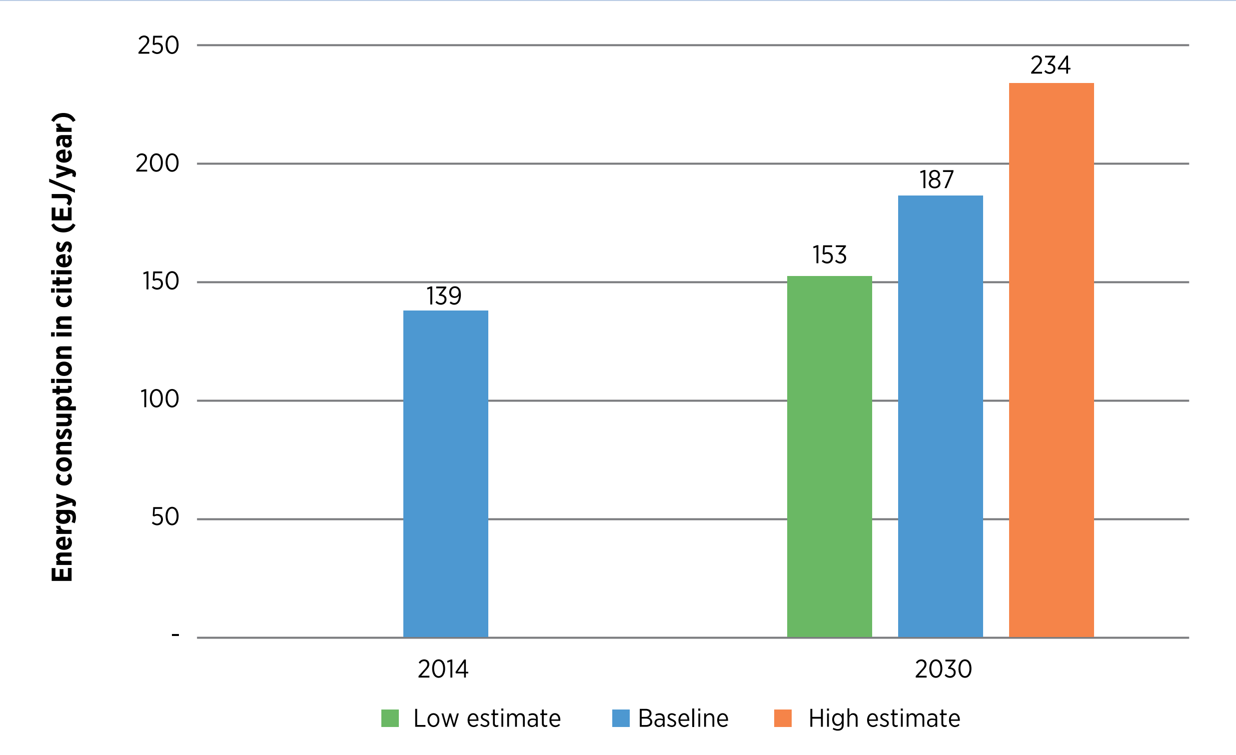
In 2014, cities worldwide used 139 exajoules (EJ) in residential and commercial buildings and for inner-city transport (Figure 9). This amounted to 60% of global energy demand. According to REmap estimates, by 2030 that number rises by 35%, to 187 EJ, although scenarios differ considerably depending on average population density, and climate change.

Generally, the use of energy in all cities is expected to converge. Cities in the countries of the Organisation for Economic Co-operation and Development (OECD) today consume significantly more energy than cities in non-OECD countries, but are expected to grow more slowly (Figure 10).

The average New Delhi citizen today uses only 25% of the energy used by a citizen of Tokyo. However, New Delhi's energy use per capita is estimated to grow by 45% by 2030, mainly driven by increasing levels of disposable income, while in Tokyo energy use per capita is expected to decline, primarily because of more efficient energy use.

Currently 37% of energy used in cities is for space and water heating (Figure 11). That is projected to shrink to

Figure 9: Energy use in buildings and for transport in cities, 2014 and 2030

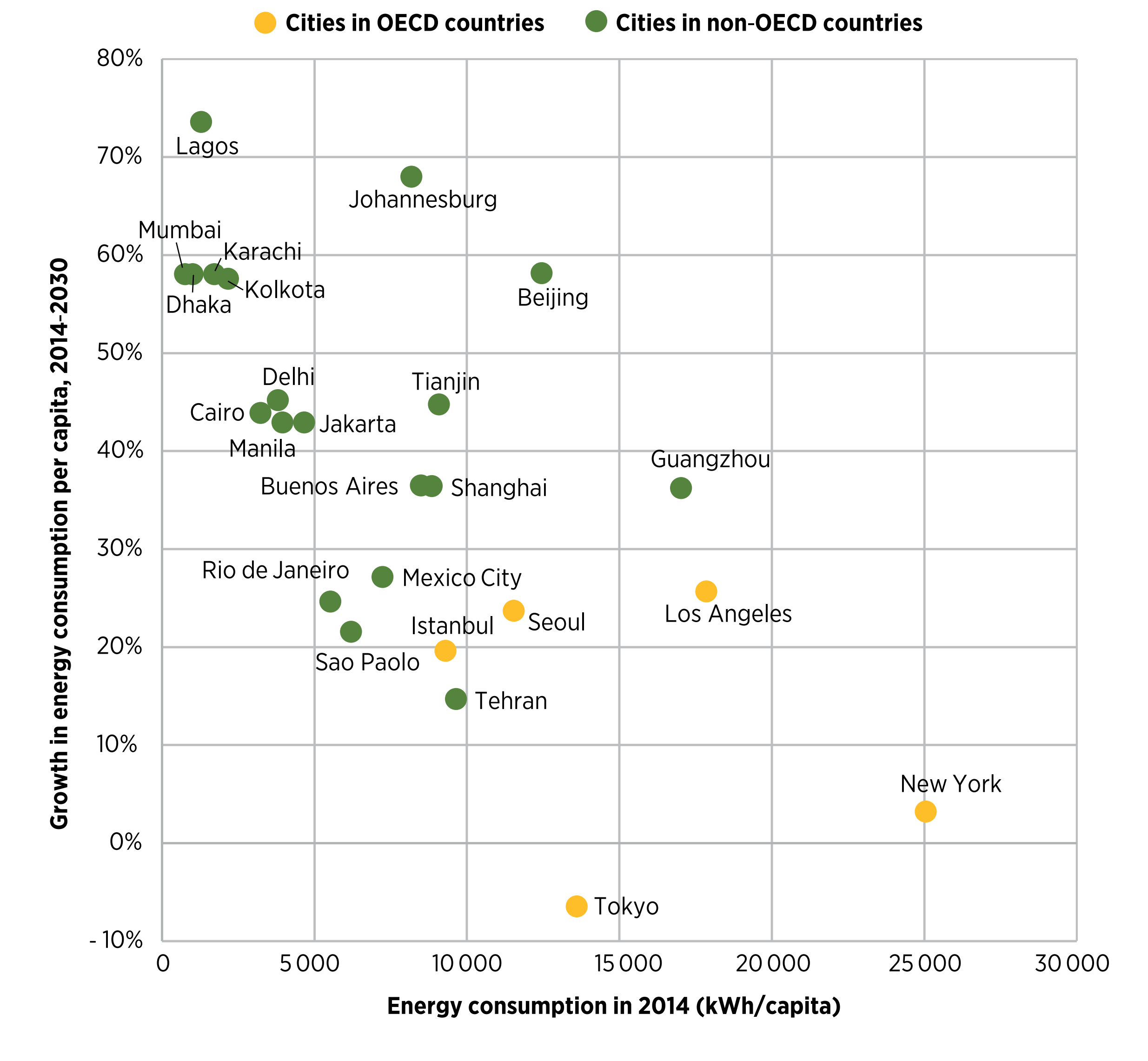


Based on IRENA estimates

Note: includes heating and electricity use in buildings and road transport energy use, and excludes energy use in industry. Low estimate includes IPCC Representative Concentration Pathway (RCP) 2.6 scenario and no change in population density. The baseline estimate includes an average of the RCP 2.6 and RCP 8.5 scenario and a 1% annual decline in population density. The high estimate includes the RCP 8.5 scenario and a 2% annual decline in population density.

The outlook for urban energy demand up to 2030 is affected greatly by urban sprawl, and to some extent by global warming.

Figure 10: Energy use and growth in energy use per capita in the world's largest cities, 2014-2030



Based on IRENA estimates

Note: includes heating and electricity use in buildings and road transport energy use, and excludes energy use in industry. Cities with expected populations exceeding 15 million by 2030 are shown.

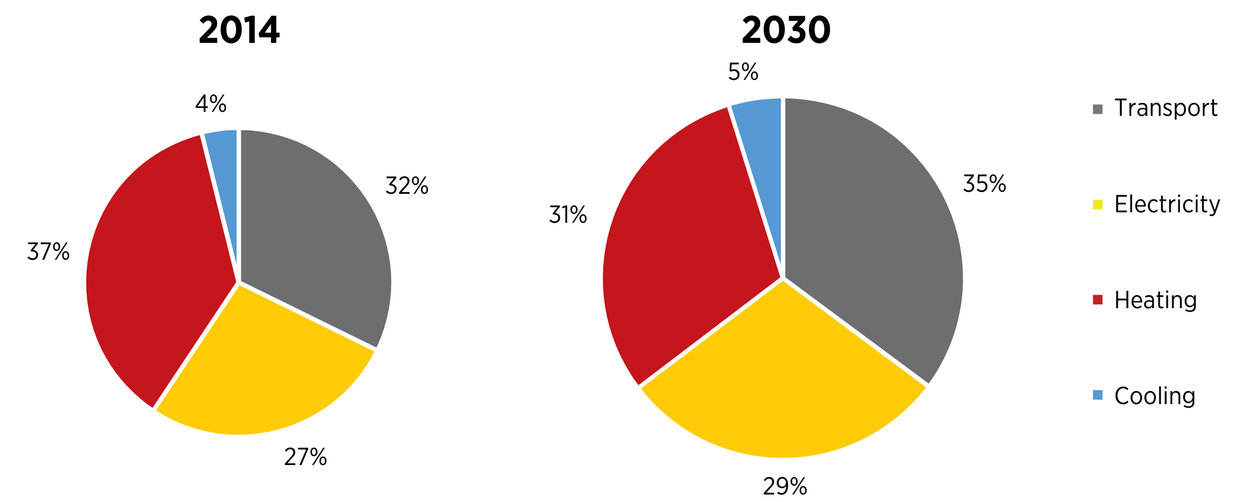
The highest growth in energy use is expected in cities in the developing world.

31% by 2030, because many of the fastest growing cities are in hot climates.

By 2030, transport is expected to account for the largest share of total energy use in cities, at 35% (up from 32% today). Half of all global passenger transport activity already takes place within city borders, and this is expected to increase. This is especially the case in cities in developing countries, due to rising levels of wealth and vehicle ownership.

Electricity use (excluding cooling) is set to increase by nearly 50%, with its share expanding from 27% today to 29% in 2030. This is mainly due to rising ownership of household appliances.

Figure 11: Energy use in buildings and for transport in cities by application, 2014 and 2030



Based on IRENA estimates

Note: includes heating and electricity use in buildings and road transport energy use. Electricity excludes energy use for cooling.

Heating accounts for the largest share of energy use in cities today. 2030 projections showing increasing shares for transport, electric appliances, and cooling.

The share of cooling in urban energy use will remain low at 5% in 2030, up from 4% today, but in absolute terms cooling energy use increases significantly, up 68% by 2030. The number of global air-conditioning units is forecast to rise from 900 million units today to 1.6 billion units in 2030 (Shah *et al.*, 2015). This implies nearly 1 out of 5 people will have an air-conditioning unit.

Most of that growth will take place in China, which already accounts for about one-third of the global air-conditioning stock today. Yet, the US will remain largest user of energy for cooling, due to large system sizes and higher daily usage levels.

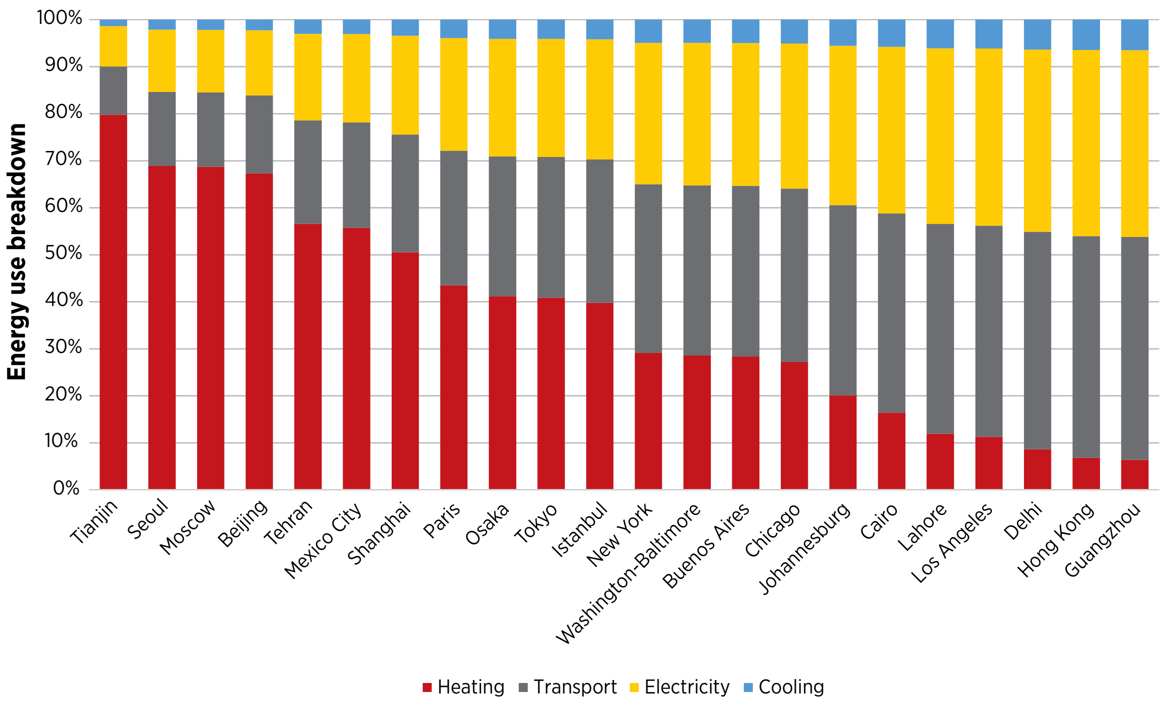
The breakdown of energy use differs significantly across cities (Figure 12). By 2030, heating is projected to account for more than two-thirds of energy use in cities such as Moscow, Seoul, and Tehran. In areas with lower heating demand, such as New Delhi, Hong Kong, and Guangzhou, transport will account for most of energy demand.

Differences also exist within countries, especially larger ones where climates and economic development levels vary. In addition, legal, administrative, and financial frameworks at the national level affect energy use, and can vary significantly between cities in different countries. Different solution pathways exist at the city level, which calls for a more localised approach to renewable energy deployment.

The Impact of density, population growth and climate

IRENA analysed the varying level of energy use and growth in 3 649 cities, categorised by population

Figure 12: Breakdown of energy use in selected cities, 2030



Note: includes heating and electricity use in buildings and road transport energy use. Electricity excludes energy use for cooling.

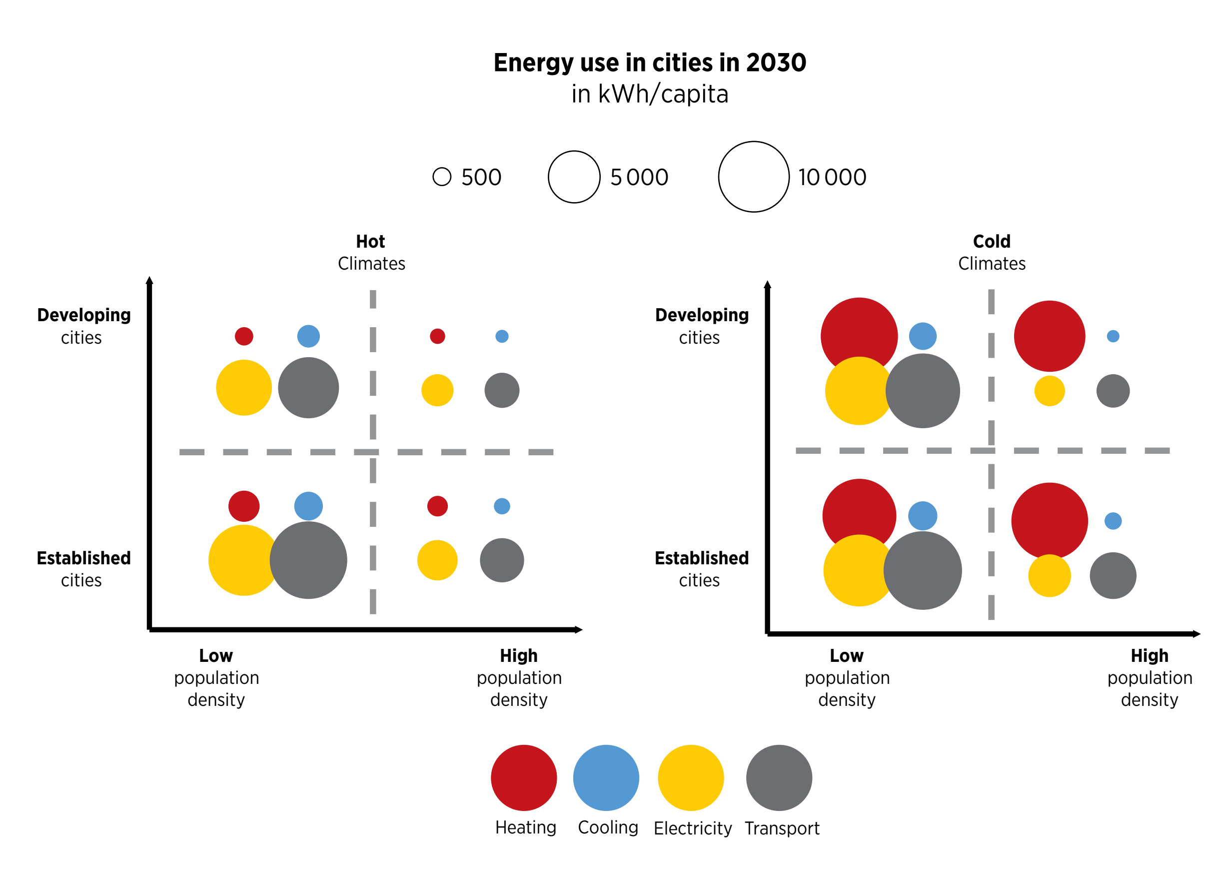
Large differences exist between cities, indicating the need for more localised strategies to promote renewable energy.

growth, number of heating degree days, and population density. Figure 13 shows the results of this analysis for 2030.

Cities in areas with cold climates represent two-thirds of the total energy use in cities by 2030, mainly because they account for nearly 90% of energy used for heating. In areas with hot climates, transportation and electricity for appliances dominate energy use, and cooling is relatively more important.

Population density also has a large impact on energy use, particularly for transport but also for electricity and cooling. Cities with lower population densities consume more than twice as much energy per capita than cities with higher population densities.

Figure 13: Energy use by application in different city types, 2030



Based on IRENA estimates

Note: to distinguish city types the city database was split into top and bottom (lowest/highest 50% of values) based on population growth 2014-2030, population density in 2014, and heating degree days in 2014. Hence, developing cities are those cities with population growth >2.1% per year in 2014-2030, mostly located in emerging economies. Established cities population growth <2.1% per year in 2014-2030. High population density is defined as >65 capita/hectare, low population density as <65 capita/hectare. Hot climates are defined as annual heating degree days > 1231, cold climates are defined as cooling degree days > 1231.

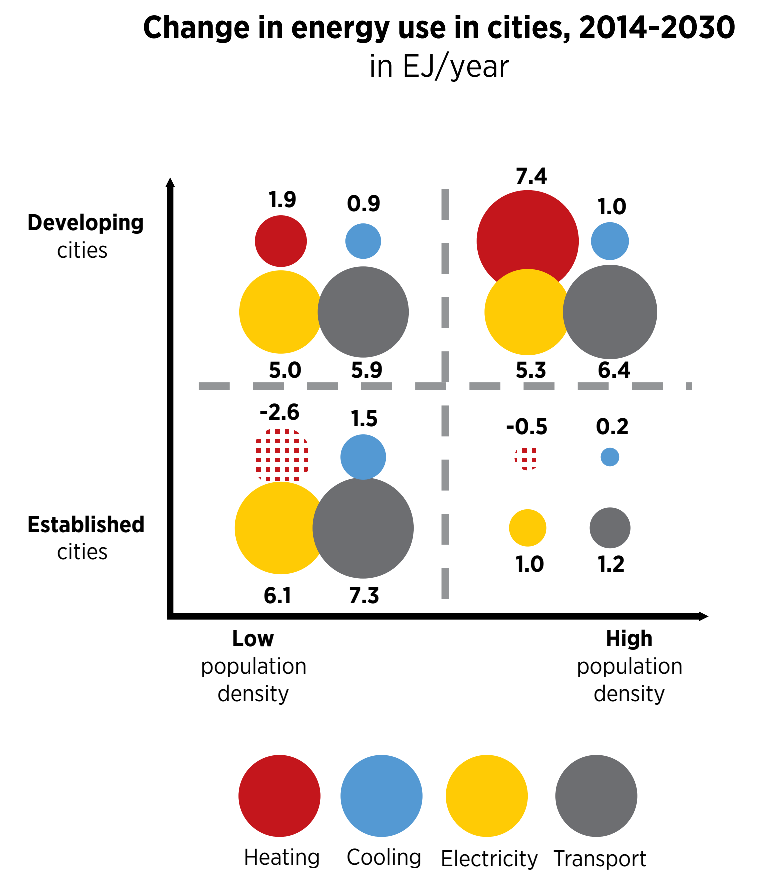
Energy use patterns in cities differ greatly between cities with different levels of development, population density and climatic conditions.

Established cities continue to have a higher level of energy use per capita in 2030. However, the projected population growth for different cities has a pronounced effect on the change in total projected energy use between 2014 and 2030 (Figure 14). Cities in emerging economies (defined as population growth >2.1% per year) account for 70% of the increase in urban energy use by 2030.

Demand for heating varies dramatically between city types. The lower urban population growth of established cities and focus on energy efficiency means heating energy use in these cities (mainly in North America and Western Europe) will decline. Heating energy use in developing cities, however, is set to grow by about 20% or 9.3 EJ up to 2030.

For transport, energy use is expected to increase in all city types. Only in established cities with high population density (such as capital cities in Europe) is less of an increase anticipated, due to an ongoing focus on more energy efficient modes of transportation, such as public transport, cycling, and walking.

Figure 14: The change in energy use by for different applications and city types, 2014-2030



Based on IRENA estimates

Note: developing cities are those cities with population growth >2.1% per year in 2014-2030, mostly located in emerging economies.. Established cities population growth <2.1% per year in 2014-2030. High population density is defined as >65 citizens/hectare, low population density as <65 citizens/hectare. Hot climates are defined as annual heating degree days > 1231, cold climates are defined as cooling degree days > 1231.

More than 70% of the growth in urban energy use is found in cities with high levels of population growth. Transport, electricity, and cooling grow in all city types, while energy use for heating is set to decline in established cities.

3.2 City-level policies to promote renewables

Cities can accelerate the switch to renewable energy in many ways (Table 5).

They work as planners, regulators, tax collectors, financiers, owners and operators of urban infrastructure. City governments are uniquely positioned to integrate renewable applications across their various functions. Likewise, citizens are coming out in vast numbers to mobilise their governments to do more, and faster on sustainability. Cities can also influence how their citizens, local businesses and other organizations behave, through community engagement, stakeholder consultations and dialogue facilitation. Businesses are lobbying cities to help them with data, information, pilot projects, etc. They also pay a pivotal role in knowledge dissemination through demonstration projects, feasibility studies, media campaigns, and education programmes.

Cities as planners

Renewables energy targets

A growing number of cities have set **renewable targets** to increase the share of renewables in their energy mix. Many are using these targets to align policies across infrastructure networks (water supply, transport, electricity, heat, waste, etc.), to create synergies and align renewable targets with climate and efficiency targets.

The effectiveness of renewable energy targets critically rests on political commitment and public and private support (IRENA, 2015c). The engagement of local politicians, and of cross-party political consensus, is

Table 5: Key roles of city-level governments to promote renewable energy

Key roles	Examples of policies and actions
Vision setting and planning	○ Set city-level RE targets and formulate sustainable energy strategies to align various policy spheres and stakeholders behind common goals ○ Establish integrated urban planning processes to promote RE, *e.g.* combining spatial and energy planning ○ Integrate renewables-based access solutions into urban development strategies ○ Foster dedicated institutional capacity to coordinate relevant stakeholders
Direct purchase and control	○ Develop and invest in city-owned RE-based power plants, district energy networks and transportation infrastructure ○ Directly purchase RE power, heating/cooling from private producers ○ Prescribe a share of RE to supply facilities and services owned and operated by cities, *e.g.* though sustainable public procurement ○ Steer the operation of district heating/cooling networks, municipal solid waste management, and outdoor street lighting to integrate higher shares of RE
Norms and regulations	○ Introduce regulations based on the legal attributions of cities to promote RE via, *e.g.* building codes, permitting procedures, solar ordinances, grid connection regulations, technical standards, public housing, local taxation, etc. ○ Enable households and businesses to purchase RE through obligations on energy suppliers, or by aggregating their electricity demand
Financing	○ Facilitate low-interest and long-term loans for property owners, project developers and small-scale purchasers to invest in renewables ○ Provide flexible financing solutions for building owners and tenants to repay RE investments through their energy bills ○ Leverage financial resources through mechanisms to de-risk investment in certain RE technologies or projects; Issue municipal green bonds and create funds to support municipal RE investments
Advocacy and facilitation	○ Influence the behavioural choices of citizens by raising awareness about the benefits of RE through public information and education campaigns, stakeholder consultations, demonstration projects, voluntary agreements, etc. ○ Disseminate relevant RE information to individuals and companies such as potentials mapping, open data portals, etc. ○ Promote knowledge sharing among various stakeholders, and strengthen local capacities and skills through dedicated training programmes on renewable energy

essential to ensure continuity across electoral cycles – in particular when city-level renewable energy targets exceed those at the national level.

This is well illustrated in the case of Freiburg in Germany, which has a long tradition of active citizen engagement to promote sustainability. In 2009, a cross-party coalition of councillors led by the Green Party adopted the Freiburg Sustainability targets of 50% CO_2 reduction by 2030 and 100% renewable energy by 2050 (City of Freiburg im Breisgau, 2014).

In some countries, cities have exceeded national targets to set an example. Malmö, Vancouver, and Canberra, for example, are working towards 100% renewable energy. 100% renewable cities include a diversity of target types and strategies. Some are short-term and directly within the control of cities' jurisdiction, such as targets aiming for 100% renewable electricity consumption in municipal buildings. Others are as ambitious as to induce deep structural transformation beyond the electricity sector, to heating and transport and across all users, both public and private.

To achieve these ambitious targets, cities often need to look beyond their own territorial boundaries, which may be too restrictive. This includes exploring opportunities in surrounding rural areas, which may have good quality renewable resources (such as agricultural residues, more land surface for solar and wind, etc.).

A key feature these cities share is that their far-reaching targets are backed by participatory processes and strong public support (ICLEI, 2016a).

In 2009, the city of Malmö, Sweden, set targets that exceeded EU and national targets significantly. The aim was to achieve carbon neutrality for municipal operations by 2020, and 100% renewable energy for the entire city by 2030 (IRENA and ICLEI, 2013c). This followed an inclusive process, involving companies, utilities, experts, academia and neighbouring regions. Notably, the major local energy utility, E.ON, was engaged in the discussions to formulate the targets.

An increasing number of cities are also targeting a share of renewable heating or cooling, such as Copenhagen, Frankfurt, Oslo, Paris and Växjö (UNEP *et al.*, 2015).

Integrated urban planning

Many urban activities do not directly focus on energy, but can have a significant impact on energy use (*e.g.* zoning, buildings, and transportation). This calls for ***integrated urban planning***, where processes of spatial and energy planning are combined to find the optimum solution for site-level development and design (Seto *et al.*, 2014), not just at the level of buildings but also at district and city levels. The integration of renewable energy options into urban planning and sectoral policies can significantly increase energy efficiency at the scale of urban infrastructure systems and at the neighbourhood level (*e.g.* district energy systems, the use of waste heat, Transit Oriented Development, etc.). This includes measures to consider the best orientation and distances between buildings, the width of streets to avoid shadows and allowing for the integration of solar PV on roofs as well as walls.

Box 3: 100% Renewable Cities

A key aspect of cities based on 100% renewable energy relates to the boundaries to which the target applies, in other words, whether it includes the whole territory of a municipality, city, or region, with the possibility of importing renewable electricity and fuels. Large cities, often characterised by dense infrastructure and high population density, may not be able to fully meet their energy demand by relying on renewable energy within their territorial confines in the foreseeable future, given that the available surface (*e.g.* on roofs but also available urban land) is limited (ICLEI, WFC and Renewable Cities, 2015). Therefore, 100% RE city strategies emphasise the importance for local governments to cooperate with neighbouring municipalities, in some cases with the region in which they are located. For example, in the region around Freiburg, a 222,000 ha area was considered to assess whether a regional 100% RE target could be achieved using local renewable energy sources. The analysis concluded that the region as a whole could meet a 100% target, if at least a 50% reduction in energy consumption could be achieved (IRENA and ICLEI, 2013b).

Therefore, a key characteristic of sustainable urban energy system options and policies is that they are *systemic* (Grubler *et al.*, 2012). An often-cited example is the integration of land-use and urban transport planning, which extends beyond typical policy spheres.

Integrated urban planning requires a deep understanding of planning processes across sectors. Urban policy makers need to coordinate both horizontally across municipal departments and local stakeholders, as well as vertically across multiple levels of governance. Successful examples, with elaborate renewable energy targets and clear action plans, include the cities of Vienna and Vancouver. The Smart City Wien Framework Strategy establishes a long-term governance structure to implement Vienna's 2050 sustainability objectives including the target of 50% gross energy consumption from renewable sources (Vienna City Administration, 2014). Vancouver's 100% Renewable City Strategy by 2050 focuses on buildings, transportation, and green economic opportunities and emphasizes the need for strong institutional capacity, not only to green the City's own operations but also to raise awareness and guide the wider public (City of Vancouver, 2015).

A more integrated urban infrastructure can improve the *resilience* and security of urban energy systems. Distributed renewable energy generators can help increase the reliability and resilience of power grids by making them less vulnerable to disruptions caused by natural disasters. In Japan, Higashimatsushima City suffered from the 2011 tsunami, which resulted in significant loss of lives and electricity outages of up to three months. Renewables form an important part of the post-disaster reconstruction plans, and the city is currently building Japan's first disaster-proof micro-grid community powered by solar PV and bio-diesel generators (Movellan, 2015a).

Integrated urban planning is challenging in implementation and requires coherence and coordination across different levels of governance. This systemic approach is most challenging in developing country contexts, with often weak institutional capacities and limited resources, especially in small- to medium-sized cities where the majority of urban growth is projected to take place in the coming decades. Yet, it is also in these cities that the greatest socio-economic benefits from renewables can be reaped.

Cities as agents of sustainable urban development

Renewable energy solutions play an important part in sustainable urban development. Decentralised power generation and clean cooking solutions can help expand access to modern energy services, a top priority in developing countries.

In 2012, close to 1 billion people were living in slums (UN DESA, 2015), without basic infrastructure. In sub-Saharan Africa, an estimated two-thirds of all new city inhabitants settle in informal settlements or slums (WBGU, 2016). Many slum dwellers do not have a legal status, and have difficulties obtaining electricity connections due to land tenancy issues.

Decentralised renewables are well suited to meet these challenges. They can be deployed at speed, to keep up with slum growth, and can be implemented using existing distribution channels. They also promote social and economic activity, contributing to local economic development.

Off-grid renewable solutions are developing quickly. The greatest uptake has been in pico-solar PV systems, which are small 1-10 W systems mainly used to substitute inefficient sources of lighting (*e.g.* kerosene lamps and candles). Over 44 million pico-solar PV systems had been sold by mid-2015, in 70 countries (BNEF and Lighting Global, 2016).

Solar PV, small hydropower, biogas, and small-scale wind systems and mini-grids are also becoming more popular, as they can be scaled up rapidly by tapping into locally available renewable energy sources. Interest in the development of mini-grids is growing as their cost decreases and technical and policy learning curves consolidate (IRENA, 2016c).

Governments – both at national and local level – have a key role to play to in providing public support, and making energy access an integral part of urban policies. As planners, municipalities can create economies of scale by encouraging project aggregation. As regulators, they can develop and implement quality and safety standards. Standards have been integral to the growth of the off-grid solar lighting market (BNEF and Lighting Global, 2016). In addition, by innovating within their mandate as tax authorities, city governments can develop a framework to incentivise off-grid renewables. The case of Kasese District in Uganda exemplifies the importance of strategic partnerships and enabling municipal frameworks.

Scaling up off-grid solutions is technically feasible and increasingly cost competitive. They now need sound enabling environments (overall policy goals, institutional capacity, stakeholder buy-in, etc.) and financial resources. Community-led approaches, and financial support to bring down the cost of connections or upfront investment (ideally complementing national support schemes) can significantly scale up renewable power solutions in informal settlements (World Bank, 2015). Off-grid solutions both reduce electricity bills for the urban poor while increasing reliability of supply (GNESD, 2013; Singh *et al.*, 2014; WGBU, 2016).

Cities as owners of municipal infrastructure

The ownership of energy systems and their regulatory links with city governments is a key aspect to understand the role of municipal governments promoting the use of renewable energy (Rezessy *et al.*, 2006).

Power supply

The mandate for energy supply and urban electrification in cities often lies with national energy utilities and national regulatory authorities. However, there are several examples of cities aiming to bring back municipal energy utilities into local public and collective ownership (WWI, 2016). This is the case in Europe and in the US, where the trend is often referred to as "remunicipalisation". These models are gaining popularity given the broader socio-economic benefits they bring to the communities, mainly in terms of local jobs and value creation. They also often help address community resistance to renewable energy projects.

In Nordic countries, numerous cities directly own municipal energy utilities, and are among the leading developers, investors and owners of wind, hydro and bioenergy power (and in case of bioenergy also heat) generation. In addition, waste and wastewater utilities often invest in biogas power generation, based on the methane capture from wastewater, sludge and landfills. Evidence from Nordic countries shows that municipal utility ownership is one of the most effective levers for municipalities to channel funding to renewables.

In Germany, local utilities gained in importance after German electricity liberalisation in the late 1990s, and have played an important role in the German clean energy transition, the Energiewende. In 2012, 860 local utilities owned and operated electricity distribution networks, while over 450 local energy co-operatives owned and ran mostly renewable electricity generation

Box 4: Kasese District's ambitious Renewable Energy Strategy

The Kasese District in Uganda is comprised of 23 rural sub-counties and one urban authority. The total population in 2014 was 700 000, 24.5% of which lived in urban areas. In 2012, District authorities, in cooperation with WWF Uganda Country Office, developed the Kasese District Renewable Energy Strategy, setting the ambitious targets of 100% access to 100% renewable energy by 2020, notably through small-scale decentralised renewable energy solutions. Socio-economic benefits were a key pillar of the Strategy, which set clear targets and a framework for increasing community support, awareness, and training (Republic of Uganda, 2013). The District government worked together with partners to develop regulations, standards, and quality control; conducted public awareness campaigns; trained community organisations and local entrepreneurs in business development; provided job training on how to install and maintain pico-solar systems; and coordination and oversight of all activities.

Since 2012, over 1 650 Kasese residents have received career training, and the number of businesses, which sell and install renewable energy equipment has expanded from 5 to 55. The District Council further encouraged renewables uptake by waiving the cost of trading licenses for small-scale solar providers, enacting tax exemptions for renewable energy technologies, and providing land for investors who were prepared to build solar PV mini-grids (IRENA and ICLEI, 2016 forthcoming).

capacity and distribution systems. Local energy co-operatives and citizens own 47% of the renewable electricity capacity (IEA, 2016).

Investments by city-run power companies can also create wider shifts in demand. As of end 2015, 14 Japanese cities had formed companies to generate renewable power from local resources. With full deregulation of Japan's electricity market starting in 2016, the government aims to have 1000 such city-operated power companies established by 2021 (WSJ, 2015).

The ownership of municipal energy utilities also has important implications for financing renewable energy investments, as discussed in the "cities as financiers" subsection.

District energy

Many cities have authority over the public distribution of electricity, gas, heating and cooling. In addition, many cities own the underground networks through which energy and communications services are supplied. Cities can manage and maintain these networks, or grant concessions to public or private parties. Vienna, for example, owns its utility companies for district heating, gas, and electricity, and exerts control to promote the share of sustainable energy (Grubler *et al.*, 2012).

The city of Paris owns a third of the Paris Urban Heating Company (CPCU). The company has a concession contract to distribute hot water or steam, and it maintains and manages the district heating network throughout the city. The City of Paris' Climate Action Plan aims to double the share of geothermal energy between 2012 and 2022. It is implemented through its part ownership of CPCU, and underpins the concession contract, which promotes a higher share of renewables in the energy mix of CPCU's network (UNEP, 2015b). By the end of 2015, CPCU reached a 50% renewable or recovered energy share. By the end of 2016, CPCU aims to increase the share of renewable and recovered energy to 53%, by launching large biomass plants near the city with a thermal power of 200 MWth, representing about 10% of its energy mix (CPCU, 2015).

In many jurisdictions, connecting to a district heating or cooling network can be made mandatory by urban planning authorities (Grubler *et al.*, 2012). This helps to create stable demand and provides the necessary visibility for large investment decisions. For example, in Växjö, Sweden, municipal regulations require homeowners to connect to a district heating network, which is fuelled by biomass. In Reykjavik, Iceland 95% of homes are connected to the geothermal-based district heating network. However, many cities also enable connections through other policies (zoning by-laws, incentives, consumer protection policies, etc.). It is important to note that mandatory connection is not the only model to encourage the use of renewables in district energy systems (UNEP, 2015a).

Numerous cities seem to be adopting a fully public model, which can support broader public policy goals such as energy poverty and affordability by controlling the tariffs charged for heating. However, the most prevalent business model is that of Public-Private Partnerships (PPP). This model enables a strong role for municipal governments without them necessarily owning district heating/cooling companies (UNEP, 2015a). In fact, a wide range of models exists for district energy systems, which closely depend on local conditions, notably the resources and priorities of cities.

Street lighting

All cities have some degree of control over outdoor street lighting, and most have full control (C40 and ARUP, 2015) (IRENA and ICLEI, 2013d). Public lighting can consume as much as 40% of a city's energy budget (Silver Spring, 2013) – this is the case in major Moroccan cities, for example (Challenge, 2016). With an estimated 300 million street lights in total (Philips, 2016), public lighting plays an important role in energy consumption worldwide.

Local governments can take a proactive role by providing the funding and managing the procurement, installation and oversight of lights. In Zimbabwe, the local board of Hwange is self-funding the installation of a pilot project of 100 solar streetlights, worth around USD 300 000. This has two objectives: reducing the crime rate, and the level of electricity bills. The board aims to raise funds through taxation to eventually replace all existing streetlights (Phiri, 2016; ZBC, 2016). In Brazil, the local government of Rio de Janeiro installed more than 4 300 solar lights along a 73 km stretch of the motorway, Arco Metropolitano. This has enhanced the level of security on the highway, without further stressing the local grid (Kronsbein, 2015).

Stand-alone PV powered street lighting is particularly beneficial for areas that do not have power grids. This can be especially relevant in rapidly urbanising areas. In informal settlements, or in under-developed areas of a city, stand-alone powered street lights can be the first step in providing a basic level of electric lighting, enabling social and productive activity at night (studying, street vending, community meetings, etc.) and can improve security conditions. Renewable energy can also be used in areas where the grid is present but not reliable, with the same benefits.

In many cases, the role of the local government may be limited to the procurement and management of the installation and operation and maintenance (O&M) of solar streetlights, with funding from other entities. In Somalia, the national government has funded the installation of solar streetlights in Las Anod, a town of 120 000. The town municipality is responsible for installation and O&M. Increased security is the primary driver of the project (Egge, 2015).

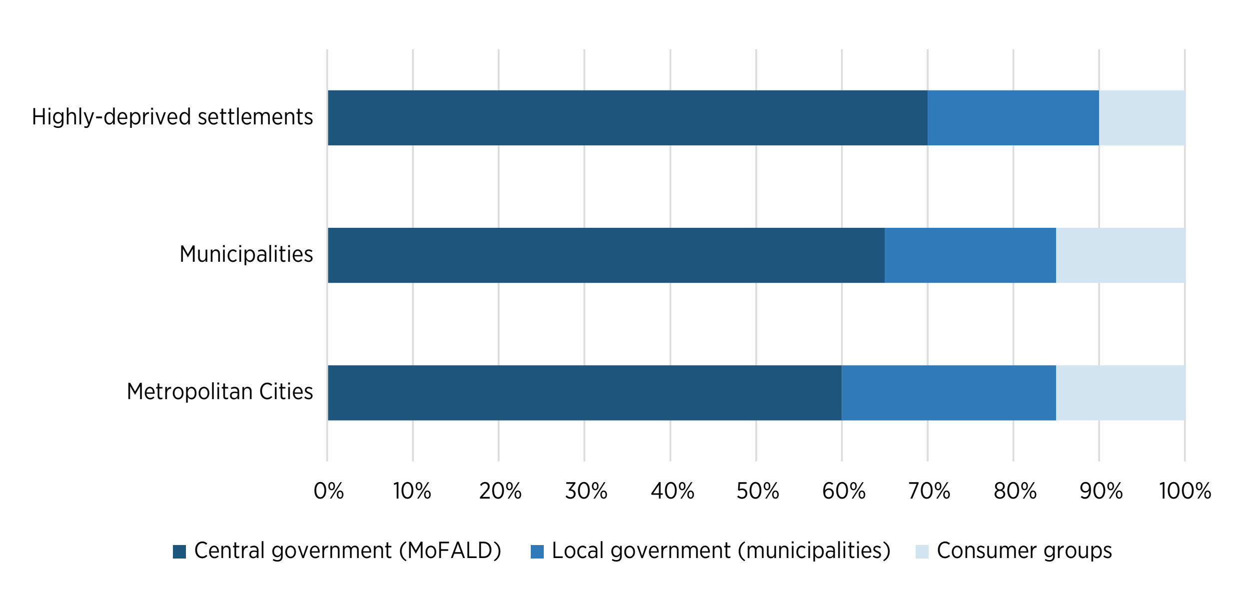
In some cases, national and city level governments can work together with consumer groups to fund, install and operate solar street lights. In Nepal, the *Public Participation Based Solar Street Light Programme* is jointly funded by the Ministry of Federal Affairs and Local Development (MoFALD), local governments and consumer groups. The central government provides the bulk of the funding, with NPR 1 billion (USD 9.4 million), and varying shares of funding from stakeholders (The Himalayan Times, 2016) (Figure 15). Municipalities across the country, including the cities of Pokhara and Durbarmarg, have invited applications from consumer groups like consumer committees, citizen awareness centres, neighbourhood development institutes and government offices to install solar street lights. These lights will provide un-interrupted service in areas that lack grid or suffer from blackouts, as well as reducing utility bills and CO_2 emissions.

Cities as direct consumers of renewable energy

Local governments are significant energy consumers in their own right, in hospitals, schools, offices and street lighting. Their high market share means they can create a critical mass of in favour of renewable energy, especially when efforts are co-ordinated at a regional or national scale.

To do this, cities can use a range of policy instruments – such as green procurement, auctions – and in

Figure 15: Shares of funding for solar streetlight projects in Nepal



Source: The Himalayan Times (2016)

some cases can become offtakers in power purchase agreements (PPA). In a PPA, a purchaser or "offtaker" buys power from a project developer at a negotiated rate for a specified term without taking ownership of the system (NREL, 2014).

Many cities can control, or influence, the source of energy they purchase. This is particularly effective when they own municipal utilities. In 2013, over 2 000 US communities, home to 1 in 7 Americans, got their electricity from city-owned utilities (ILSR, 2013). The Sacramento Municipal Utility District was one of the first in the country to offer a comprehensive, long-term contract to local solar producers. By 2012, the entire 100 MW programme had been completed, costing the utility a low (at the time) 12 US cents per kWh.

In other cases, franchise agreements (legally binding agreements, which spell out some of the conditions that apply to a utility company that is using public property to provide utility services and place a value on the company's use of the public right-of-way) between cities as consumers and utilities as suppliers can be instrumental.

In 2014, the twenty-year utility franchise agreement between the City of Minneapolis and its two utilities (Xcel Energy for electricity and CenterPoint Energy for natural gas) was set to expire. The City used the negotiations to explore options to achieve its goal to generate 10% of its electricity from local, renewable sources by 2025, which also provided an opportunity for better grid integration planning of distributed solar PV.

In 2011, Austin, Texas, made history as the largest local government in the United States to procure 100% renewable energy for all municipal buildings and facilities, through a programme called GreenChoice®. This city-level policy also helped the state of Texas take a leading role in wind energy production in the United States.

In some cases, city authorities can use auctions to procure renewable energy. These auctions can result in long-term PPAs between the city authorities (or utility) and a large-scale RE supplier. This can have the dual effect of helping cities achieve renewable energy goals in a cost effective manner, while also creating the demand for large-scale renewable energy projects.

For example, in December 2015, the District of Columbia (D.C.) in the US signed a PPA with Nextility for 11.4 MW of capacity, which will be generated by solar PV panels on roofs and in parking lots of 34 facilities owned by the city. This is the largest onsite municipal project in the US (D.C. Government, 2015).

Cities can also join with other organisations to generate demand for renewables. Several businesses and universities have teamed up with municipal authorities in the Melbourne Renewable Energy Project. Developed and managed by the city council, it is tendering for 110 GWh of renewable energy per year (enough to power 28 500 households). Melbourne aims to source 25% of electricity consumption from renewables by 2018 and to have zero net emissions by 2020 (Sparkes, 2016).

Box 5: GreenChoice® Program in Austin, USA

The GreenChoice® Program in Austin (US) is a longstanding example of a municipal approach to sustainable procurement of renewable energy (IRENA and ICLEI, 2013e). Active since 2001, GreenChoice® – which is offered by the publicly owned utility Austin Energy, and backed by the City – has played an important role in stimulating and sustaining demand for electricity from renewable sources.

As more residents and businesses subscribe to GreenChoice®, the amount of wind energy in the municipal composition rises. As a result, Austin Energy became the national leader for voluntary market sales of renewable energy between 2002 through 2010. This helped the state of Texas emerge as a worldwide leader in the production of wind energy. In 2015, Austin Energy, the City of Austin's electric utility, finished first among all public power utilities in the US for sales of renewable energy, according to the latest rankings from the Department of Energy's National Renewable Energy Laboratory (NREL, 2015).

Cities as regulators

City governments can also promote renewable energy in their role as regulators. Mechanisms include land-use planning and zoning, business and residential building permitting, urban building codes, solar ordinances, grid connection regulations, technical standards, land-use planning, and public housing programmes.

Municipal governments can help streamline municipal **building codes.** This can include waving height restrictions for rooftop solar systems, simplifying requirements for building permits, or imposing energy efficiency and renewable energy requirements, as in the case of the San Francisco.

Making new buildings "solar-ready" adds almost no additional construction costs (City of Minneapolis, 2013). Cities therefore stand to benefit greatly from making all new buildings ready for the next generation of energy production. Municipalities can distribute information on solar-ready guidelines during the permitting or the design review process.

Social housing programmes also offer a good opportunity, as savings from renewables naturally support affordable housing (WWI, 2016).

The City of Boston's (USA) Department of Neighbourhood Development (DND) has since 2007 required all affordable housing developments be built according to the Solar Ready Building Planning guidelines of the National Renewable Energy Laboratory (NREL).

Municipal thermal mandates, also known as **Solar Ordinances,** are a compelling example of the impact of city regulations. In 2007, São Paulo adopted a Solar Ordinance to lower electricity demand for water heating. It required all new residential, commercial and industrial buildings to install solar water heating systems to cover at least 40% of the energy used for heating water. The ordinance is estimated to have avoided expenditures of more than USD 400 million between 2007 and 2015, according to DASOL ABRAVA (the Brazilian Association of Refrigeration, Air Conditioned, Ventilation and Heating Services) (IRENA and ICLEI, 2013f).

A range of social housing programmes have integrated renewable energies in their planning. The savings achieved through renewables naturally support affordable housing (WWI, 2016). Mexico City's Social Housing Programme endorses the use of PV panels for all multi-family structures (WWI, 2016); (IEA, 2016). The City of Johannesburg, South Africa, installed solar energy systems in 2 700 new homes, while refurbishing the city centre for social housing (WWI, 2016).

Cities can encourage solar PV deployment by creating a regulatory environment that allows households to feed or sell their surplus electricity production back to the grid, including by enacting **net metering** rules. Net metering is an electricity sector regulation that allows

Box 6: Solar Ready Building Planning guidelines of the US National Renewable Energy Laboratory (NREL)

NREL's *Solar Ready Buildings Planning Guide* (2009) serves to shape the design of new solar ready buildings. The objective is to lower solar installation costs while increasing electricity output when using solar PV technologies. The guide presents three sections on: solar PV, solar thermal (ST) and solar ventilation preheat (SVP) installations. A checklist and more detailed guidelines provide information to city planners, policymakers and developers for the planning and construction phase of new buildings.

NREL's *Solar Ready: Overview of Implementation Practices* (2012) presents cost advantages through solar ready construction and discusses relevant legislation and policy tools. It points out that solar ready construction may be most effective when combined with other tools including Green Building codes, certification programmes, and education campaigns. The overview further provides Sample Solar Ready Legislation as a template for regional and local policy makers, which can be adapted to local conditions of solar ready building requirements, both for commercial and residential construction.

consumers who generate their own electricity to get a credit on their bill for the quantity they generate. The credit can later be used to offset consumption and excess credit can be remunerated at a specific rate.

As discussed above in the subsection on "Cities as owners of municipal infrastructure", in some cases, these rules have been developed by cities with special jurisdiction over municipal power distribution companies – such as Dubai and Cape Town.

The Dubai Electricity and Water Authority (DEWA) has initiated a net metering programme called "Shams Dubai". This allows solar PV plants to be connected to the electricity network, and to be compensated for surplus electricity fed to the grid by "banking" it for later consumption. As such, the programme only allows offsetting of demand and does not allow any payments for excess generation.

So far, DEWA has received many applications for installation. The Dubai Ports authority, for instance, announced in 2015 that they will be adding 30 to 40 MW of capacity on their premises under the programme.

In some cases, city governments therefore possess the legislative capability to enact electricity sector regulations such as net metering, when a similar policy has not been enacted at a higher government level. This gap can be an opportunity for municipal authorities to assert their mandate as local electricity regulators, in particular by ensuring quality and technical standards.

In about 60% of South African cities, municipal electricity departments play a formal role in electricity supply and grid extension. They purchase and sell electricity to end-users, thereby generating on average 30% and in some cases up to 90% of municipal revenues (EUEI PDF, 2016 forthcoming). Cape Town, as other cities in South Africa, sells and distributes electricity to final consumers. It recently announced a net metering programme, which, like Dubai, does not offer any payment for excess generation. Excess generation can be used as credit to offset later consumption. So far, the city has succeeded in commissioning more than 4.5 MW of grid connected small-scale solar PV capacity, almost all of which has been in commercial and industrial buildings. The city also developed guidelines to promote the safe and legal installation of rooftop solar PV systems.

Where cities have a limited role in creating policies to promote renewables in the power sector, they can play a central role in administering and coordinating national or state level initiatives.

Bangalore, the largest city in the Indian state of Karnataka, is benefiting from a net-metering programme to develop rooftop solar capacity. The programme involves several local and state-level entities including the Government of Karnataka, the Karnataka Electricity Regulatory Commission (KERC), and the Bangalore Electricity Supply Company (BESCOM). The KERC is responsible for determining the tariffs while BESCOM is responsible for the administration of the programme. The programme has grown steadily, with 14 MW of solar PV installed in the past 3 years.

Local government buildings themselves offer considerable roof surface, which can be used to produce solar or wind electricity, and lower their utility bills. There are numerous examples of such actions in cities across Australia, China, Europe, India, Latin America, North Africa, and the US.

Cities as aggregators of demand

Community Choice Aggregation **(CCA)** is a growing trend in US energy procurement that could further increase demand for renewable energy. Under this model, a municipality or a group of municipalities forms a new entity known as a community choice aggregator. This new entity procures electricity in bulk to cover the combined load of interested residents and businesses within the municipalities' political boundaries. By aggregating energy demand, cities can negotiate competitive rates with power suppliers and developers, between 3% and 10% lower than utility rates (US LEAN, 2015).

Much of the electricity comes from independent power producers that provide renewable energy to the CCA under a long-term power purchase agreement. The local utility, which in these cases no longer generates the electricity, remains responsible for transmission and distribution of the power, as well as for billing, collections and other customer services.

Most CCAs offer customers the option of buying electricity with a higher renewable energy content than what is available from utilities. In 2012, Chicago launched

Box 7: Cape Town Requirements for Small-Scale Embedded Generation

There is currently no South African standard for PV installation, nor is there a nationally-accredited PV installation training course. This creates several technical issues for small-scale solar PV, including the lack of standards for inverters, the absence of wiring regulations, and a limited number of qualified electricians who are experienced in the use of direct-current wiring. To address these issues, the City of Cape Town published guidelines to promote safe and legal installations of rooftop solar PV systems in commercial and residential settings, which detail the application process to become a small-scale embedded generator in the City of Cape Town (City of Cape Town, 2016a). The City developed a visually appealing brochure on the safe and legal installation of rooftop solar PV, and is reviewing low-voltage inspection practices to promote the safety of municipal staff. The brochure assists potential end-users in selecting a qualified service provider, and provides an overview of the key requirements to be met prior, during, and after installation (City of Cape Town, 2016b).

a CCA programme that offered savings of 25% to 30% compared to power utilities, based on a 50% share of renewable power (OECD, 2012), but the programme was discontinued in 2015 when the utility dropped its electricity tariffs. Local officials say the programme may be resumed if market conditions change (Chadbourne, 2016).

CCAs have seen the most traction in California. The state went from having one CCA serving 6 000 customers in 2010 to four CCAs serving more than 400 000 customers as of mid-2016 (Chadbourne, 2016).

Mechanisms like CCA are also being used outside the United States. In Japan, community utilities are working with municipal governments in Yamagata and Gunma prefectures to provide renewable energy to consumers through CCA arrangements.

The municipality of Nakanojo, a town in Gunma prefecture, owns 60% of Nakanojo Electric. The company buys electricity from the town-owned PV systems and re-sells it to 30 public facilities, including schools and community centres, at a lower rate than Tokyo Power Electric Company, the major national-utility. The neighbouring Yamagata prefecture is also planning to set up a publicly owned Yamagata Power Company which will offer renewable energy to its consumers based on a CCA programme (Movellan, 2015).

In Finland, 34 municipalities – including Helsinki, Tampere, Oulu and Seinäjoki – plan to take part in the joint procurement of solar power plants organised by the Finnish Environment Institute and a joint purchasing body (KL-Kuntahankinnat Oy) acting on behalf of the regional and local governments. Currently, 81 solar power plants with a combined capacity of 1.2 MWp (megawatt-peak) are being ordered, and this is set to increase further. Installation will mainly be in the form of rooftop systems on hospitals, schools and other municipal buildings.

Cities as financiers of renewable energy projects

Cities primarily obtain income from tax collection, as well as transfers from other levels of government, fines and penalties, charges for services, rents/leases, or by issuing local debt. In many countries, local tax collection can amount to several percentage points of GDP, reaching levels close to 15% of GDP in Scandinavian countries (Kitchen, 2004; Fjeldstad *et al.*, 2014; Norregaard, 2013; Spahn, 1995).

In general, however, cities have a limited tax base, and many are in a weak financial situation. This reduces the possibility of municipal tax incentives, compared with national and state-level tax credits (REN21, ISEP and ICLEI, 2011). Despite their low overall use, the most used local tax incentives are applied through property taxes (REN21, ISEP and ICLEI, 2011).

One innovative financing mechanism used by local governments is to **subsidise low-interest loans** for homeowners to invest in renewable energy or energy-efficiency, which they gradually pay back through slightly higher property taxes. This mechanism underpins the property-assessed clean energy (PACE) financing model used in the United States (PACE).

The PACE seeks to eliminate the disincentive of property owners who want to sell their property to invest in renewable energy or efficiency upgrades, by transferring the repayment obligation to the new property owner (OECD, 2013). These financing costs come at a reduced rate, as local governments can obtain debt at a lower cost than individuals can.

Property taxes can also be used to recover investments by the municipality (*e.g.* in public transport, district heating and cooling networks or smart energy system) which increase the value of land and buildings. The same principle is used to structure loans for household PV in Berkeley, California and other cities in the US (REN21, ISEP and ICLEI, 2011).

In cities that own municipal energy utilities, the ownership model is the most effective lever to channel funding to energy investments, including renewables.

Finnish municipalities have an established financing structure to own and finance power generation, called the "Mankala model". In the model, a large number of municipalities and operators create a joint venture, each owning a small share. In the Mankala model, the power company sells the electricity and heat to shareholders at no profit. The shareholders commit to paying the company's costs in proportion to their shares. As a result, the Mankala company becomes de-risked and can obtain high credit ratings, thereby attracting low-interest, long-term loans with high financial leverage. Finally, as it commits to zero profit, it pays no taxes (Makitalo, 2015). Two examples of wind power municipal energy utility Mankala companies are Suomen Hyotytuuli Oy (*http://www.hyotytuuli.com/*) and Puhuri Oy (*http://www.puhuri.fi/*).

Municipal green bonds are another mechanism used to finance renewable energy investment. Many cities in developing and emerging countries have limited access to capital markets. Green bonds can provide municipal governments with access to low-cost capital to meet their energy investment needs. Recent analysis shows that only 1.7% of green bonds proceeds flow to cities and city-based infrastructure in developing countries. To date, Johannesburg is the only city in a developing market to have issued a green bond (CPI, 2016).

In June 2014, Johannesburg issued South Africa's first Green Bond (COJGO1) on the Johannesburg Stock Exchange. Maturing in 2024, this 1.46 billion rand (USD 140 million) Green Bond aims to finance a biogas to energy project and a solar water-heating project. The bond auction was oversubscribed by 150%.

The city's sound financial situation was instrumental in attracting investors, building on a solid track record of issuing bonds since 2004. Johannesburg also received a positive investment rating from major ratings agencies (WRI, 2016).

Another example is the City of Gothenburg in Sweden, which issued its first green bond in September 2013, selling approximately USD 60 million worth of debt. The city subsequently issued more bonds in 2014 and 2016. Eligible projects include renewable energy (solar, wind, wave and hydro), energy efficiency, waste management, biofuel production from forestry waste, and smart grids.

Box 8: Vancouver's Renewable City Information campaign

In the summer of 2015, the City of Vancouver held The *Bright Green Summer*, a series of stakeholder consultations and workshops where citizens engaged with elected officials to learn about the Greenest City 2020 Action Plan and the Renewable City Strategy - which aims for 100% RE by 2050. City staff participated in public events such as the Pacific National Exhibition showground, 'Doors Open Vancouver', Pop-up City Hall, downtown Block Party and the Vancouver Public Library summer reading events, to present existing and new Greenest City goals, and to gather feedback from citizens.

One aspect of this strategy was the *Greenest City Conversations:* multiple channels were used to engage Vancouver citizens on the topic of sustainability, including: Mobile Apps; Table-top Games; Performing Art; Social Media; Neighbourhood Workshops; and MetroQuest, a multi-scenario interface. At the end of the consultation process, the City organised a survey on renewables with over 850 respondents. Nearly 80% of them supported the City's direction on climate action work (City of Vancouver, 2015).

Despite these initiatives, the role of cities in financing renewable energy investment remains limited based on available data. National governments still have a key role in supporting the growth of renewable energy investment in cities.

Cities as advocates and facilitators

The direct interaction between city decision-makers, mayors and citizens grant cities unique influence over behavioural choices. As providers of public knowledge, they can pilot demonstration projects, conduct stakeholder consultations and feasibility studies, and disseminate relevant information to companies, educational facilities and media outlets. Studies show that despite their sometimes-limited formal powers over key energy decisions, cities can considerably leverage their actions and resources by taking a collaborative approach, in particular by collaborating with the private sector and civil society (C40 and ARUP, 2015).

Because cities around the world share many similarities in their functions and levers for action to promote RE, and more broadly, sustainability, they can greatly benefit from sharing experiences with partner cities around the world. In recent years, several initiatives have been launched to address urban sustainability, some of which are shown in Table 6. These help cities discuss the economically most viable and carbon-effective options, while bearing in mind their diverse conditions and priorities. Dialogues ideally involve all stakeholders, in order to ensure long-term public support. Despite their sometimes-limited formal powers over key energy decisions, cities can

Table 6: Selected recent international initiatives addressing sustainability in cities.

Initiative	Founded	Institutions	Objectives
Global Covenant of Mayors for Climate & Energy	2016 (merger of Covenant of Mayors and Compact of Mayors)	European Commission, C40, ICLEI, UCLG, UN Habitat	Mitigation, adaptation, and secure, sustainable and affordable energy in cities, impact of cities on emissions and climate risk
Global Platform for Sustainable Cities	2016	World Bank, GEF (funded), with C40, ICLEI and WRI as partners	Mobilising investment for urban sustainability
Coalition for Urban Transitions	2016	C40 Cities Climate Leadership Group, WRI (Ross Center), New Climate Economy	Improving economic, social, and environmental performance (incl. reducing risk of climate change)
100% Renewable Energy Network of Cities and Regions	2015	ICLEI as contribution to the 100% RE Campaign	Supporting ambitious lead cities who strive for a 100%RE future.
Transformative Actions Program (TAP)	2015	ICLEI, C40, UCLG, R20	Scaling up investments, increased engagement in national/global mechanisms, capacity building, technology transfer, access to climate finance.
Global District Energy in Cities Initiative	2014	40 public and private institutions (SEforALL, GEF, ICLEI, C40, EBRD, IFC, Danfoss, ENGIE, UN Habitat etc)	Accelerate sustainable energy (energy efficiency and renewable energy) in cities through increased investment in modern district energy systems. Policy and planning, capacity building, and demonstration projects.
The Cities Climate Finance Leadership Alliance (CCFLA)	2014	36 institutions (ICLEI, C40, EIB, KfW, GEF, etc.)	Closing the Low-carbon, Resilient Urban Investment Gap

exert tremendous influence though advocacy and facilitation.

National governments as enablers of cities

Based on the analysis of more than 3600 cities, this study shows that the potential for renewables is high, particularly in buildings and transport, but it differs greatly depending on key city characteristics such as the level of population density, city growth prospects and demand profiles in cold versus hot climate areas. Accordingly, renewable energy deployment strategies require tailored approaches for cities with specific technology options and enabling policy frameworks.

The relative power of national, state and municipal authorities varies greatly among countries, and among policy areas and sectors. Municipalities typically have higher levels of autonomy regarding spatial planning, urban transport and the management of municipal companies and assets. In many cases, they have lower levels of control over the provision of energy supply.

However, there is growing evidence that cities have several levers to steer the direction of urban energy systems towards renewables. Given the wide range of city-specific contexts, promoting sustainable energy in cities can be best achieved at the municipal level whether through planning, regulation, direct investment, provision of services, or awareness raising. In some countries, accelerating the switch to renewables would benefit from significant decentralisation of power regarding land use management, local energy supply and transportation infrastructure, and scaling up financial resources.

Nevertheless, as local governments are bound by national frameworks and infrastructure systems, cooperation and coordination of policies and initiatives across different levels of governance is an essential enabling factor. It can unlock financial support, capacity building and technical support, data availability, and new mandates that can accelerate the transition to a sustainable energy future. National governments in the developing world have a key role in providing the supporting framework for cities to develop their own capacity.

The integration of cities in national and global energy agendas can increase the level of ambition and catalyse action both at the local and at the global level.

3.3 The potential for renewable energy in different city types

The potential for renewable energy in cities differs greatly depending on population density, the level of development, and the demand for cooling and heating (Figure 16).

Heating and cooling

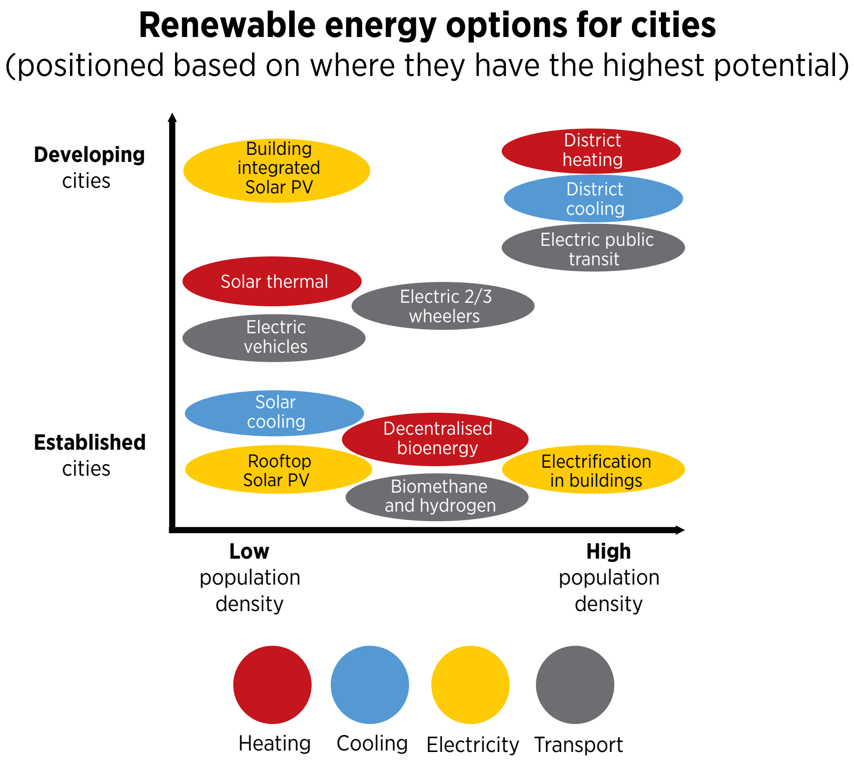
In cold climates, most energy in buildings is used for heating. In cities in the northern hemisphere, space heating accounts for nearly a quarter of total urban energy use in buildings. **Solid biofuels** combusted in decentralised boilers in apartments or single family houses, as well as in district CHP systems, have so far been the main choice of renewable energy in most countries.

In cities with high population densities, **district heating** using renewables (including solar and geothermal energy) has significant potential, as network costs form a large part of the delivered cost of heating. This is particularly the case for cities in emerging economies, where heating demand is set to grow the most, and networks can be integrated from the start with new construction, which is easier and more cost-effective than retrofitting existing city blocks.

In established cities, where heating energy use is expected to decline, renewables can substitute fossil fuels in existing district heating networks. For cities where district heating networks are absent, the potential for decentralised biomass boilers might be higher. Solid biofuels could be used with minor modifications in existing boilers and therefore can be used in both existing and new capacity.

Hot water is required in most countries regardless of the climatic zone, and with increasing income levels. Its demand is also increasing. Today, it accounts for about 10% of urban energy use in buildings. District heating can provide the energy for water heating in high density cities. Solar water heaters and renewable electricity sourced heat pumps can deliver low temperature hot water, and can be easily added to both new and existing buildings. Solar thermal collectors have more potential in low density cities, given the higher availability of rooftop space per unit of energy consumed.

Figure 16: The potential for renewable energy options for transport and in buildings in different city types.



Note: renewable energy is assumed to be used for the electrification and district energy options. Renewable energy options are positioned based on where they have the highest potential.

The applicability of renewable energy options in cities is conditioned by climatic conditions, but also population density, and expected growth.

For **cooking**, which accounts for 10% of global energy use in buildings in cities, electrification presents the largest opportunity. In developing countries there is also the potential for modern cookstoves fuelled by bioenergy.

Renewable energy technologies for **cooling** are at an earlier stage of deployment. Distributed solar cooling technologies hold potential, provided there is sufficient availability of rooftop space. District cooling – leveraging solar thermal energy or cold water from rivers, lakes or the sea – can supply directly to commercial buildings or residential districts with higher population density. This provides more opportunities in expanding cities, as district cooling systems are easier to incorporate into designs for new offices, malls, and apartment buildings, rather than retrofitting existing infrastructure.

Transport

For **transport**, two pathways exist to increase renewable usage: by the use of biofuels (liquid and gaseous) and through increasing the share of electricity (which can be generated by renewable power).

Electric mobility has clear advantages for cities in mitigating air pollution. This has historically consisted of public transit, such as trams, metro, and train systems. More recently, cities have seen the rise of electric buses, trucks, cars, scooters and bikes.

Electric public transit and electric two- to three wheelers are especially efficient in compact cities and can meet the fast growing energy demand for transport in cities located in emerging economies with high population density. Electric cars will be most applicable in low population density cities, where the energy used for transport is significantly higher, due to larger travelling distances and less frequent use of public transit.

Integrated cities

Finally, with the expected growth of distributed power generation and storage, electric mobility, as well as the overall increase in variable renewable power generation, it is no longer sufficient for cities to look at energy sectors in isolation.

There needs to be a transition to the systemic and comprehensive planning of the urban energy system. This should cover the interrelationships across the end-use sectors (buildings, industry, and transport) and transformation (power and district heat) sectors, but also look beyond the energy sector, to urban planning, building design, waste management, and urban agriculture.

4. CONCLUSIONS AND KEY MESSAGES

Increasing the share of renewable energy sources is essential to the long-term sustainability and wellbeing of cities. City-level policy makers have a rich set of technologies to choose from, along with the opportunity to take a more integrated approach to a multiplicity of activities and services. To scale up rapidly and substantially, most cities will need to increase their focus on renewables for buildings and transport.

In buildings, rooftop solar PV and solar water heating are easy to install and offer significant economic gains. Other effective technologies include renewable-based district heating and cooling systems, which are most economical in densely populated cities, and renewable-sourced heat pumps, which can be easily integrated in both new and existing buildings.

In transport, electric mobility, when powered by renewable sources, reduces air pollution and is increasingly cost competitive. Electricity is already widely used to power public transport, such as tramways, metros, and other rail systems. Electric trucks, cars, scooters and bikes have also recently gained momentum and are well suited to the demands of all types of cities.

As renewable energy technologies spread, buildings and transport will become increasingly interconnected with the power system. Building and transport uses can help to balance the demand and supply of electricity and provide a flexibility option as the share of variable renewables such as solar and wind power increases. Linkages between the electricity and heat sectors will also gain in importance, through the expanding use of heat pumps as well as renewables-based district heating and cooling networks.

This requires new system-level thinking, in order to create synergies and manage demand. Many innovative technologies and concepts exist to promote this, such as demand-side management, virtual power plants, vehicle-to-grid, and smart power and district energy networks. To cope with increasing electric mobility, distributed generation and storage, as well as smart appliances, cities need to plan for integrated urban energy systems, using expertise from multiple sectors – from urban planning to waste management.

Energy use varies widely between different cities, depending on their population density, climate, and rate of growth. While energy policies are often decided at a national level, city governments are best placed to tailor renewable energy strategies to specific local circumstances.

Municipal authorities possess many levers to effect change. These include planning; regulation; direct investment; provision of services; and education and awareness. Accelerating the switch to renewables often depends on more decentralised decision-making on land use management, energy supply and transportation infrastructure, and scaling up financial resources.

Greater cooperation and coordination of policies is needed across different levels of governance. This can unlock financial and technical support as well as access to knowledge and data. National governments can do more to help cities develop their own capacities. Likewise, the integration of cities into national and global energy agendas can increase ambition and catalyse action for all. The success of international efforts to curb climate change will be determined, in large part, by the transition to renewable energy in cities.

REFERENCES

ADA (n.d.), *King Abdulaziz Project for Riyadh Public Transport*, http://www.ada.gov.sa/ADA_e/DocumentShow_e/?url=/res/ADA/En/Projects/RiyadhMetro/index.html

Birkmann, J., Welle, T., Solecki, W., Lwasa, S., Garschagen, M. (2016), *'Boost resilience of small and mid-sized cities'*, *Nature*, 537(7622), pp. 605–608.

Bjerkan, K.Y., . Nørbech, T.E.; Nordtømme, M.E. (2016), *Incentives for promoting Battery Electric Vehicle (BEV) adoption in Norway*, Transportation Research Part D: Transport and Environment, 43, pp. 169–180.

Bloomberg New Energy Finance (BNEF) and Lighting Global (2016), *Off-Grid Solar Market Trends Report 2016*, https://www.lightingglobal.org/wp-content/uploads/2016/03/20160301_OffGridSolarTrendsReport.pdf

C40 (2011), *C40 Case Studies: Barcelona's Solar Hot Water Ordinance*, http://www.c40.org/case_studies/barcelonas-solar-hot-water-ordinance

C40 (2012), *C40 Cities: Why Cities? Ending Climate Change Begins in the City*, http://c40.org/ending-climate-change-begins-in-the-city

C40 (2014), *C40 Case Studies: The Electric Vehicle Capital of the World.*, http://www.c40.org/case_studies/the-electric-vehicle-capital-of-the-world

C40 and ARUP (2015), *Climate Action in Megacites 3.0 – Networking works, there is no global solution without local action*, http://www.cam3.c40.org/images/C40ClimateActionInMegacities3.pdf

Chadbourne (2016), *Another Potential Offtaker: Community Choice Aggregators*, August 2016, by Deanne M. Barrow, http://www.chadbourne.com/another-potential-offtaker-community-choice-aggregators-project-finance-august-2016

CHIC (2013), *Clean Hydrogen In Cities Project,* Hydrogen London, http://www.hydrogenlondon.org/projects/london-hydrogen-bus-project/

Challenge (2016), *Eclairage Public au Maroc : Vers un nouveau mode de gestion,* Challenge Maroc, 21 April 2016, http://www.challenge.ma/vers-un-nouveau-mode-de-gestion-67407/

City and County of San Francisco (2016), *File No. 160154, Ordinance*, https://sfgov.legistar.com/View.ashx?M=F&ID=4399794&GUID=FE220DFF-2C3F-4F0B-8C9B-39F1A61039F2

City of Cape Town (2016a), *Requirements For Small Scale Embedded Generation – Application process to become a small scale embedded generator in the City of Cape Town,* published on 3 March 2016, https://www.capetown.gov.za/en/electricity/Application%20Forms/CCTRequirenemstforEmbeddedGeneration-V41-3-March-2016-Final.pdf

City of Cape Town (2016b), Safe and Legal Installations of Rooftop Photovoltaic Systems Commercial And Residential – In Cape Town, March 2016, https://www.capetown.gov.za/en/EnvironmentalResourceManagement/publications/Documents/CCT_Safe_and_legal_photovoltaic_installations_2016-03.pdf

City of Freiburg im Breisgau (2014), *Freiburg GreenCity – Approaches to Sustainability,* City of Freiburg International Affairs Division – Green City Office, September 2014, https://www.freiburg.de/pb/site/Freiburg/get/params_E256863245/640888/Green-City-Brochure_English.pdf.

City of Minneapolis (2013), *Climate Action Plan*, http://www.minneapolismn.gov/www/groups/public/@citycoordinator/documents/webcontent/wcms1p-109331.pdf.

City of Vancouver (2015), *Renewable Energy Strategy 2015 – 2050*, http://vancouver.ca/files/cov/renewable-city-strategy-booklet-2015.pdf

Clark-Sutton, K. *et al.* (2016) *Plug-in electric vehicle readiness: Rating cities in the United States*, The Electricity Journal, 29 (1), pp. 30–40.

Cooke, L. (2016), *Chile introduces world's first metro to be powered largely by renewables*. Inhabitat.com. http://inhabitat.com/chile-introduces-worlds-first-metro-to-be-powered-largely-by-renewables/

CPI – Climate Policy Initiative blog (2016), *Understanding green bond data can help cities in developing countries tap the market*, September 2016, http://climatepolicyinitiative.org/2016/09/06/understanding-green-bond-data-to-help-cities-developing-countries-tap-market/

CPCU – Paris Urban Heating Company (2015) *Stratégie énergétique*, http://www.cpcu.fr/Reseau-de-chaleur/ATOUTS/Le-bouquet-energetique-coeur-du-systeme-CPCU

D.C. Government (2015), Executive Office of the Mayor, *Mayor Bowser Announces Largest Municipal Onsite Solar Project in US*, http://mayor.dc.gov/release/mayor-bowser-announces-largest-municipal-onsite-solar-project-us

Egge, M. A. (2015), *Somaliland: Solar Street Lights for Lasanod*, December 19, 2015. http://www.somalilandpress.com/somalilandsolar-street-lights-for-lasanod/.

Ericsson, Karin (2009), *Introduction and development of the Swedish district heating systems Critical factors and lessons learned*, Lund University, Sweden: http://www.res-h-policy.eu/downloads/Swedish_district_heating_case-study_(D5)_final.pdf

ESMAP (2015), *The State of the Global Clean and Improved Cooking Sector*, Energy Sector Management Assistance Program / Global Alliance for Clean Cookstoves / The World Bank, Washington D.C., USA, https://openknowledge.worldbank.org/bitstream/handle/10986/21878/96499.pdf

EUEI PDF (2016 forthcoming), *Future Energy Scenarios for African Cities – Unlocking Opportunities for Climate Responsive Development*, http://www.euei-pdf.org/en/seads/thematic-research-and-knowledge-sharing/future-energy-scenarios-for-african-cities-unlocking

European Commission (2014), Energy Research Knowledge Centre (ERKC), *Thematic Research Summary: Smart district heating and cooling*. https://setis.ec.europa.eu/energy-research/sites/default/files/library/ERKC_%20TRS_Smart_District_HC.pdf

European Commission (2015), *Science for Environment Policy, Thematic Issue: Noise impacts on health*, http://ec.europa.eu/environment/integration/research/newsalert/pdf/47si.pdf

Fischer, D., Lindberg, K., Mueller, S., Wiemken, E., Wille-Haussmann, B. (2014), *Potential for Balancing Wind and Solar Power Using Heat Pump Heating And Cooling Systems*. Green heat pump, Workpackage 10, http://www.greenhp.eu/work-packages/wp10-smart-grid/?eID=dam_frontend_push&docID=2584

Fjeldstad, O-H.; Chambas, G. and Brun, J-F. (2014), L*ocal government taxation in Sub-Saharan Africa. A review and an agenda for research*, CMI Working Paper, WP 2014: 2, https://www.cmi.no/publications/file/5098-local-government-taxation-in-sub-saharan-africa.pdf

GIZ (n.d.), *How a metro system generates its own electricity*, https://www.giz.de/en/workingwithgiz/35868.html

Government of Nepal (2012), *Alternative Energy Promotion Centre (AEPC) National Rural and Renewable Energy Programme (NRREP) Biogas Subcomponent – Targets and Achievements*, http://www.aepc.gov.np/?option=nrrep&page=subsubtechsupport&mid=5&sub_id=37&ssid=1&cat=Targets and Achievements

GNESD (2013), *Policy Synthesis Report. Energy Poverty in Developing Countries' Urban Poor Communities: Assessments and Recommendations. Urban and Peri-Urban Energy Access III*. Report Prepared for Global Network on Energy for Sustainable Development (GNESD) by The Energy and Resources Institue (TERI). Roskilde: GNESD, http://www.gnesd.org/~/media/Sites/GNESD/Publication%20pdfs/Urban%20Peri-Urban%20Theme/UPEA%20III%20-%20Newly%20Edited/Final_UPEAIII_Synthesis_final.ashx

Government of Nepal (2012), Alternative Energy Promotion Centre (AEPC) National Rural and Renewable Energy Programme (NRREP) Biogas Subcomponent – Targets and Achievements. http://www.aepc.gov.np/?option=nrrep&page=nrrepcom&mid=4&sub_id=31&ssid=1&cat=Targets and Achievement

Green Energy BioFuels (n.d.), *Green Energy BioFuels corporate website*, http://www.gebiofuels.com/

Grubler, A., X. Bai, T. Buettner, S. Dhakal, D. J. Fisk, T. Ichinose, J. E. Keirstead, G. Sammer, D. Satterthwaite, N. B. Schulz, N. Shah, J. Steinberger and H. Weisz (2012), *Urban Energy Systems*, Chapter 18 in *Global Energy Assessment – Toward a Sustainable Future*, Cambridge University Press, Cambridge, UK and New York, NY, USA and the International Institute for Applied Systems Analysis, Laxenburg, Austria, pp. 1307-1400. http://www.iiasa.ac.at/web/home/research/Flagship-Projects/Global-Energy-Assessment/GEA-Summary-web.pdf

H2-international (2016), *H2-international corporate website*, http://www.h2-international.com/2016/09/29/beezeros-fuel-cell-carsharing-offer/

Heinsdorf, M. (2015), *Code or standard? What's the difference between a code and a standard?* Retrieved from Consulting – Specifying Engineer, 1 July 2015: http://www.csemag.com/single-article/code-or-standard/6b11e1ef3b1bc0ebcacc1915fd1a33a5.html

Honolulu SWAC (n.d.), *Honolulu Seawater Air Conditioning*, http://honoluluswac.com/community.html

ICCT (2015), *Assessment of leading electric vehicle promotion activites in United States cities*, http://www.theicct.org/sites/default/files/publications/ICCT_EV-promotion-US-cities_20150729.pdf

ICLEI – Local Governments for Sustainability (2014a), *Using solar energy: Supporting community energy self-sufficiency, Urban-LEDS, Barcelona, Spain*, http://www.iclei.org/fileadmin/PUBLICATIONS/Case_Studies/ICLEI_cs_173_Barcelona_UrbanLEDS_2014.pdf

ICLEI (2014b), *Waste to fuel: biogas powered buses in Lille Metropole.*, Urban NEXUS Case Study, http://www.iclei.org/fileadmin/PUBLICATIONS/Case_Studies/Urban_NEXUS_cs07_Lille_ICLEI-GIZ_2014.pdf

ICLEI (2016a), *Connect with the 100% Renewable Energy Cities and Regions Network*, Issue 1 – September 2016. Bonn, www.iclei.org/lowcarboncity/100re

ICLEI (2016b), *EcoMobility Alliance: Report 2012-2015*, http://ecomobility.org/wpdm-package/ecomobility-alliance-report-2012-2015/?wpdmdl=2297&ind=-OFMwEjSAkQ_yQ83QWumD_MZvte1CXb2DK26baHP0vuQjOqvFEPYi4WExiYkjnG-.

ICLEI, WFC and Renewable Cities (2016), *Dialogue Report: 100% Renewable Energy in Cities.* Available at: http://e-lib.iclei.org/wp-content/uploads/2016/03/Dialogue-Report-100RE.pdf

IEA (2013), *Modernising Building Energy Codes*, OECD/IEA, France, https://www.iea.org/publications/freepublications/publication/PolicyPathwaysModernisingBuildingEnergyCodes.pdf

IEA (2015a), *Energy efficiency market report 2015: Market trends and medium-term prospects*, OECD/IEA: Paris, France: https://www.iea.org/publications/freepublications/publication/MediumTermEnergyefficiencyMarketReport2015.pdf

IEA (2015b), *Global EV Outlook 2015 – Key takeaways*. OECD/IEA, France, http://www.iea.org/evi/Global-EV-Outlook-2015-Update_1page.pdf

IEA (2016), *Energy Technology Perspectives 2016 – Towards Sustainable Urban Energy Systems*. OECD/IEA, France, https://www.iea.org/etp/etp2016/.IEA (2016b) Global EV Outlook 2016. OECD/IEA: Paris, France, https://www.iea.org/publications/freepublications/publication/Global_EV_Outlook_2016.pdf

IEA-SHC (n.d.), *China country report*, http://www.iea-shc.org/country-report-china

IRENA – International Renewable Energy Agency (2014a), *Renewable Energy in Manufacturing: A technology roadmap for REmap 2030*. IRENA (International Renewable Energy Agency), Abu Dhabi, https://www.irena.org/remap/REmap%202030%20Renewable-Energy-in-Manufacturing.pdf

IRENA (2014b), *Renewable Energy Prospects: China*. IRENA, Abu Dhabi, http://irena.org/remap/IRENA_REmap_China_report_2014.pdf

IRENA (2015a), *Renewable energy options for the industry sector: Global and Regional Potential until 2030*. IRENA, Abu Dhabi, http://www.irena.org/remap/IRENA_RE_Potential_for_Industry_BP_2015.pdf

IRENA (2015b), *Renewable Energy Policy Brief: Brazil*, IRENA, Abu Dhabi, UAE, http://www.irena.org/DocumentDownloads/Publications/IRENA_RE_Latin_America_Policies_2015_Country_Brazil.pdf

IRENA (2015c), *Renewable Energy Target Setting*, IRENA, Abu Dhabi, http://www.irena.org/DocumentDownloads/Publications/IRENA_RE_Target_Setting_2015.pdf

IRENA (2016a), *Renewable Energy Benefits: Measuring the Economics*, IRENA, Abu Dhabi, http://www.irena.org/DocumentDownloads/Publications/IRENA_Measuring-the-Economics_2016.pdf

IRENA (2016b), *REmap: Roadmap for A Renewable Energy Future: 2016 Edition.* IRENA: Abu Dhabi, http://www.irena.org/DocumentDownloads/Publications/IRENA_REmap_2016_edition_report.pdf

IRENA (2016c), *Policies and Regulations for Private Sector Renewable Energy Mini-grids.* IRENA, Abu Dhabi, http://www.irena.org/DocumentDownloads/Publications/IRENA_Policies_Regulations_minigrids_2016.pdf

IRENA (2016 forthcoming), *Innovation Technology Outlook for Advanced Liquid Biofuels.* IRENA, Abu Dhabi

IRENA and ICLEI (2013a), *Renewable Energy Policy in Cities Case Studies: Waste to Energy for More Effective Landfill Site Management – Belo Horizonte, Brazil*, https://www.irena.org/Publications/RE_Policy_Cities_CaseStudies/IRENA%20cities%20case%203%20Belo%20Horizonte.pdf

IRENA and ICLEI (2013b), *Renewable Energy Policy in Cities Case Studies: Potential Analysis of Renewable Energy for Targeted Policy Intervention – Chemnitz, Germany*, 2013, https://www.irena.org/Publications/RE_Policy_Cities_CaseStudies/IRENA%20cities%20case%202%20Chemnitz.pdf

IRENA and ICLEI (2013c), *Renewable Energy Policy in Cities Case Studies: Integrating Ambitious Renewable Energy Targets in City Planning – Malmö, Sweden*, https://www.irena.org/Publications/RE_Policy_Cities_CaseStudies/IRENA%20cities%20case%207%20Malmo.pdf

IRENA and ICLEI (2013d), *Renewable Energy Policy in Cities Case Studies: Lighting up the streets – Sydney,* *Australia – Nagpur, India*, http://www.iclei.org/fileadmin/PUBLICATIONS/Case_Studies/5_SydneyNagpur_-_ICLEI-IRENA_2012.pdf

IRENA and ICLEI (2013e), *Renewable Energy Policy in Cities Case Studies: Stimulating Renewable Energy through Public and Private Procurement – Austin, USA*, http://www.irena.org/Publications/RE_Policy_Cities_CaseStudies/IRENA%20cities%20case%204%20Austin.pdf

IRENA and ICLEI (2013f), *Renewable Energy Policy in Cities Case Studies: Local Government Regulation: Ordinances and Laws to Promote Renewable Energy – Sao Paulo, Brazil*, http://www.irena.org/Publications/RE_Policy_Cities_CaseStudies/IRENA%20cities%20case%206%20Sao%20Paulo.pdf

IRENA and ICLEI (2016 forthcoming), *Renewable Energy Policy in Cities Case Studies: Strategic Partnerships and Enabling Municipal Frameworks – Kasese District, Uganda.*

IRENA and IEA-ETSAP (2013), *Thermal Energy Storage: Technology Brief.* IRENA, Abu Dhabi, https://www.irena.org/DocumentDownloads/Publications/IRENA-ETSAP%20Tech%20Brief%20E17%20Thermal%20Energy%20Storage.pdf

IRENA and IEA-ETSAP (2015), *Solar Heating and Cooling for Residential Applications: Technology Brief.* IRENA, Abu Dhabi, UAE, http://www.irena.org/documentdownloads/publications/irena_etsap_tech_brief_r12_solar_thermal_residential_2015.pdf

ILSR – Institute for Local Self-Reliance (2013), *City Power Play: 8 Practical Local Energy Policies to Boost the Economy*, http://ilsr.org/wp-content/uploads/downloads/2013/10/City-Power-Play-8-Practical-Local-Energy-Policies-to-Boost-the-Economy.pdf

Jonerholm, K. (2012) *Production and supply of biogas in the Stockholm region, Baltic Biogas Bus project*, http://www.balticbiogasbus.eu/web/Upload/Supply_of_biogas/Act_4_6/Production%20and%20supply%20of%20biogas%20in%20the%20Stockholm%20region.pdf

Junmian, Z. (2013), *Subway solar roof installation to begin operation*, China.org.cn, http://beijing.china.org.cn/2013-07/12/content_29402455.htm

Kitchen, H. (2004), *Local Taxation in Selected Countries: A Comparative Examination*, Working Paper 2004(5), IIGR, Queen's University, https://www.trentu.ca/economics/WorkingPapers/Local%20Taxation.pdf

Kronsbein (2015), *Rio de Janeiro: Solar street lights illuminate 73-km motorway*, *Sun & Wind Energy*, http://www.sunwindenergy.com/photovoltaics/rio-de-janeiro-solar-street-lights-illuminate-73-km-motorway

Makitalo (2015), *Wind Finland 2015 – What Are Mankala Corporations*, http://www.tuulivoimayhdistys.fi/filebank/814-VilleVyyrylainen.pdf

Movellan, J. (2015a), *Born from Disaster: Japan Establishes First Microgrid Community*, Renewable Energy World, http://www.renewableenergyworld.com/articles/2015/05/born-from-disaster-japans-first-microgrid-community-represents-future-of-energy.html

Movellan, J. (2015b), *Tokyo's Renewable Energy Transformation To Be Showcased in the 2020 Olympics.*, Renewableenergyworld.com, http://www.renewableenergyworld.com/articles/2015/06/tokyo-s-renewable-energy-transformation-to-be-showcased-in-the-2020-olympics.html

Movellan, J. (2015c), *Japan Electricity Deregulation: Birth of Municipally Owned Electric Utilities*, http://www.renewableenergyworld.com/articles/2015/09/japan-electricity-deregulation-birth-of-municipally-owned-electric-utilities.html

Norregaard J. (2013), *Taxing Immovable Property Revenue Potential and Implementation Challenges*, IMF Working Paper Fiscal Affairs Department, https://www.imf.org/external/pubs/ft/wp/2013/wp13129.pdf

NREL – National Renewable Energy Laboratory (2014), *Using Power Purchase Agreements for Solar Deployment at Universities*, http://www.nrel.gov/docs/gen/fy16/65567.pdf

NREL (2015), *Top Ten Utility Green Power Programs*, US Department of Energy, National Renewable Energy Laboratory / The Green Power Network, December 2015, http://apps3.eere.energy.gov/greenpower/resources/tables/topten.shtml

OECD (2013), *Green Growth in Cities,* OECD Green Growth Studies, OECD Publishing, doi: http://dx.doi.org/10.1787/9789264195325-en

OECD (2012), *OECD Territorial Reviews: The Chicago Tri-State Metropolitan Area,* United States 2012, OECD Publishing, doi: 10.1787/9789264170315-en.

OECD (2007), *Climate change could triple population at risk from coastal flooding by 2070,* http://www.oecd.org/general/climatechangecouldtriplepopulationatriskfromcoastalfloodingby2070findsoecd.htm

Philips (2016), *Philips Lighting, Philips corporate website*, http://www.lighting.philips.com/main/systemsconnected-lighting/connected-lighting-for-smart-cities/connected-lighting-for-smart-cities

Phiri, K. (2016), *Hwange installs street lights,* The Chronicle, http://www.chronicle.co.zw/hwange-installs-street-lights/

REN21, ISEP and ICLEI (2011), *Global Status Report on Local Renewable Energy Policies,* http://www.ren21.net/Portals/0/documents/Resources/REN21_Local_Renewables_Policies_2011.pdf

Republic of Uganda (2013), *Kasese District Renewable Energy Strategy (2013-2020)*, publication supported by WWF Uganda, https://d2ouvy59p0dg6k.cloudfront.net/downloads/kasese_district_renewable_energy_strategy.pdf

Rezessy, S., Dimitrov, K., Urge-Vorsatz, D., Baruch, S. (2006), *Municipalities and Energy Efficiency in Countries in Transition: Review of Factors that Determine Municipal Involvement in the Markets for Energy Services and Energy Efficient Equipment, or How to Augment the Role of Municipalities as Market Players*, *Energy Policy*, Vol. 34.

Rizhao Government. (2015), *Rizhao Municipal People's Government*. Retrieved from http://www.rizhao.gov.cn/ContShow.php?category_id=183&aiticle_id=38197

South African Local Government Association (SALGA) in partnership with South African German Energy Programme (SAGEN) (2012), City of Johannesburg Project: Northern Works Biogas to Energy. http://www.cityenergy.org.za/uploads/resource_336.pdf

Scherffius, L. (2015), *Ecuador Pushing for Switch from Gas to Induction Cooktops,* teleSUR, 28 January, http://www.telesurtv.net/english/news/Ecuador-Pushing-for-Switch-from-Gas-to-Induction-Cooktops-20150128-0035.html

Seto K. C., S. Dhakal, A. Bigio, H. Blanco, G. C. Delgado, D. Dewar, L. Huang, A. Inaba, A. Kansal, S. Lwasa, J. E. McMahon, D. B. Müller, J. Murakami, H. Nagendra, and A. Ramaswami, (2014): *Human Settlements, Infrastructure and Spatial Planning*. In: *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. https://www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_chapter12.pdf

Shah, N., Wei, M., Letschert, V., Phadke, A. (2015), *Benefits of Leapfrogging to Superefficiency and Low Global Warming Potential Refrigerants in Room Air Conditioning*. Berkeley, US: LBNL, http://eetd.lbl.gov/sites/all/files/lbnl-1003671_0.pdf

Silver Spring (2013), *The Business Case for Smart Street Lights*, http://www.silverspringnet.com/wp-content/uploads/SilverSpring-Whitepaper-Smart-Street-Light-Bizcase.pdf

Singh, R., Wang, X., Ackom, E. K. and Reyes, J. C. M. (2014), *Energy Access Realities in Urban Poor Communities of Developing Countries: Assessments and Recommendations.* Report Prepared for the Global Network on Energy for Sustainable Development (GNESD) by the Energy and Resources Institute (TERI) and the GNESD Secretariat. Summary for Policy-Makers. Roskilde: GNESD, http://orbit.dtu.dk/files/106352494/Energy_access_realities_v_final_updated.pdf

SMUD – Sacramento Municipal Utility District (2016), *SMUD Releases Request for Offers for Solar, SMUD*, https://www.smud.org/en/about-smud/news-media/news-releases/2016/2016-03-15-offers-for-solar.htm

Spahn, P. B. (1995), *Local Taxation: Principles and Scope*, in Jayanta Roy (ed.), *Macroeconomic Management and Fiscal Decentralization*, EDI Seminar Series, The World Bank, Washington D.C., 221-232, https://mpra.ub.uni-muenchen.de/13111/1/MPRA_paper_13111.pdf

Sparkes, David (2016), *Climate Change: Melbourne Renewable Energy Project Provides Global Blueprint,* The Guardian, June 10, sec. Guardian Sustainable Business. https://www.theguardian.com/sustainable-business/2016/jun/10/climate-change-melbourne-renewable-energy-project-provides-global-blueprint

Tao, H. (2011), *Solar heating and cooling in China*, http://www.solarthermalworld.org/sites/gstec/files/Presentation%20of%20Tao%20He.pdf

Tecnologico de Monterrey (2013), *Asociación Público-Privada Entre Bioeléctrica S.A. De C.V. Y El Gobierno Del Estado De Nuevo León*. Retrieved from APP Bioelectrica. http://www.cca.org.mx/ps/funcionarios/muniapp/descargas/Documentos_de_apoyo/informacion tematica/capp/APP_Bioelectrica.pdf

The International Bank for Reconstruction and Development (IBRD) and The World Bank (2010), *Mainstreaming building energy efficiency codes in developing countries. Global experiences and lessons from early adopters.* The World Bank, Washington, D.C. http://www.esmap.org/sites/esmap.org/files/WP_204_GBL_Mainstreaming%20Building%20Energy%20Efficiency%20Codes%20in%20Developing%20Countries_Overview_1.pdf

The Himalayan Times (2016), *Grants Allocated for Solar Light Installation*, https://thehimalayantimes.com/kathmandu/grants-allocated-solar-light-installation/.The Kathmandu Post (2015) Waste to energy: Construction of biogas plants can contribute to energy security, http://

kathmandupost.ekantipur.com/news/2015-11-06/waste-to-energy.html

The World Bank (2012), *What a waste – A global review of solid waste management.*, Urban development series knowledge papers,: http://siteresources.worldbank.org/INTURBANDEVELOPMENT/Resources/336387-1334852610766/What_a_Waste2012_Final.pdf

The World Bank (2015), *Bringing Electricity to Kenya's Slums: Hard Lessons Lead to Great Gains,* Feature Story, August 20, 2015, http://www.worldbank.org/en/news/feature/2015/08/17/bringing-electricity-to-kenyas-slums-hard-lessons-lead-to-great-gains

UITP (2015a), *Mobility in cities database, synthesis report*, http://www.uitp.org/sites/default/files/cck-focus-papers-files/MCD_2015_synthesis_web_0.pdf

UITP (2015b), *World metro figures – Statistics Brief*, http://www.uitp.org/sites/default/files/cck-focus-papers-files/Metro%20report%20Stat%20brief-web_oct2014.pdf

UITP (2015c), *Light rail in figures – statistics brief*, http://www.uitp.org/sites/default/files/cck-focus-papers-files/UITP_Statistic_Brief_4p-Light%20rail-Web.pdf

UNEP (2015a), *District Energy in Cities: Unlocking the potential of energy efficiency and renewable energy*. UNEP, http://www.unep.org/energy/portals/50177/DES_District_Energy_Report_full_02_d.pdf

UNEP (2015b), *District Energy in Cities: Paris case study,* http://districtenergyinitiative.org/case-studies/PARIS-CASE-STUDY.pdf

UN Department of Economic and Social Affairs (UN DESA) (2013), *World Economic and Social Survey 2013 – Sustainable Development Challenges* E/2013/50/Rev. 1 ST/ESA/344. https://sustainabledevelopment.un.org/content/documents/2843WESS2013.pdf

UN DESA (2015), *World Urbanization Prospects: The 2015 Revision. Key Findings and Advance Tables*. Working Paper No. ESA/P/WP.241. https://esa.un.org/unpd/wpp/publications/files/key_findings_wpp_2015.pdf

UN Habitat (2008), *State of the World's Cities 2008/2009*. London, Sterling, VA: UN Habitat, https://sustainabledevelopment.un.org/content/documents/11192562_alt-1.pdf

US LEAN – US Local Energy Aggregation Network (2015), *Community Choice Aggregation – Frequently Asked Questions,* May 2015, http://www.leanenergyus.org/wp-content/uploads/2015/05/CCA-FAQ.CA_.May_.FINAL3_.pdf

Vienna City Administration (2014), *Smart City Wien: Framework Strategy*, July 2014, https://smartcity.wien.gv.at/site/files/2014/09/SmartCityWien_FrameworkStrategy_english_doublepage.pdf

Vögeli, Y. and Zurbrügg, C. (2008), *Biogas in cities – a new trend?*, Sandec News, https://www.eawag.ch/fileadmin/Domain1/Abteilungen/sandec/publikationen/SWM/Anaerobic_Digestion/SN9_Biogas_Cities.pdf

Vorrath, S. (2016), *Adelaide solar leasing scheme targets rental, low-income market for rooftop PV. One Step Off The Grid*, 6 April 2016, http://onestepoffthegrid.com.au/adelaide-solar-leasing-scheme-targets-rental-low-income-market-for-rooftop-pv/

Weinert, J., Ma, C., and Cherry, C. (2007), *The Transition to Electric Bikes in China: History and Key Reasons for Rapid Growth*, World Transit Research, 1 January 2007, https://static1.squarespace.com/static/51b5da43e4b0c02e88c7f54d/t/527abe24e4b04a4b55102d0c/1383775780436/2006_UCD-ITS-RR-06-12-Weinart-1.pdf

WGBU (2016), *Humanity on the move: Unlocking the transformative power of cities*, German Advisory Council on Global Change / Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveraenderungen, http://www.wbgu.de/fileadmin/templates/dateien/veroeffentlichungen/hauptgutachten/hg2016/hg2016_en.pdf

WHO (2016), *Ambient air pollution: a global assessment of exposure and burden of disease*, http://apps.who.int/iris/bitstream/10665/250141/1/9789241511353-eng.pdf?ua=1

WRI – World Resources Institute (2016), *Accelerating Building Efficiency – Eight Actions for Urban Leaders*. World Resources Institute, http://publications.wri.org/buildingefficiency/

WSJ – The Wall Street Journal (2015), *Japanese Towns Bank on Renewable Energy. City-run companies invest in renewables after Fukushima nuclear accident undercut efforts to lessen Japan's dependency on foreign energy*, The Wall Street Journal, 20 December 2015, http://www.wsj.com/articles/japanese-towns-bank-on-renewable-energy-1450640000

WWI – Worldwatch Institute (2016), *State of the World Report. Can a City be Sustainable?*, World Watch Institute, http://www.worldwatch.org/http%3A/%252Fwww.worldwatch.org/bookstore/publication/state-world-can-city-be-sustainable-2016

ZBC – Zimbabwe Broadcasting Corporation (2016), *Solar street lighting for Hwange*, *Zimbabwe Broadcasting Corporation*, http://www.zbc.co.zw/index.php/news-categories/local-news/69361-solar-street-lighting-for-hwange

IRENA

International Renewable Energy Agency

www.irena.org