Faster and Cleaner 2

KICK-STARTING GLOBAL DECARBONIZATION: IT ONLY TAKES A FEW ACTORS TO GET THE BALL ROLLING

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Climate Action Tracker

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EXECUTIVE SUMMARY

Meeting the Paris Agreement's long-term temperature limit requires a decarbonization of the global energy system by mid-century. Decarbonizing the power sector is the first step in the comprehensive transformation of the energy system (Rogelj et al. 2015). This requires transformational changes in each sector of the energy system before 2050.

This policy brief looks at the technology trends driving decarbonization in three sectors—power, transportation, and buildings—along with empirical evidence on what can drive these rapid transitions.

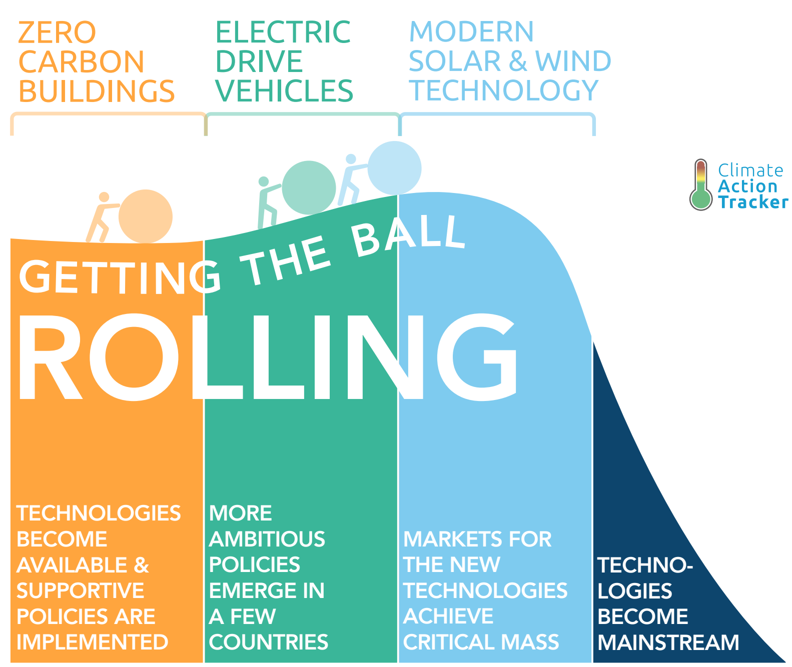
It identifies success factors that could support transitions in other areas to make the transformation scalable. The stringency of the Paris Agreement's aim to pursue efforts to limit global temperature increase to 1.5°C places significant additional pressure on the rate of transformation needed in each of these sectors.

Technological trends in these three sectors have experienced different levels of change, with the power sector witnessing the most transformation due to the rapid development of renewables that have far exceeded expectations. The accelerated uptake of electric-drive vehicles (EDVs) in the transport sector, if fully scaled, could trigger further transformation for that sector. The building sector, however, has seen limited progress and lags far behind its technological potential.

The transformational changes in the power and transport sectors have so far been triggered by policymaking efforts of only a few frontrunners —a small group of countries and regions with the right policy incentives—who have transformed the global market for the technologies and allowed the transition to move beyond the frontrunners to a wider circle. A transformative coalition of countries and sub-national actors in the building sector could accelerate the sector's decarbonization with approaches that take into account the considerable differences between the building stocks in various regions.

Lessons learned from these early-mover countries could enable these kinds of transitions to become mainstream, achieve critical mass—and transform not just the internal markets of countries participating but significantly influence development outside of those markets (Figure 1), eventually allowing for rapid global decarbonization.

Figure 1 — Stages of system change achieved by zero-carbon buildings, electric-drive vehicles, and modern solar and wind power technologies.



MAJOR FINDINGS

- **Renewable energy technologies are transforming the power sector,** which, in 2014, was responsible for almost 42 percent of energy-related CO_2 emissions (IEA 2016a), making it the largest single sector contributing to climate change.

  The increase in installed renewable energy capacity, particularly wind and solar energy, has consistently exceeded mainstream expectations. Support mechanisms in a few first-mover countries (Denmark, Germany, Spain) and regions (California, Texas), with stable government policies and financial incentives, spurred RD&D and demand. Adoption of similar policies in other countries, notably China, and now in India, led to rapid growth of low cost renewable energy products and manufacturing at scale.

  Should recent trends continue, future renewable capacity installations are set to dwarf what seemed ambitious forecasts a few years ago. Current progress is encouraging, and needs to be bolstered with policies to support the integration of high shares of renewables and replacement of CO_2-emitting fossil fuel-based electricity generation in order to meet 2050 deep decarbonization targets—in particular through corresponding grid and storage development as well as transforming electricity markets. A decarbonized power sector plays an important role in decarbonizing the transport and building sectors.

- **Electric-drive vehicles are now beginning to transform the transport sector** which, in 2013, was responsible for roughly 23 percent of global energy-related emissions, of which three-quarters were attributable to road transport (IEA 2016a). There are three commonly accepted ways to reduce emissions in the transport sector: avoiding motorized travel, shifting travel demand to more energy-efficient modes, and improving the fuel and carbon efficiency of vehicle technology.

  Although the first two have seen limited development, the third has shown progress. Increasing fuel efficiency standards for conventional internal combustion engine vehicles have played a role in this progress but are not sufficient for deep decarbonization—the solution lies in a rapid diffusion of zero-emission vehicle technologies.

  Norway, the Netherlands, California—and more recently China—have developed markets for electric-drive vehicles (EDVs) that have contributed significantly to electric car sales reaching close to a million in 2016 (Kuramochi et al. 2016), but EDV uptake needs to accelerate significantly.

  Climate Action Tracker analysis indicates that half of all light-duty vehicles on the road would need to be electric-drive by 2050 for 2°C compatibility, and for 1.5°C compatibility nearly all vehicles on the road need to be EDVs, implying that no internal combustion engine cars should be sold after roughly 2035 (Sterl et al. 2016).

- **The building sector has seen modest progress, but lags far behind its technological potential.** It represented some 19 percent of global energy-related greenhouse gas (GHG emissions) in 2010 (Lucon et al. 2014) through heating and cooling, use of appliances (including lighting), and cooking. Energy use related to heating and cooling, in particular, has shown little positive movement.

  Although there are proven technological solutions, they are applied primarily at the margin and in niche markets. If these solutions were effectively combined, they could result in zero-carbon buildings and, some argue, be cost-effective over a building's lifetime. They have failed to reach critical mass because of financial, geographical and other barriers.

  The evolution and adoption of new financial mechanisms can help increase the rate of retrofitting of buildings across geographies, both in markets with sizable existing building stocks—such as the E.U. and the US—as well as in large emerging economies such as Brazil, China and India (Energy Programs Consortium 2017). By 2050, this sector would need to see a 70–80% reduction in 2050 emissions for a 2°C compatible pathway and 80–90% for a 1.5°C compatible pathway (Rogelj et al. 2015).

- **We conclude that single countries and a diverse set of actors within them taking action in parallel has, in some sectors, led to dynamics that are shifting global markets.** Nevertheless, the pace of technology deployment is not sufficiently rapid to meet the Paris Agreement's goal of limiting temperature rise to well below 2 degrees Celsius above pre-industrial levels.

- **One way to speed up technology deployment are "transformative coalitions."** Under the umbrella of such coalitions, countries and sub-national actors interested in advancing a particular low-carbon technology can work together to create similar market dynamics. Our research shows that an important base factor in creating such dynamics is the implementation of effective policy packages.

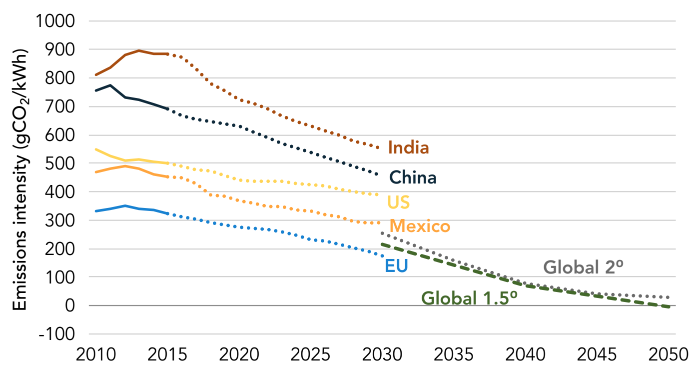
The success of low-carbon technology deployment in the power sector and partly in the transport sector would suggest that some policies may be particularly supportive. Transformative coalitions can identify and develop best practice policy packages that then can be tailored to the particular situation in each country. This strategy would ensure effective policy implementation in a number of countries, triggering a global market dynamic.

POWER SECTOR
MODERN SOLAR AND WIND TECHNOLOGY

Over the last decade, as renewable energy technology capacity installations have started to accelerate, the energy sector has begun to decarbonize in several countries. Recent developments in the deployment of modern renewable energy technologies have consistently exceeded expectations (Cronin et al. 2015). Between 2006 and 2015 the installed wind power and solar energy capacity increased 6-fold, and 35-fold respectively (IRENA 2016b). Over the same period, energy demand in many developing countries grew ever faster. Many of these countries implemented renewable energy to meet part of the rising demand, although some also increased their reliance on conventional energy sources.

This decarbonization trend is expected to intensify as renewable energy sources continue to gain market share. The dynamic is being driven by a reduction in costs: in several regions, renewable energy sources such as solar PV have reached grid parity (IRENA 2014). By 2030, solar PV is projected to become the cheapest energy generation source in most countries (BNEF 2016b). But to meet the Paris Agreement's temperature goal, the decarbonization trend must be supported by a continuation of historical growth rates in new renewable energy of 25–30 percent for the next 5 to 10 years (Kuramochi et al. 2016). Only with such rates can the power sector become essentially zero-carbon emitting by 2050 (Rogelj et al. 2015). Yet current 2030 trend scenarios for five major economies suggest that such rates will not be achieved without additional policies (see Figure 2).

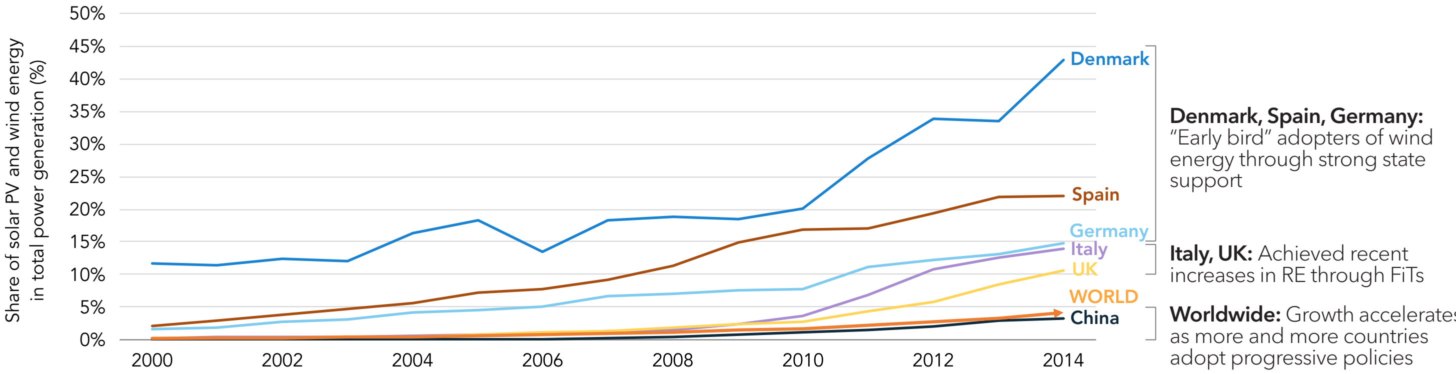
Figure 2 – Historical and projected emissions intensity of electricity (gCO_2/kWh) according to ClimateWorks Carbon Transparency Initiative (CTI) models.



Sources: Emission factor–ClimateWorks Foundation (2016); 2°C pathway (global) from Krabbe et al. (2015). Data for 1.5°C pathway adapted after Rogelj et al. (2015, 2013).

Ambitious policy frameworks implemented simultaneously in a few countries have created a momentum that has led to the recent observed growth in renewables' market share. Development of photovoltaic and wind energy was initially driven by a group of early-mover countries, including Germany, Denmark, and Spain. These actors implemented ambitious policy packages, including targets for the share of renewables in the power sector, financial support schemes such as feed-in tariffs (FiTs), and support for the development of new—and improvement of existing—technologies. These packages enabled the technologies to enter the market and, using the benefits of economies of scale, to decrease their costs.

Figure 3 – Increase in solar PV and wind energy generation in early-adopter countries.



Data source: IEA 2016a.

As shown in Figure 3, the parallel actions of a handful of countries constituted the beginnings of an informal transformative coalition, which created the momentum that led other countries to increase their own share of modern renewables in electricity generation.

By implementing ambitious targets, governments provided clear signals to investors and technology developers to invest in the new technologies. The first renewable energy targets were set as early as 1985 by Denmark. The EU's 2001 renewable energy directive included "indicative" targets for all member states. In 2005, the number of countries with targets for renewable electricity stood at 42 and by 2015 it had risen to 150 (IRENA 2016a). These targets indicated to investors that renewable technologies should attain significant market shares.

To achieve these targets, the early-adopter countries implemented policies to help renewables enter the market and compete with established technologies. A particularly successful support mechanism was the feed-in tariff (FiT) that, due to its simplicity and guaranteed return on investment, allowed several new actors–such as project developers and independent power producers, as well as "prosumers"[1]–to enter the market. Other examples of financial support schemes for renewables include tax exemptions at the industry and household level and quota obligations whereby energy suppliers must purchase set amounts of renewable energy (European Commission 2013).

Simultaneously, technology development support through research, development, and demonstration (RD&D) spending helped drive down the costs of the new technologies as manufacturing capacity surged. In OECD economies, public RD&D spending on solar PV and wind technology reached around 800 million USD/year in 2015, roughly twice the average levels in the period 1990-2009 (IEA 2016c). Although concentrated in a few countries, public RD&D spending for renewables also made a contribution to the steep decline in the cost of electricity, particularly electricity generated from solar PV (Koseoglu et al. 2013). For instance support by the Chinese state played a crucial role in driving down costs in China's solar panel manufacturing industry (Fialka 2016).

Countries implementing policy packages that included–in some form or another–targets, support policies, and technology development have experienced greater than anticipated renewables deployment and deep renewables cost decreases (Cronin et al. 2015). However, **with increasing market penetration of new capacity comes a new challenge:** large shares of intermittent renewable energy sources require increased flexibility in the energy system and new regulatory and market approaches (Papaefthymiou et al. 2014; IEA 2017).

Even though there are known technical and institutional solutions to this challenge, such as electricity storage, grid development and interconnection, and demand response, none offer a perfect solution on their own and they need to be advanced together with the appropriate regulatory and energy market. Indeed, a mix of these solutions and the appropriate long-term planning and regulatory and market framework needs to be implemented to decrease the costs of the system transformation, taking into

1 Prosumers is the term used for consumers of electricity that also sell electricity back to the grid, for instance, with solar PV on rooftops.

account an increasing coupling with demand sectors (in particular transport and buildings, but also industry). This mix will depend on local circumstances (e.g., the mix of renewables, potential for interconnections and storage).

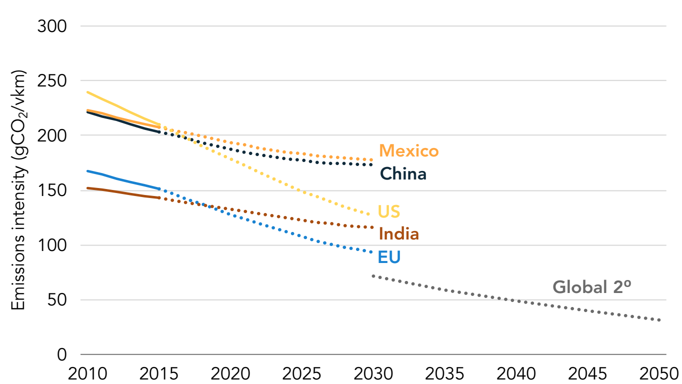
Lessons from the experiences of early-mover countries—or indeed from a new, informal or formal, transformative coalition of countries—could lead to successful policy frameworks that more efficiently and effectively support integration of renewable energy generation into a flexible grid.

TRANSPORT SECTOR

ELECTRIC-DRIVE VEHICLES

Although the recent decrease in the transport sector's carbon intensity is commendable, the improvements are insufficient to support the Paris Agreement's temperature goals, as shown in Figure 4. **Increasing fuel efficiency standards for conventional internal combustion engine vehicles is critical but not enough for deep decarbonization—the solution lies in rapid diffusion of zero-emission vehicle technologies.** These technologies, such as electric-drive vehicles, can—and should—be promoted by transformative coalitions of countries and regions with supportive policy packages.

Figure 4 – Projected fleet-average emission factor of LDVs in ClimateWorks' CTI model.

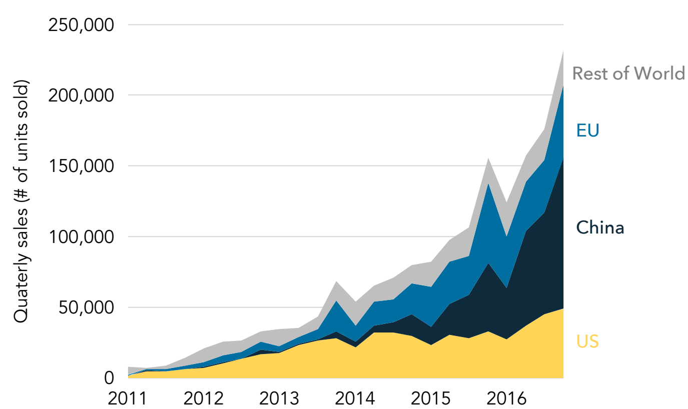


Sources: Emission factor—ClimateWorks Foundation (2016); 2°C pathway (global) adapted from Krabbe et al. (2015) with the methodology of Sterl et al. (2016). Data for 1.5 degree excluded due to lack of suitable analysis.

Note: Projections for China do not yet include Phase IV fuel consumption standards for passenger vehicles.

In recent years, demand for electric-drive vehicles has grown much faster than initially expected (Cronin et al. 2015).[2] Like modern renewable energy generation in the power sector, development of EDV markets has been led by a small number of countries. EDV uptake in the United States increased from 2011 to 2013, slowed down slightly in 2014 and 2015, and bounced back in 2016. EDV sales picked up in the EU in 2013 and in China in 2014. Now, China has surpassed both US and the EU in those sales (Figure 5).

Figure 5 – Differences in historical EDV (BEV and PHEV) quarterly sales numbers in major regions worldwide.



Data source: BNEF 2016a.

As more EDVs join the fleet on the road, infrastructure expansions become necessary. The number of slow chargers, for instance, has increased markedly in seven countries that together account for 76 percent of all slow chargers worldwide (IEA 2016b).

This decarbonisation trend in the transport sector is projected to intensify in the future as electric-drive vehicles, which are substantially more efficient than internal combustion engine (ICE) vehicles (IEA 2016b), continue to gain market share. As the power sector decarbonizes, this improvement becomes more drastic over the vehicle's lifetime. However, the extent to which the nascent EDV market will continue to grow is uncertain.

2 We consider here both battery electric vehicles (BEVs) and plug-in hybrid vehicles (PHEVs).

Trend scenarios for several major economies suggest that EDV market penetration rates may not reach levels in line with Paris Agreement temperature goals by 2030 without additional policies, although current growth rates have exceeded expectations (Cronin et al. 2015). For 2°C compatibility, half of all light-duty vehicles (LDVs) on the road would need to be electric-drive vehicles by 2050 (assuming simultaneous strong improvements in ICE vehicle standards), and for 1.5°C compatibility basically the entire fleet should be zero-emission, implying that no ICE cars can be sold after roughly 2035 (Sterl et al. 2016).

Ambitious policy packages implemented simultaneously in multiple countries have created today's observed EDV growth. Although the global market for electric-drive vehicles is dominated by the EU, China, and the US, which together account for some 80 percent of the global EDV stock (IEA 2016b), it is smaller countries such as Norway and the Netherlands, and subnational actors such as California, that have achieved the highest EDV penetration rates. Their success has come through policy packages that led to dissemination of the technology beyond niche markets. In their effort to increase EDV shares, they started to develop targets, combined financial incentive schemes with behavioral policies, supported the expansion of EV charging infrastructure, and increased their RD&D spending.

The most successful policy package is found in Norway, which combines financial incentives for EDV users with behavioral incentives. In the Netherlands, taxation rates for leased electric-drive vehicles are based on tank-to-wheel emissions levels; full electric-drive vehicles pay the lowest rate. In China, the combination of government purchase subsidies and exemption from vehicle ownership restrictions in several major cities has precipitated a boom in EDV sales (Wang et al. 2017). Several other countries, such as Germany, France, Sweden, and the UK, provide purchase subsidies for EDVs (Nijland et al. 2016). In the Netherlands, sales have peaked when policies to tighten financial incentives are imminent, which shows the high sensitivity of EDV uptake to financial support.

In parallel, governments are starting to implement targets to increase investment certainty. Several European countries and US states have targets for the number of electric-drive vehicles on the road within the next 5 to 10 years. In 2016, the Dutch Parliament passed a motion to ban non-EDV sales after 2025 (NRC 2016), although this motion has not yet made it onto the government agenda (Ministerie van Economische Zaken 2016). China is considering a minimum EDV quota in new car sales from 2018 onward (Bloomberg 2016). If implemented, the quota would put pressure on car manufacturers for whom China is an important market.

Technology development support, especially public RD&D spending, has picked up. Ten years ago, in 2007, public spending on RD&D for EDV systems and vehicle battery and storage technologies was almost negligible in comparison to the sum spent on modern renewable energy technologies. This spending has risen rapidly as the need for better, cheaper, and more efficient electric-drive vehicles has become ever more apparent. Public spending on EDV RD&D in OECD economies is now on the same order of magnitude as that for solar PV and wind energy technology—100-200 million USD/year for the former as compared to roughly 800 million USD/year for the latter (IEA 2016c).

As public RD&D investment has increased, the cost of EDV technology is expected to decrease. From 2008 to 2016, the price per unit of stored energy for EDV battery units decreased by a factor of four, while battery energy density increased by a factor of three to four, bringing cost parity with conventional cars ever closer. Today, increasing numbers of companies are running their own "EDV line," indicating that they see an opportunity in long-term profitable strategies for EDV technology development.

As EDV sales grow substantially in a number of countries, the kinds of policy packages and legislation needed to increase EDV market share is becoming clear. Such policy packages have proven effective in some countries and regions and could, if further supported, lead the market to flip as it did in favour of modern renewable energy technology. As increasing numbers of countries, and sub-national actors, support electric-drive vehicles, they could form a transformative coalition, coordinating efforts to help the technology to diffuse. Global penetration of electric-drive vehicles (currently a mere 0.1 percent) will increase as the technology spreads and becomes mainstream, but whether the transport sector evolves in a way that is compatible with the Paris Agreement's long-term temperature goals depends on the speed at which this transformation occurs.

BUILDING SECTOR
ZERO-CARBON BUILDINGS

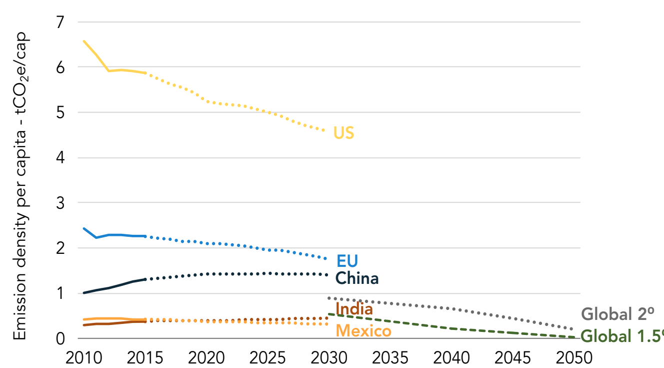
Decarbonization is just starting in the transport sector and is well under way in the power sector, but it has yet to take off in the building sector. A pervasive set of barriers has meant limited progress despite the technological possibilities. Overcoming these barriers requires a concerted effort to implement existing policies and to develop new mechanisms that enable transformation, both at the national and the sub-national level. From 1990 to 2010, annual emissions from the sector more than doubled to over 9 $GtCO_2e$. This growth has come overwhelmingly from indirect emissions, mostly from increased electricity use, which accounts for 6 $GtCO_2e$. Meanwhile, direct emissions (i.e., emissions from fuel use in buildings, mostly for heating and cooking) have remained steady at 3 $GtCO_2e$ (Lucon et al. 2014).

The growth in emissions from power use in buildings is linked to a rapid increase in the use of electrical appliances. **Great strides have already been made in improving the efficiency of such appliances:** energy savings are now balancing out demand growth in OECD regions, leading to a stagnation in electricity use of buildings there. Stringent efficiency standards, ideally adopted globally, in concert with a decarbonizing power sector, spell out a path to phasing out indirect emissions in buildings over the coming decades.

This cannot be said about direct emissions. In developed regions, such as the EU and the US, the emissions intensity per floor area and per capita have declined only modestly over recent decades. Projections of current policies show this trend continuing (see Figure 6). **However, to steer the building sector towards a scenario compatible with the Paris Agreement temperature limit, more ambitious efforts are required, especially when it comes to direct emissions.** All new buildings in the OECD regions built after 2020 would have to be zero-carbon buildings,[3] and only a few years later, non-OECD regions would have to follow suit. This transition would have to be complemented by an immediate scale-up of deep renovation efforts of 5 percent of floor space per year in OECD regions and 3 percent per year in non-OECD regions (Wouters et al. 2016).

For comparison, current renovation rates in the EU are approximately 1 percent per year (Renovate Europe 2017). Given the current policy outlook, the feasibility of such immediate-action scenarios is low, illustrating the urgent need for a set of leading countries to kick start a rapid transformation in the building sector. Many countries with diverse national circumstances have developed their own policies focused on building energy performance (e.g. Chile, Indonesia, Singapore, etc.), however these often have less ambitious emissions intensity targets than is consistent with long term climate goals (UNEP 2016). Delay in action places additional pressure for emissions reductions on other sectors and also increases the need for negative emissions technologies in the long term.

Figure 6 – Historical and projected building sector emissions intensity (includes both direct and indirect emissions) per capita in tCO_2e/cap



Sources: ClimateWorks' CTI Model from ClimateWorks Foundation (2016); 2-degree pathway represents the median of 2°C-compatible scenarios from IIASA (2015). 1.5 degree pathway adapted after Rogelj et al. (2015, 2013).

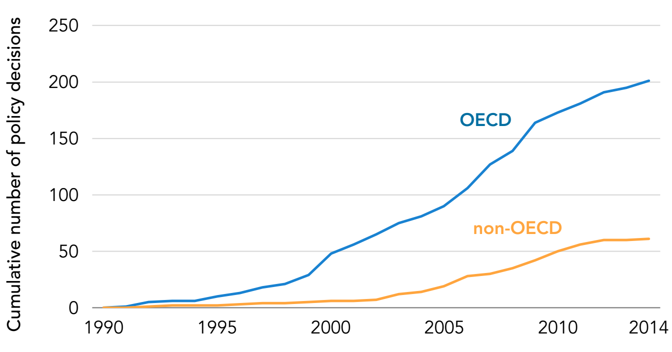
The building sector's underwhelming decarbonization rate—both observed and projected—contrasts starkly with the maturity of the technological solutions available. We have known how to build zero-carbon buildings for several decades, and have seen recent advances in technology, architecture and know-how—mainly with regards to heating and cooling (UNEP 2016). The clear majority of zero-carbon buildings are

3 In this briefing we define a "zero-energy building" as a building that generates as much renewable energy on-site as it consumes annually. This can also be referred to as a "net zero-energy building". Zero-energy buildings are in general also zero-carbon buildings. Non-zero energy buildings can also be zero-carbon buildings through the use of renewable energy generated off-site.

located in Europe and North America, with projects in nearly all states in the US and in parts of Canada, and these buildings are starting to appear all over the world (New Buildings Institute 2016). Despite the rising numbers, zero-carbon buildings represent a negligible share of total building construction worldwide.

Many building-related policies and targets have been implemented in OECD countries, and non-OECD countries are also responding. These policies have resulted in the gradual downward trend in emissions intensity per floor area. While the number of policies has grown, the rate of new policy adoption has slowed ever since 2009, the year of the Copenhagen Climate Change Conference (Figure 7). Moreover, the number of national policies on the books says little about their effectiveness in realizing energy and carbon savings, particularly through sub-national level implementation. Typically, limited human and financial resources for compliance monitoring and enforcement will still be the key barrier to the successful implementation of buildings policies (UNEP 2016). In a well-designed policy package, various elements (e.g., building standards, information instruments, and financial incentives) can support and reinforce one another. The interactions among robust sets of policies increase their overall effectiveness.

Figure 7 – Number of building sector climate policy decisions globally



Source: NewClimate Institute (2016).

Note: This number is not reflective of all countries and regions, but it serves to indicate the scale of the increased uptake of related policies.

Standards for new buildings and retrofits are not sufficiently ambitious, resulting in buildings that will need to be retrofitted—again—before the middle of the century, even in frontrunner regions like the EU.

The EU Energy Performance of Buildings Directive (EPBD), implemented in 2010, requires all buildings to be nearly zero-energy buildings (nZEBs) by the end of 2020. It also mandates standards for the renovation and retrofit of existing buildings. The EU Energy Efficiency Directive (EED) aims to increase the rate of renovations to central government-owned and occupied buildings by at least 3 percent a year (European Commission 2016). Since the EPBD's adoption, the share of new buildings constructed according to—or better than—the national nZEB definition has risen significantly, and some member states have exceeded the EPBD's minimum requirements. However, in other member states, the share has remained negligible (Enerdata 2016). Moreover, member states have set their own definitions of nZEB to reflect their national circumstances and cost-optimal levels. The standards' ambition levels vary and must be increased to be compatible with a 1.5°C or well below 2°C pathway.

Decarbonization in the building sector is not accelerating. Pathways to spread decarbonization solutions from one region, state or even city to the next are often not as straightforward in the building sector as in other sectors. Technologies in the power and transport sectors—such as electric vehicles and photovoltaics—can be applied worldwide, but in the building sector, space heating and cooling solutions still need to be tailored to the local climate, culture, and geography. An important distinction between interventions in the building sector and those in the power and transport sectors is that in the latter sectors, new technologies replace incumbent technologies unit for unit, whereas in the former, technologies gradually move toward zero carbon. In most cases, today's renovation is only one in a series of renovations required by mid-century.

Despite the significant savings and non-monetary benefits resulting from various energy efficiency investments in buildings, a persistent set of barriers mean investments often fail to materialize. The financial barriers include high upfront costs, the so-called principal-agent problem and the need for innovative energy efficiency loan products. Lack of awareness, financing, and know-how can all result in low-ambition policies and measures and the lock in of suboptimal technologies. The provision of information, technology transfer, securitization and new financial mechanisms and capacity building therefore play critical roles in incentivizing energy efficiency investments in buildings.

A formal and global commitment to buildings' energy efficiency is likely to be advantageous (IEA 2013). A transformative coalition of countries and sub-national actors in the building sector could accelerate the sector's decarbonization with approaches that take into account the considerable differences between the building stocks in various regions. Non-state-actor initiatives could join forces and drive such a coalition. The existence of initiatives such as the World Green Building Council and the Global Alliance for Buildings and Construction and Architecture 2030 as well as independent initiatives through groups such as C40 and the City Energy Project indicate growing support for voluntary collaboration, and private sector buy-in provides a clear signal to governments that more ambitious policy action is welcome.

Our analysis shows that we lack two components for achieving critical mass for decarbonization in the building sector: policy ambition and investment in capacity and new financial mechanisms to implement stringent standards. To be successful, a transformative coalition would need to work jointly with governments in various countries to ensure the implementation of ambitious and coordinated policy packages—including building codes and standards as well as financial and information instruments—in line with the coalition's objectives. The close cooperation of public authorities, finance providers, and the building sector will be needed to adapt the approaches to specific national or regional circumstances.

CONCLUSIONS AND DISCUSSION

This brief describes observed trends in the spread of modern solar and wind technology, electric-drive vehicles, and zero-carbon buildings and explains how these trends have been shaped by policy setting and innovation. Mainstreaming of modern renewables technology is well under way in the power sector, and it appears to have begun with electric vehicles in the transport sector, but zero-carbon buildings are at the starting block in global uptake.

We argue that a major determinant of whether a new technology achieves a competitive market position is the presence of bold action by a few countries with long-term targets that send a market signal, supporting policy packages, and efforts in innovation, research, and development that continually improve and reduce the cost of the technology. With these three elements in place, the technology can spread to other regions and support global decarbonization.

This template has worked for **modern renewables** (solar and wind), which were kick-started by a few frontrunner countries and regions' demonstration of the effectiveness of support policies in driving demand and leading to ever better and cheaper products. The next challenge in the power sector is ensuring that existing power systems are adapted to cope with variable energy sources and large numbers of distributed providers. Countries, regions, and states should be learning from one another about the effectiveness of different solutions and necessary policies. Such cooperation in the framework of transformative coalitions could significantly lower the costs of the global transition to low-carbon sources of energy in the power sector and to options for integration of those sources in energy-demand sectors (Kuramochi et al. 2016).

In the transport sector, frontrunner countries and regions are trying out various types of policy packages to incentivize **electric-drive vehicle** uptake, with different degrees of success. Now is a critical moment to ensure continued momentum to lower costs and support additional deployment.

In the building sector, ambitious targets and solid support policies for **zero-carbon buildings** are generally lacking, although there are examples of ambitious policies leading to faster development of technologies and reduced prices. Even though there is no one-size-fits-all technology, lessons can be learned from successful examples. A transformative coalition of countries and sub-national actors can kick-start broader and faster technological change and decarbonization in the sector.

Other decarbonization opportunities are ripe for a transformative coalition approach. Such an approach could create a global market for low- or no-carbon **appliances, industrial products** such as steel and cement, and **food products**—all of which are amenable to a one-size-fits-all technological change.

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