

The Low Carbon Economy

GS SUSTAIN equity investor's guide to a low carbon world, 2015-25

We explore the low carbon economy, now a growing, \$600 bn+ pa revenue opportunity. Between 2015 and 2020, solar PV and onshore wind will add more to global energy supply than US shale oil production did between 2010 and 2015. By 2020, six in ten lightbulbs will be LEDs; and our analysts expect carmakers to sell 25 million hybrid & electric vehicles by 2025, 10x more than today. We estimate that these technologies will save >5 Gt of CO₂ emissions per annum by 2025 and could help global emissions to peak earlier than expected around 2020, with ripple effects felt across our global coverage.

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... (3) can contribute to market fragmentation ...	45
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The prices in the body of this report are based on the market close of November 27, 2015.

This report is a modified version of The Low Carbon Economy, originally published on November 30, 2015.

The Low-Carbon Future in Numbers

A NARROW FIELD

4

The number of **low-carbon technologies** that have the most potential to move markets and reduce emissions in the next 10 years. (Page 14)

A CHANGING MARKET

90%

The amount of **market capitalization the four biggest US coal companies lost** in 2015. These companies struggled as coal prices fell and clean energy options became more competitive. (Page 48)

CARBON COSTS...

39

The number of **countries that price carbon**. At the company level, 450+ now use internal carbon pricing to guide investment. (Page 31)

...BUT NOT ENOUGH

12%

The percentage of **global emissions** that existing carbon schemes cover. (Page 31)

POWERING DOWN

2025

The year the UK government plans to shut down its **last coal-fired power plant**. (Page 5)

REGULATIONS AHEAD

**118g/
km**

The **vehicle fleet CO₂ limit** that China has set for 2020. The current US limit is a more-forgiving 146g/km. (Page 23)

A BETTER BULB?

>85%

The amount of **energy an LED bulb saves** compared to a traditional incandescent bulb. (Page 20)

A BIGGER SHARE

70%

The expected **LED lamp market share** in 2020. (Page 20)

GOING GREEN

**\$240
billion**

The expected market opportunity for **electric vehicles and plug-in hybrids** by 2025. (Page 15)

CLEANER CARS CATCHING ON

16%

The electric and plug-in hybrid **share of Norway's 2015 auto sales**. That's 40x the global average. (Page 37)

RENEWABLES' ROLE

**6.2
mbpd**

The amount **solar PV and wind will contribute to the global energy supply** between 2015 and 2020, in oil terms. The US shale oil boom added 5.7 million barrels per day. (Page 22)

A POWERFUL SOURCE

29%

The **share of Iowa's 2014 electricity demand satisfied by wind**. Wind powers the equivalent of more than 16 million homes across the US. (Page 21)

CAPACITY COMMITMENTS

**150
GW**

The total **solar capacity that China is targeting for 2020**. When the country first adopted a solar target in 2007, it committed to only 1.8GW. (Page 34)

LOWER COSTS, GREATER INTEREST

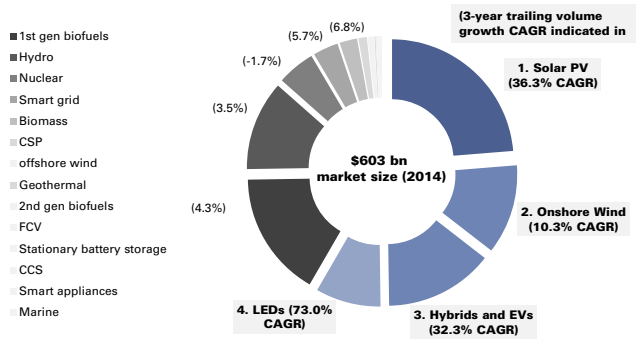
**\$1
trillion**

The **global investment in wind and solar** capacity between 2009 and 2014. Unsurprisingly, this corresponded to a significant decrease in the costs of these technologies. (Page 21)

The Low Carbon Economy – our thesis in six charts

Exhibit 1: Four front runners combining growth and scale dominate low carbon technologies

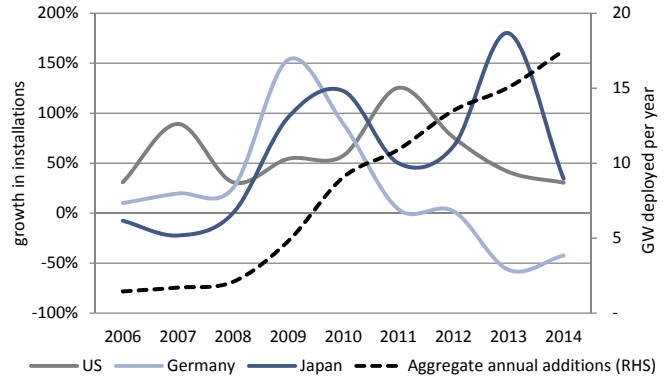
LCE technologies by market size and 3-year growth CAGR



Source: BP, UNEP, OECD/FAO, IHS, Advanced Energy Economy, Goldman Sachs Global Investment Research.

Exhibit 2: Policy pressure is intensifying although it remains volatile at the national level

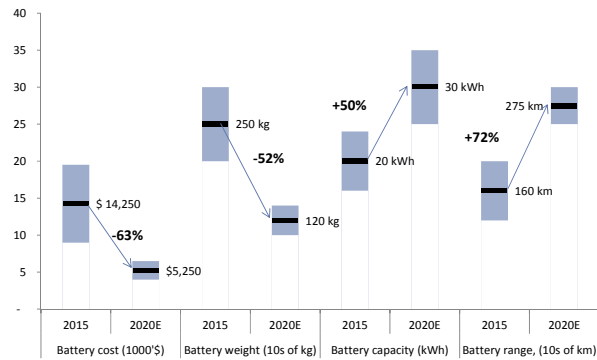
Solar PV growth in the US, Japan, Germany, 2006-14



Source: Goldman Sachs Global Investment Research.

Exhibit 3: Low carbon technologies achieve rapid performance improvements and cost reductions...

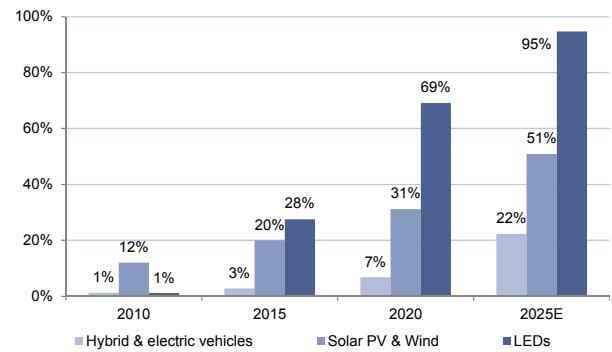
Battery cost reduction/performance improvements



Source: NEDO, Goldman Sachs Global Investment Research.

Exhibit 4: ...and are taking market share in autos, power generation and global lighting...

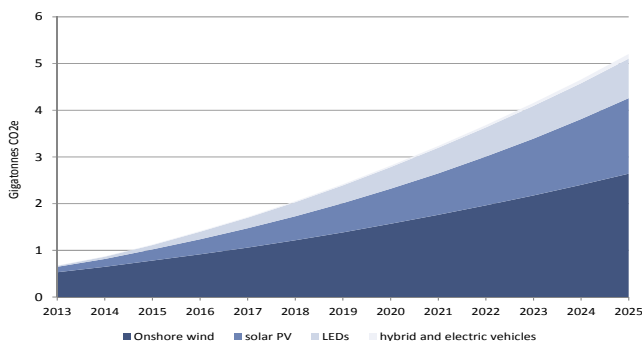
Market shares in autos, power generation and lighting



Source: Goldman Sachs Global Investment Research.

Exhibit 5: ...saving >5 Gt CO₂e emissions pa by 2025

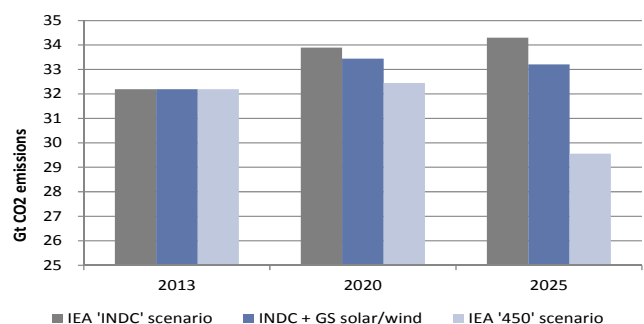
Avoided emissions from four LCE technologies



Source: IEA, EPA, ICCT, BP, Goldman Sachs Global Investment Research.

Exhibit 6: Global CO₂ emissions may peak earlier than in common scenarios

CO₂ emissions in IEA 'INDC' and '450' scenarios, and INDC scenario with our solar/wind forecasts



Source: IEA, Goldman Sachs Global Investment Research.

Overview: A growing Low Carbon Economy

As world leaders gather for the Global Climate Summit in Paris, we highlight the impact of tightening emissions regulation on our coverage. This structural challenge is reflected across the GS SUSTAIN approach, from our Governance and Risk Management framework (GRM) to the Competitive Positioning frameworks of our sector teams in key sectors such as autos and utilities.

In this report we focus on how evolving low carbon technologies are beginning to reshape global industries. We identify LEDs, solar PV, onshore wind, and hybrid & electric vehicles as clear front runners in the emerging low carbon economy, now a \$600 bn+ pa revenue opportunity. As they benefit from growing regulatory pressure and cost reductions, these technologies are taking market share in lighting, power generation, and autos. In the process they are not only delivering emission reductions at the Gigatonne scale, but also changing competitive dynamics, with ripple effects across our coverage.

2015 shapes up as a watershed year for the low carbon economy. Wind and solar are on track to exceed 100 GW in new installations for the first time and on our estimates now save a gigatonne in CO₂ emissions per year. In autos, the VW scandal has highlighted growing emissions-related compliance and reputational risks. In coal, the market cap of the top four US coal companies has dropped by over 90% in 2015 as they have struggled with a combination of cheap gas, renewables, emission regulations and weak exports; and in the UK, the government has announced that coal-fired power generation will cease altogether by 2025.

This is not the beginning of the end for fossil fuels; but marks the end of the beginning for the low carbon economy. Oil, gas and coal generate two-thirds of electricity, power over 75% of industry and fuel 95% of the global transport fleet. However, they also emit c.32 gigatonnes (Gt) of CO₂e per annum, and public pressure to find ways to reduce this is increasing (a theme we have highlighted in past reports, see GS SUSTAIN *Change is coming: A framework for climate change* May 2009; GS SUSTAIN *What is the climate for change?* October 2013). Solutions range from switching from coal to less polluting gas, boosting efficiency (e.g. in cars), as well as introducing transformative low-carbon technologies, the focus of this report.

While the policy debates often center on 2030 forecasts and 2050 targets, we expect the greatest market dislocations to occur between 2015 and 2025. We estimate that in 2015-2020, new wind and solar installations will add the oil equivalent of 6.2 mn barrels per day (mbpd) to global energy supply. This is more than the 5.7 mbpd US shale oil production added over 2010-15. Our analysts expect China to add 23 GW coal and 40 GW gas power capacity by 2020, but this compares to 193 GW of wind and solar the country will add at the same time. In lighting, our analysts forecast that LEDs will account for 69% of light bulbs sold and over 60% of the installed global base by 2020. In autos, our analysts expect carmakers to sell c.25 mn hybrid and electric vehicles by 2025 –10x more than today and a \$600 bn+ revenue opportunity.

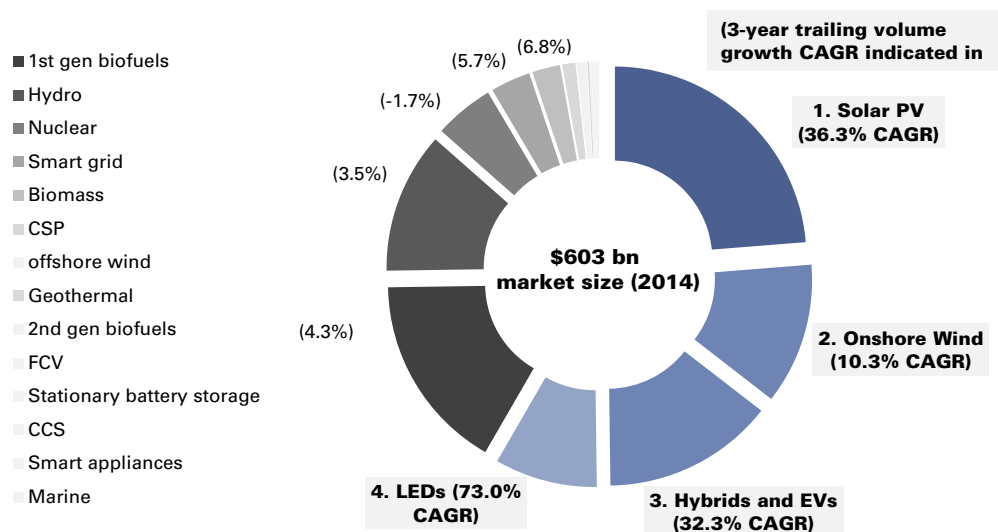
In this report we explore where and how the low carbon economy is taking shape, and how it is likely to impact emissions and competitive dynamics. At GS SUSTAIN, we see the low carbon economy as a growing, structural trend shaping our coverage, which we find reflected in some of our Competitive Positioning frameworks for relevant industries (e.g. in autos and utilities). We also see growing reputational and compliance risks, which we try to assess as part of our GS SUSTAIN Governance and Risk Management (GRM) framework. In this report we focus on how technology and regulation will change markets in the next ten years, and leave the analysis of evolving global environmental challenges and policy recommendations to better-positioned observers.

Key findings

In the crowded field of low carbon technologies, four front-runners stand out...

We assess commonly discussed low carbon technologies to determine which could meaningfully move markets and emissions over the next 5-10 years. LEDs, onshore wind, solar PV, and hybrid & electric vehicles stand out by combining market scale (>10 bn pa revenue opportunity) with a consistent track record of volume growth (>10% 3y trailing CAGR).

Exhibit 7: Among low carbon technologies, four front-runners combine scale and growth...
Annual sales in lamps, vehicles, fuels, smart appliances, smart grid equipment, new installations in power generation & CCS capacity



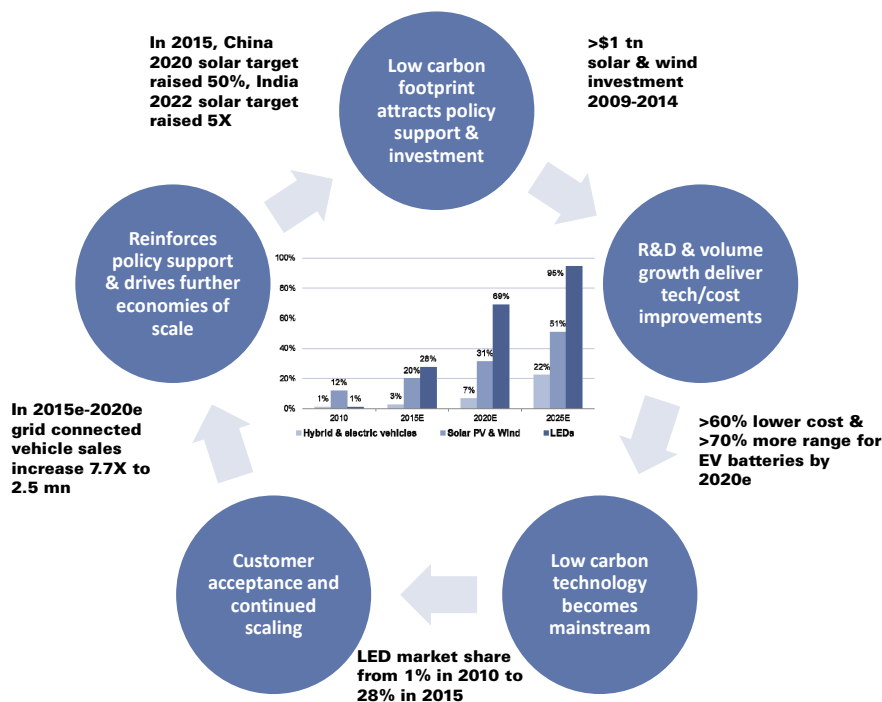
Source: BP, UNEP/Bloomberg New Energy Finance, OECD/FAO, IHS, Advanced Energy Economy, Goldman Sachs Global Investment Research.

We believe these are the low carbon technologies that are likely to have the greatest global impact over the next decade. Others include: (1) mature technologies with relatively slow, stable growth trajectories (nuclear and hydro are growing in line with or below electricity demand); (2) early stage technologies that see growth but still lack scale (our analysts estimate that fuel cell vehicles will grow at an 80%+ CAGR out to 2025 but by then will still have <1% market share); and (3) technologies that are gradually losing regulatory support (e.g., carbon-capture and storage (CCS) or biofuels, that have seen subsidy cuts and stagnating private sector investment).

...with a winning mix of policy, scale, and technical & cost advances...

We see a combination of policy support, market acceptance, technical advances and cost reductions explaining the success of these technologies. LEDs, onshore wind, solar PV, and hybrid & electric vehicles are at different stages of their development, but in each case we see similar dynamics at play:

(1) A low carbon footprint attracts regulatory incentives and investment (2009-14 solar & wind investment was >\$1 tn). **(2)** R&D and rapid volume growth deliver cost reductions and performance improvements (we expect >60% lower cost and >70% range improvements for EV batteries by 2020). **(3)** This transforms niche applications into viable alternatives to incumbent technology (LED market share has gone from 1% in 2010 to 28% in 2015), which **(4)** drives customer acceptance and allows continued scaling (we expect sales in grid connected vehicles to increase 7.7x by 2020 to 2.5 mn vehicles). In turn, this **(5)** reinforces regulatory support and drives further cost reductions (China just increased its 2020 solar target by 50% to 150 GW, India raised its 2022 target 5x to 100 GW).

Exhibit 8: Our front runners benefit from a mix of policy, technology and scale

Source: Goldman Sachs Global Investment Research.

...although they are not necessarily the cheapest way to cut carbon

This virtuous cycle drives rapid growth and commercial success, even if these technologies are not necessarily the cheapest or fastest near-term solutions to reducing emissions. Coal-to-gas (C2G) switching or energy efficiency measures could, for example, deliver emission savings at relatively low cost and at significant scale. Existing regulatory and market incentives however are not necessarily sufficient to drive implementation of these well-understood solutions. In the US, C2G switching has led to a significant drop in emissions as cheap gas has replaced coal. Falling gas prices in combination with meaningful carbon pricing could bring similar benefits in Europe and Asia (*Heat Sensor: Towards a new LNG equilibrium*, November 5, 2015).

Evolving battery technology could become a strategic linchpin

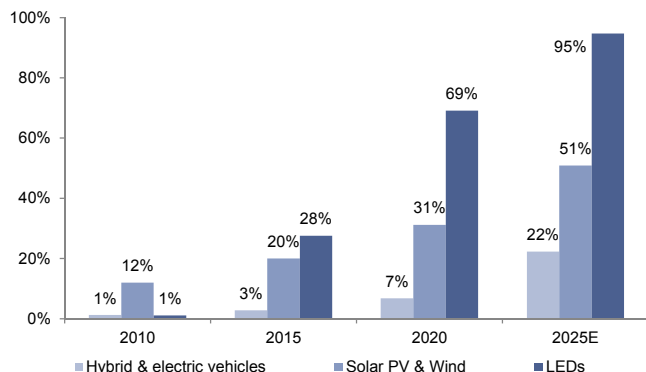
Rapidly advancing battery technology is shaping up to be a strategic linchpin for the low carbon economy. Large-scale investment is expected to bring significant cost reductions and performance improvements for lithium-based batteries (*The Great Battery Race: Framing the next frontier in clean technology*, October 18, 2015). Delivering on this potential is not only critical to support a market breakthrough of grid connected vehicles. It could also become a game-changer for the economics of wind and, in particular, solar power, and could create material upside to current growth projections.

We see low carbon technologies reshaping competitive dynamics...

Collectively LEDs, onshore wind, solar PV, and hybrid & electric vehicles present a set of breakthrough technologies that are rapidly taking market share in global lighting (69% by 2020 vs. 28% today), new power generation (51% by 2025 vs. 20% today), and autos (22% in 2025 vs. 3% today). This creates significant new opportunities. Solar and wind installations are now a \$200 bn+ pa market and our analysts project grid-connected vehicle sales growing from c.\$12 bn in 2015 to \$88 bn by 2020, and \$244 bn by 2025.

Exhibit 9: Low carbon technologies are making rapid inroads across lighting, power, and autos...

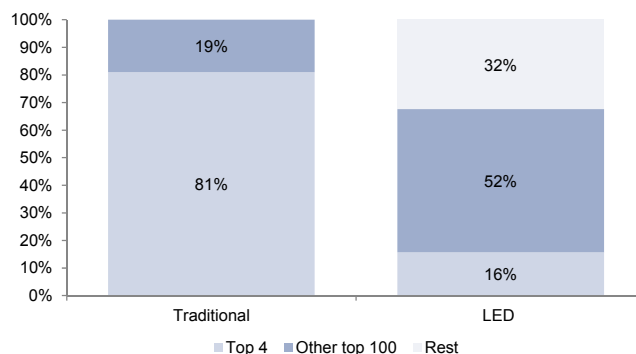
Market shares of low carbon technologies in autos, power generation and lighting



Source: Goldman Sachs Global Investment Research

Exhibit 10: ...and reshaping competitive dynamics

Market share in the lighting industry



Source: CSIL 2011, Goldman Sachs Global Investment Research

...with parallels to other sectors in the grip of fast-paced tech change...

As they take market share, these technologies are also transforming competitive dynamics; with parallels to other industries in the grip of fast-paced technological change, from retail (e-commerce) to oil E&P (shale technology) (see *GS SUSTAIN: Germany AG: Don't look back*, September 16, 2015). Market fragmentation is one common symptom. In lighting, four companies used to dominate with >80% market share. In LEDs, the four largest producers control just 16%. In solar power, we see similar dynamics with the four largest PV manufacturers controlling just 22% of supply.

A shift in technology can place a strain on market incumbents, lowering their margins and forcing them to make large investments in rapidly evolving technologies. It also often attracts a new set of competitors, often with radically different business models. We see such low-carbon led disruption now slowing in lighting, in full swing in the power sector, and still in the early innings in autos (see *Global Automobiles: Cars 2025L Vol. 2: Solving CO₂ - Engines, Batteries and Fuel Cells* August 5, 2015).

...and ripple effects across our global coverage

We see ripple effects from the growing low carbon economy across our global coverage. In basic materials, this contributes to the structural decline in seaborne coal demand (see *Heat Sensors: Thermal coal reaches retirement age*, January 23, 2015). Meanwhile, lithium, which is a critical raw material for the battery supply chain, is among the few commodities that have managed to escape the broad decline in commodity prices. Similarly, companies with exposure to wind power are among the few in the capital goods sector that have managed to avoid the global decline in capital expenditure (see *Fortnightly Answers Questions: Where are the capex hotspots?* November 23, 2015).

We also see mounting emissions-related compliance costs and reputational risks across our coverage (something we try to reflect in our GS SUSTAIN Governance and Risk Management metrics, see *Governance and Risk Management – expanding coverage, narrowing focus*, March 1, 2015). This is particularly relevant in carbon-intensive heavy industries such as cement, steel, chemicals, and paper & pulp, where public scrutiny and regulatory costs are increasing. However, we believe that this is also an increasingly important factor in consumer-facing businesses with large carbon footprints such as airlines, where reputational risks can be material.

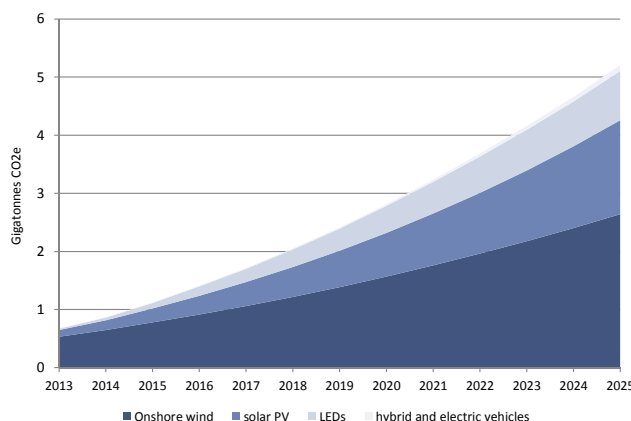
Emissions: Beginning to bend the curve

It is no coincidence that lighting, power and autos are at the forefront of the low carbon economy; with power generation and transport accounting for over half of energy-related CO₂ emissions and lighting consuming 15% to 20% of electricity.

As onshore wind, solar PV, LEDs and grid-connected vehicles continue to scale, they deliver material emission savings. For these technologies we estimate that the installed base at the end of 2015 will help to save roughly 1.1 Gt of CO₂ emissions per year– up from 0.87 Gt at the end of 2014. We forecast that these emission savings could increase to 5.3 Gt CO₂e per annum by 2025. Low carbon technologies in these industries offer no ‘silver bullet’ to rein in CO₂. However, our analysis indicates that they could contribute to an early peak of global CO₂ emissions around 2020 – rather than continued steady growth to 2025, as anticipated by mainstream scenarios.

Exhibit 11: Low carbon technologies could save >5 Gt CO₂ emissions pa by 2025...

Annual emission savings from four low carbon technologies



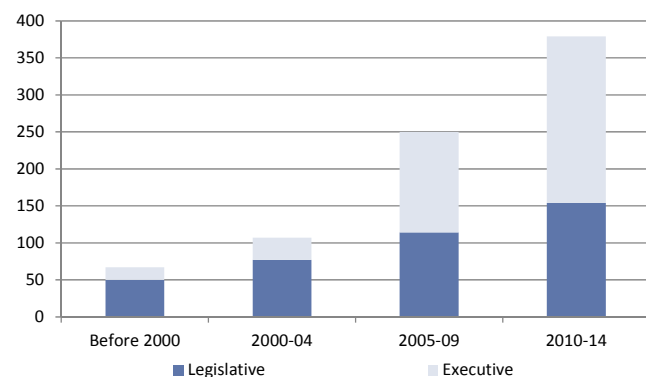
Source: IEA, EPA, ICCT, BP, Goldman Sachs Global Investment Research.

Low carbon regulation: Policy will remain an unstable patchwork

While we see regulatory pressure continuing to intensify in 2015-25, we expect the global policy landscape to stay fragmented and volatile. Key incentives will continue to:

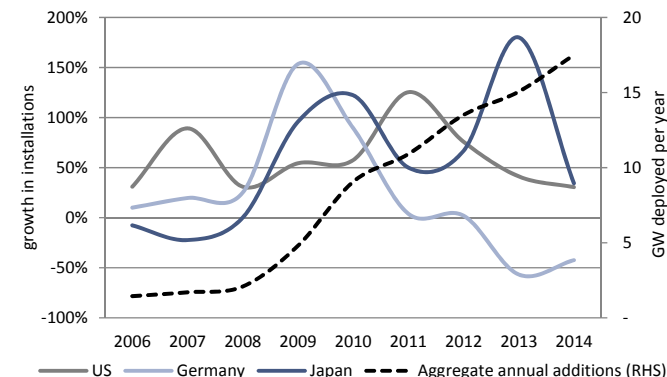
- be established at the national (and in some cases sub-national) level, rather than in multilateral negotiations. Key markets (China, EU, select US states) remain regulatory ‘pressure points’, with disproportionate global influence;
- be piecemeal, with incentives tied to specific sectors and technologies. Despite inherent efficiency advantages, carbon pricing is likely to remain one regulatory instrument among many, with limited coverage and relatively low price levels;
- be subject to frequent changes driven by (a) continued adjustment of policy to evolving technology and market conditions, (b) political controversy, and (c) regulatory innovation and contagion.

Exhibit 12: Regulatory pressure keeps increasing...
national laws & regulations related to CO₂ emissions



Source: London School of Economics, Goldman Sachs Investment Research.

Exhibit 13: ...although it remains volatile across countries
Solar PV growth in the US, Japan, Germany, 2006-14



Source: Goldman Sachs Global Investment Research.

What to expect from Paris?

We emphasize that negotiations do not aim to produce a global rulebook and have already achieved their most important goal: major advanced and emerging economies have presented new, relatively ambitious national plans to cut emissions and promote low carbon technologies. Negotiations will focus on how these voluntary pledges will be reviewed (though not enforced) and what support poorer countries will get in implementing them. Leaving aside an unlikely (but possible) last minute breakdown in negotiations, we see limited scope for surprises: any agreement is likely to be hailed as success, while we see little potential for major additional commitments.

Long-term policy trends for our front-runner technologies

LEDs

Policy will now take the backseat in LED deployment, following mandatory phase-outs for key incumbent technology (incandescent light bulbs) in key markets, including the EU, US, and China. Consumer preferences and commercial considerations will dominate deployment, with policy (such as the planned EU 2018 halogen ban or growing LED support in India) offering only incremental upside.

Solar PV and onshore wind

We see regulation on solar and wind being shaped by two conflicting trends as these technologies become increasingly competitive. (1) We expect governments to continue to revise solar and wind targets upwards. This creates upside particularly in emerging markets, where renewables are seen as an increasingly attractive option to meet growing energy demand. (2) We see growing downside risks as governments try to wean solar and wind off subsidies. We also expect growing attempts to shoulder renewables with part of the cost of maintaining the grid and providing back-up capacity. Frequent policy shifts are likely in our view as politicians try to navigate these tensions.

Hybrid and electric vehicles

We see hybrid and electric vehicles as the technology with the greatest potential upside from government regulation. In the near term, they are likely to benefit as regulators step up the enforcement of emission rules in the wake of the VW scandal. In the medium term, we also see a growing trend towards incentivizing electric vehicles and plug-in hybrids at the expense of ordinary hybrids, something we already see playing out at the subnational

level (e.g. in Beijing, London, California). This could include the deployment of charging infrastructure, benefits such as free parking and the right to use bus lanes, as well as further tax exemptions and subsidies.

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Low carbon technology: Taking off the training wheels

Low carbon technology: Taking off the training wheels

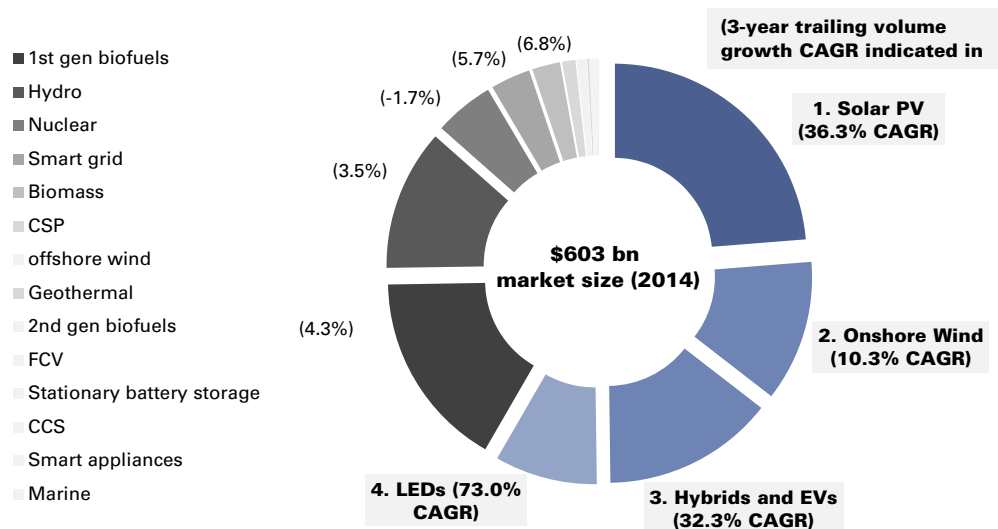
We see LEDs, on-shore wind, solar PV and hybrid & electric vehicles as the first wave of low carbon technologies that have the potential to begin “bending the emissions curve”. We believe investors should focus on these front-runners that benefit from a combination of (1) continued strong regulatory support; (2) the ability to rapidly scale up to mass-market; (3) a clear pathway to full cost competitiveness with incumbent technologies; and (4) growing customer acceptance. They are at various stages of maturity: LEDs are already past the “point of no return” where little additional regulatory support is needed; solar and wind which are getting closer; and grid-connected vehicles (EVs/PHEVs) now have an opportunity to deliver on growing investment and regulatory support.

Four front-runners stand out among low carbon technologies

Some 20+ years of low-carbon R&D are beginning to bear fruit. Policies to promote low-carbon technologies have been built on the premise that with appropriate incentives in place, commercially viable and scalable low-carbon technologies will emerge over time. We see these efforts beginning to pay off. Many low-carbon technologies have seen rapid performance improvements and costs reductions in recent years. We believe they are now gaining global market acceptance as viable alternatives to incumbent technologies, putting them on the cusp of full-scale commercialization.

Exhibit 14: Among low carbon technologies, four front-runners combine scale and growth...

Annual sales in lamps, vehicles, fuels, smart appliances, smart grid equipment, new installations in power generation & CCS capacity



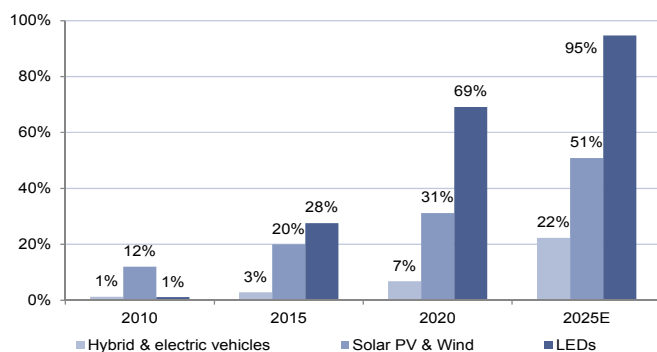
Source: BP, UNEP/Bloomberg New Energy Finance, OECD/FAO, IHS, Advanced Energy Economy, Goldman Sachs Global Investment Research.

However, progress has been highly uneven and we see LEDs, onshore wind, solar PV and electric and hybrid vehicles now as the clear front-runners in the crowded space of low carbon technologies. Exhibit 14 provides an overview of key differences between commonly discussed low-carbon technologies in terms of today’s market scale and recent growth trajectory. What sets these front-runner technologies apart from others in our view is that they combine significant scale (>10 bn pa revenue opportunity) with sustained, significant volume growth (>10%).

We believe investors should focus on this set of front-runners with the potential to shift emission trajectories and reshape competitive dynamics on a 5-10 year view. Collectively they represent a set of breakthrough technologies that:

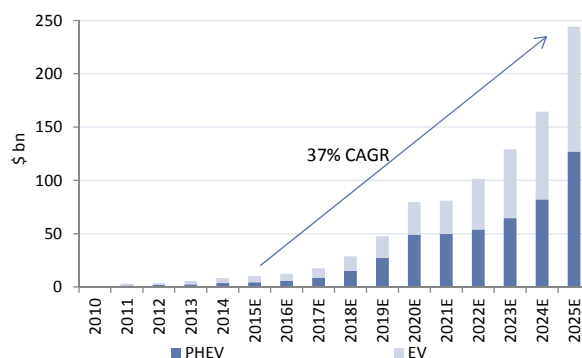
- Attract the lion’s share of low carbon investment and offer a **growing, \$350 bn+ revenue opportunity**. Grid connected vehicles (electric vehicles and plug-in hybrids) grow from c.\$12 bn in sales in 2015 to \$88 bn by 2020 and \$244 bn by 2025 on our analysts’ numbers.
- Are **reshaping competitive dynamics** as they are rapidly taking market share from incumbent technologies. By 2020, our analysts estimate that LEDs will dominate the market with over two thirds of market share and 61% of the installed base. On current trends, 9 in 10 lightbulbs sold worldwide will be LEDs by 2025.
- Are beginning to make a **tangible impact on global emission trajectories**. We calculate that onshore wind and solar PV could help avoid as much as 5 Gt in CO₂e emissions per annum by 2025. They could contribute to an early peak in global CO₂ emissions around 2020 – rather than continued steady growth to 2025, as anticipated by mainstream scenarios.

Exhibit 15: Four technologies are (1) rapidly taking market share in lighting, power generation and automobiles...
Market share respectively in lighting installations; gross power generation capacity additions; light duty vehicle sales



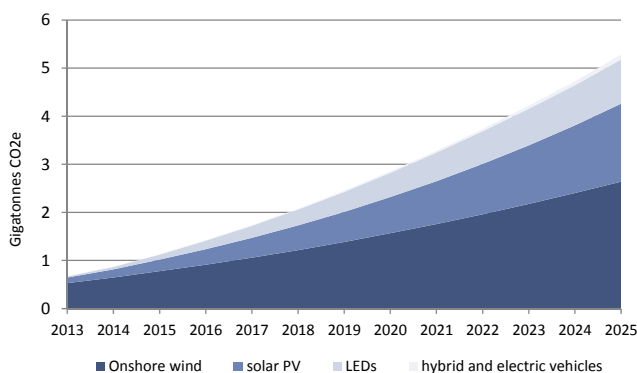
Source: Goldman Sachs Global Investment Research.

Exhibit 16: ...(2) creating significant new revenue opportunities...
Revenue opportunity in grid connected vehicles, 2010-25



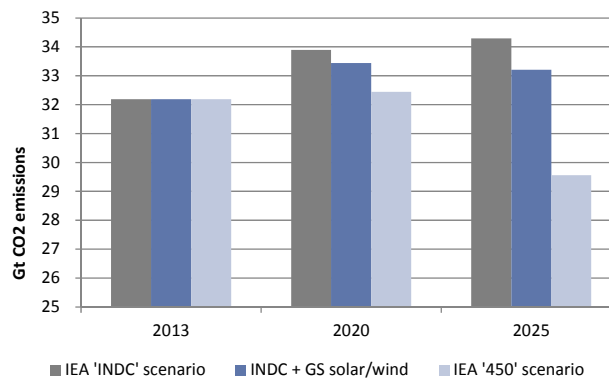
Source: Goldman Sachs Global Investment Research.

Exhibit 17: ...(3) are on track to help saving 5+ Gt of CO₂e emissions pa by 2025...
Gt CO₂e equivalent emissions avoided by the front-runner technologies



Source: IEA, EPA, ICCT, BP, Goldman Sachs Global Investment Research.

Exhibit 18: ...and (4) are beginning to bend the global emissions curve.
Power sector emissions under the IEA ‘INDC’ scenario, incl. our solar & wind forecasts, and the IEA 450 scenario



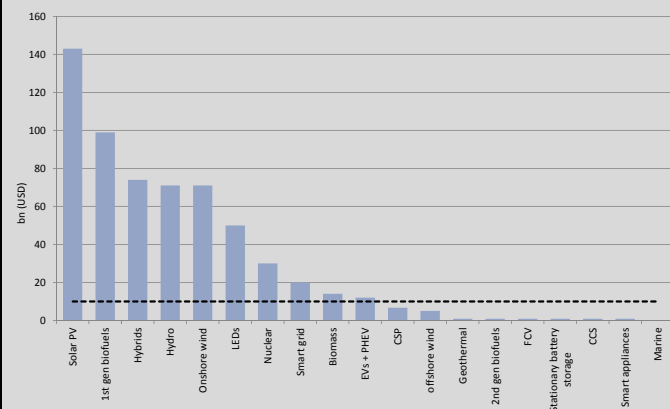
Source: IEA, Goldman Sachs Global Investment Research.

We see less impact for other low carbon technologies

Aside from LEDs, onshore wind, solar PV and hybrid & electric vehicles, there are many other low carbon technologies that either lack the scale, or the momentum to drive significant large-scale global change in 2015-25. They include: (1) mature technologies with relatively slow, stable growth trajectories; (2) early stage technologies that have growth but still lack of scale; and (3) technologies that are gradually losing regulatory support.

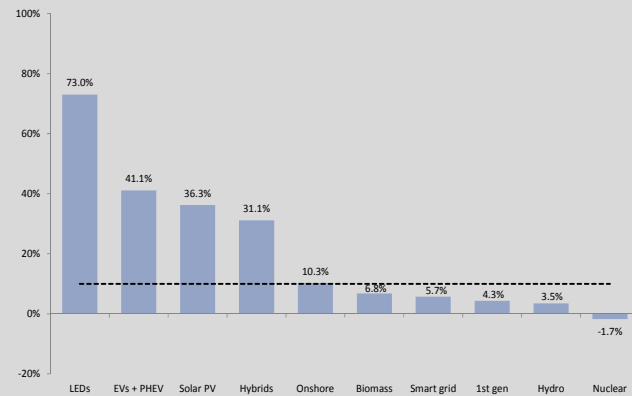
- **Nuclear and hydro power** remain important low carbon sources in the global energy mix, but face a combination of growth constraints that mean that they continue to struggle to keep pace with global electricity demand. In 2000, they accounted for 35% of global electricity production; by 2014 they made up just 27%.
- **Biofuels** have been among the most heavily subsidized low carbon technologies, but growth is fading. Governments are scaling back their support as they worry not only about the impact on global food security (biofuels supply only c.3% of global fuel, but use 2%-3% of global farmland) but also about the limited emissions savings once the entire lifecycle is taken into account.
- **Offshore wind and concentrated solar power** are no match for onshore wind and solar PV, whether in terms of scale, volume growth, or cost reductions. They make up a mere 2% of wind and solar power installed, and are still heavily dependent on subsidies. We see few indications of a significant shift.
- **Marine power and fuel cell vehicles** are intriguing technologies, but are still in the early stages of commercialization. Our Autos team forecasts FCVs to grow at an 86% CAGR for the ten years from 2015 to 2025. Even at triple the pace, less than 1% of cars sold in 2025 would be FCVs.
- **CCS** Less than 15 CCS projects are operational today and a number of CCS flagship projects in the US and Europe have been cancelled in the past two years. With limited potential for carbon pricing at a level that would justify capital intensive CCS investment, we see limited near-term potential.

Exhibit 19: A number of technologies lack scale...
Estimated 2014 global revenue by technology, \$ bn USD



Source: BP, UNEP, OECD/FAO, IHS, Advanced Energy Economy, Goldman Sachs Global Investment Research.

Exhibit 20: ...and among those with scale many have not seen growth in recent years
3-year trailing volume CAGR



Source: BP, UNEP, OECD/FAO, IHS, Advanced Energy Economy, Goldman Sachs Global Investment Research.

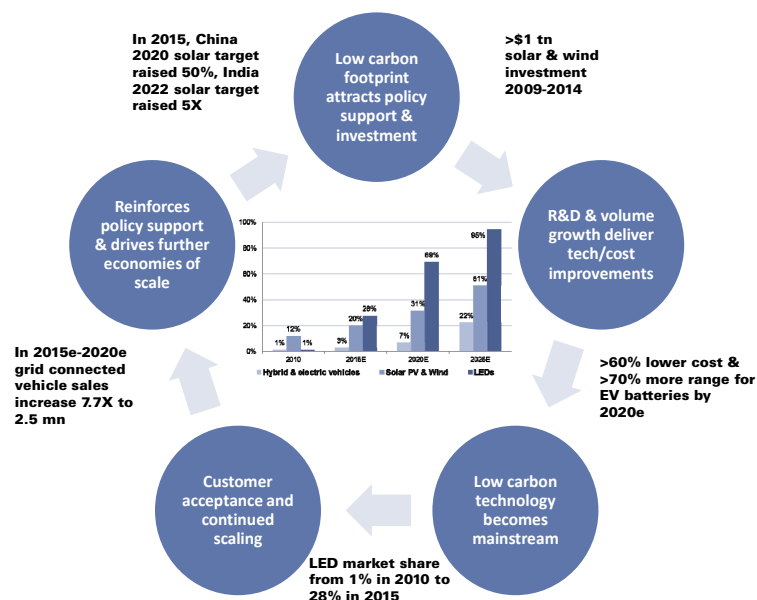
Some of these will remain important technologies in their own right and make important contributions to mitigating carbon emissions. However, the lack of growth means that they are unlikely to take significant market share from incumbent technologies in the near future, limiting their impact on emissions or competitive dynamics.

Others could experience technical breakthroughs and attain scale towards 2030. Every new technology starts small, and monitoring early stage R&D remains important for understanding long-term trends towards 2030 and beyond. Like emerging technologies in biotech or materials science, they can also offer attractive investment opportunities, but these opportunities come with large margins of uncertainty and their global impact will be limited on a 2015-2025 timeframe.

Winning low carbon technologies benefit from a mix of policy, scale and technology...

LEDs, onshore wind, solar PV and hybrid and electric vehicles are fundamentally different technologies at various stages of their development, but in each case we see similar dynamics at play: **(1)** Their low carbon footprint makes them key beneficiaries of regulatory incentives and attracts investment; **(2)** successful R&D is delivering a rapid succession of performance improvements and cost reductions; which is **(3)** transforming them from high-tech gadgets with niche applications into viable alternatives to incumbent technologies. This **(4)** drives customer acceptance and allows them to scale rapidly, which **(5)** in turn reinforces regulatory support and drives further cost reductions.

Exhibit 21: Our front runners benefit from a mix of policy, technology and scale



Source: Goldman Sachs Global Investment Research.

Driven by this dynamic, we expect these technologies to continue to make rapid inroads into lighting, power generation and automotives. By 2025, we expect them to account for over a fifth of vehicles sold globally, over half of gross additions in the power sector (in capacity-adjusted terms), and almost all lighting sold globally (Exhibit 15).

Smart homes – the dark horse in the low-carbon technology race?

Taken together, smart appliances/smart grid applications/home batteries and other smart home applications could be a significant revenue opportunity and offer large-scale energy and carbon reductions. We see appliance makers, tech companies and utilities pushing into this space with ongoing rapid innovation (see *The Internet of Things: Vol. 3 - The next industrial revolution: Moving from B-R-I-C-K-S to B-I-T-S*, July 14, 2014). As in the case of LEDs, relatively short replacement cycles and the ability to tap into existing business models could offer the possibility for rapid growth. However, proven business models, customer acceptance and regulatory incentives are still lacking. While we see significant potential, we remain cautious and believe margins of uncertainty remain large.

It is no coincidence that these three sectors find themselves at the forefront of the low carbon economy. Electricity generation and transport account for over half of human carbon emissions and regulatory pressure and R&D efforts have focused on these sectors (we discuss this in greater depth in Section 2). Other parts of the economy have also seen mounting regulatory pressure to rein in Today marks the beginning of this year’s Climate Change Conference in Paris. In our report we focus on four technologies that we believe

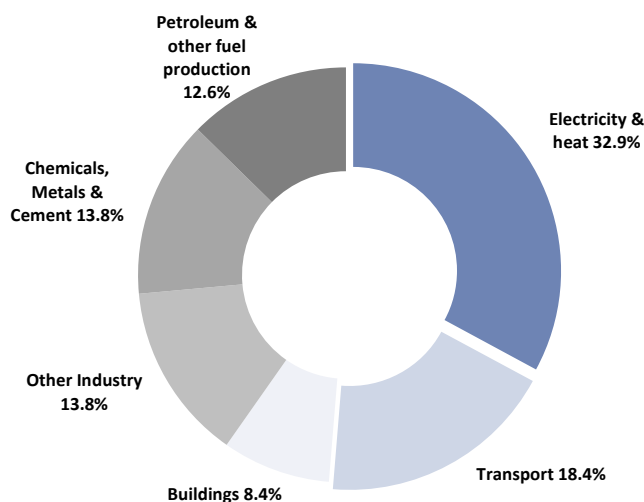
are in the best position, both in terms of scale and growth, to bend the curve on global emissions. This is a \$600bn+ revenue opportunity.

We emphasize that it is the confluence of regulatory support, market acceptance, cost reductions and technology advances that delivers market breakthroughs, rather than economic or environmental efficiency considerations *per se*. Energy efficiency measures (such as building insulation), or hydro power are some of the options that in theory could deliver near-term emission savings at low cost and significant scale. But these well-understood solutions in many cases lack the regulatory support, consumer acceptance or a monetizable business model for large-scale implementation (Exhibits 19 and 20).

Coal to gas switching illustrates this point. Our Commodities and Utilities team have highlighted that an abundance of cheap new gas supplies could drive significant C2G switching particularly in Europe, offering large climate benefits (every tonne of coal that is replaced by gas delivers c.1.3 tonnes of CO₂ savings). But this is mainly driven by shifting prices in global markets, with policy such as carbon pricing playing only an auxiliary role.

Exhibit 22: Electricity and transport dominate carbon emissions

Anthropogenic GHG emissions by source (excl. agriculture, forestry, and land use changes)



Source: IPCC, Goldman Sachs Global Investment Research.

...and are shaping the low carbon economy, 2015-25

The structural transition to low carbon technologies is transforming the competitive landscape in lighting, power generation and autos, with ripple effects across our coverage, from capital goods to energy and materials (we discuss this in greater depth in Section 3).

As in the case of other technological revolutions, from shale oil to e-commerce, we see few winners and many losers, both among incumbents and among challengers. As compliance costs and risks escalate and growth prospects for carbon intensive technology taper, and the business models of incumbents come under pressure. At the same time, rapid innovation lowers barriers to entry, remakes supply chains, erodes margins, and requires large-scale, risky investments.

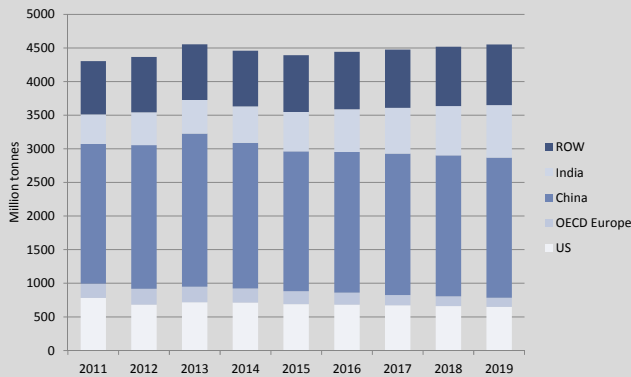
We believe this process is slowing in lighting, where LEDs have already radically reshaped the industry and we see early signs of re-consolidation. In the power sector, we believe this process is beginning to reach critical mass as onshore wind and solar PV are approaching cost competitiveness. In contrast, this dynamic is in the early stages in autos, where grid connected vehicles have not yet achieved full-scale commercialization.

Cheap gas and carbon pricing could deliver significant emission savings from coal-to-gas switching

Replacing carbon intensive coal-fired power generation with cleaner gas-fired power generation could be a cheap way to reduce global emissions at relatively low cost. Every tonne of coal that is replaced by gas saves c.1.3 t of CO₂. Coal-to-gas (C2G) switching could indeed deliver significant near-term emission savings. In the US, the abundance of cheap shale gas has led to significant C2G switching in recent years, lowering coal consumption and reducing CO₂ emissions.

Exhibit 23: Global coal use for electricity generation may have peaked in 2013

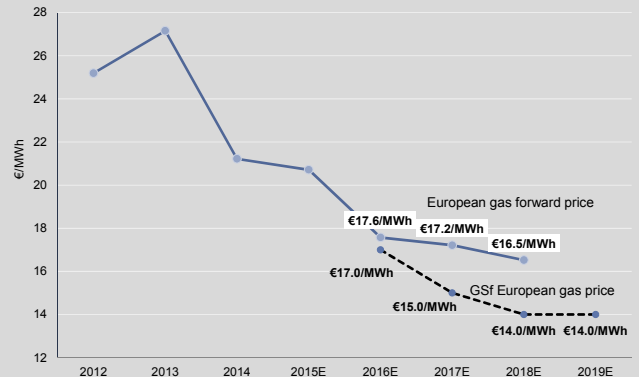
Power sector coal consumption by region, 2011-19



Source: IEA, McCloskey, Goldman Sachs Global Investment Research.

Exhibit 24: Our analysts see significant downside risks to European gas prices

European gas prices (forward prices vs. GS forecast)

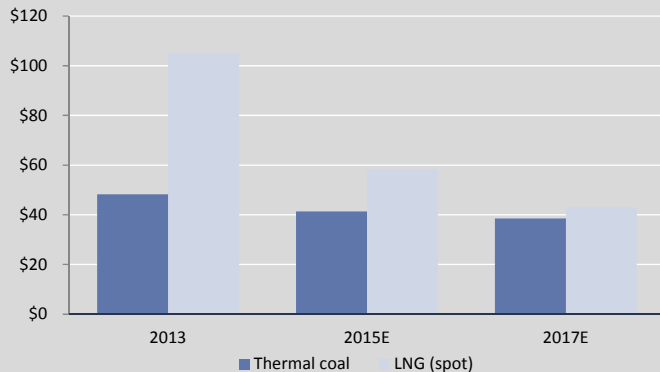


Source: Platts, McCloskey, Goldman Sachs Global Investment Research.

C2G switching could deliver large emissions savings in regions such as Europe, where significant idle gas capacity is available. Our Commodities and Utilities teams have highlighted that an abundance of cheap new gas supplies is likely to drive significant C2G switching particularly in Europe, offering large climate benefits (see *Heat Sensor: Towards a new LNG equilibrium*, November 5, 2015). But this is mainly driven by shifting prices in global markets, with policy such as carbon pricing playing an auxiliary role.

Exhibit 25: While there is less downside in coal prices...

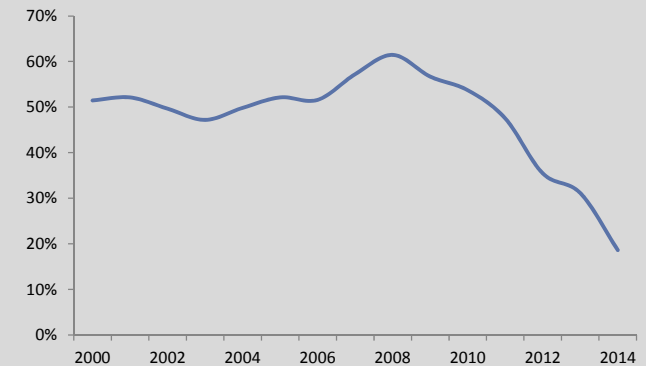
Base load power generation costs in Europe – US\$/MWh



Source: Platts, Goldman Sachs Global Investment Research.

Exhibit 26: ...creating significant potential for C2G switching in Europe owing to idle gas capacity

Average utilization rate of the European fleet of gas-fired generation



Source: IEA, Goldman Sachs Global Investment Research

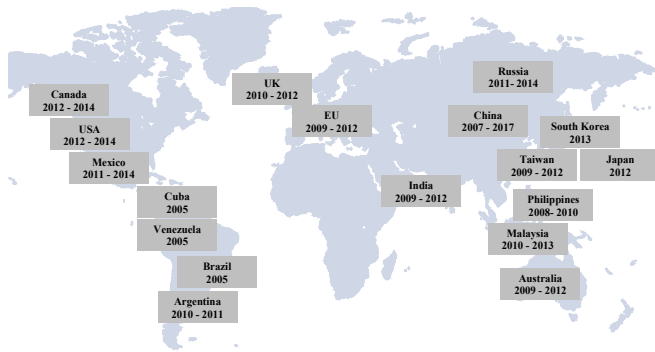
LEDs: Transforming the global lighting industry

Semiconductor-based lighting technology for general lighting purposes (anywhere between 15% and 20% of global electricity consumption) is the first fully-commercialized low carbon technology.

Sharp cost reductions and performance improvements, relatively short replacement cycles for incumbent technologies, and aggressive policy support (including bans on incandescent technology in major markets such as the US, the EU and China) have helped LEDs to rapidly take market share. With almost 3 bn lamps sold globally, LEDs will this year be on a par with compact fluorescent lights at 28% of the global lighting market, up from 1% of global lamp sales in 2010. By 2020, our analysts estimate that LEDs will dominate the market with over two thirds of market share and 61% of the installed base. On current trends, 9 out of 10 lightbulbs in 2025 will be LEDs.

Exhibit 27: Continued policy pressure...

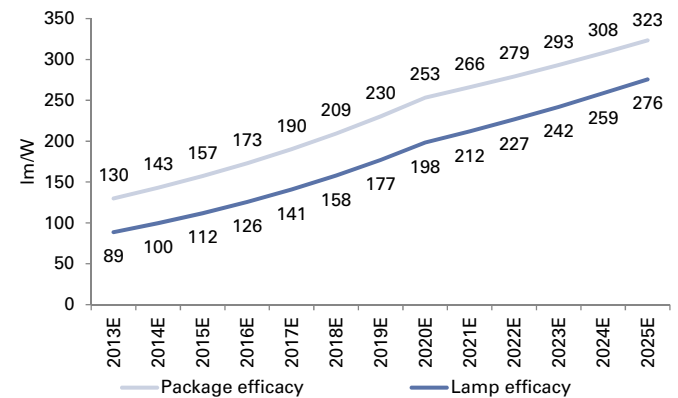
Policies to ban or phase out incandescent light bulbs by country



Source: IEA, DOE, Goldman Sachs Global Investment Research.

Exhibit 28: ...in combination with steady performance improvements...

The light output per unit of electricity continues to increase rapidly

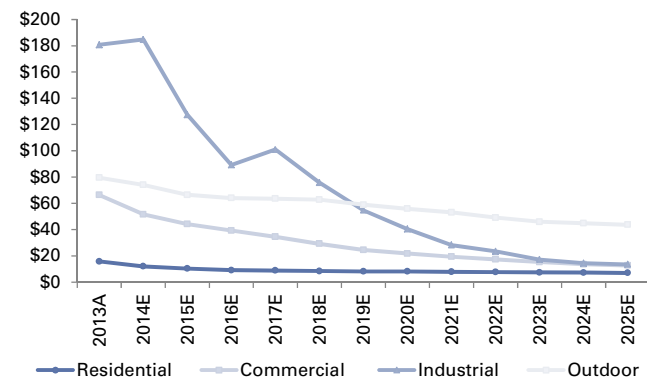


Source: Goldman Sachs Global Investment Research.

Rapid technology improvements have been key to the rapid spread of LEDs. Today light emitting diodes (LEDs) cut electricity consumption by over 85% compared to incandescent light bulbs and around 40% compared to fluorescent lights. As the efficacy of LEDs continues to advance rapidly, our clean-tech analysts forecast that this will increase to over 90% for incandescent lightbulbs and over 50% compared to fluorescent lamps by 2020.

Exhibit 29: ...and sharp cost reductions...

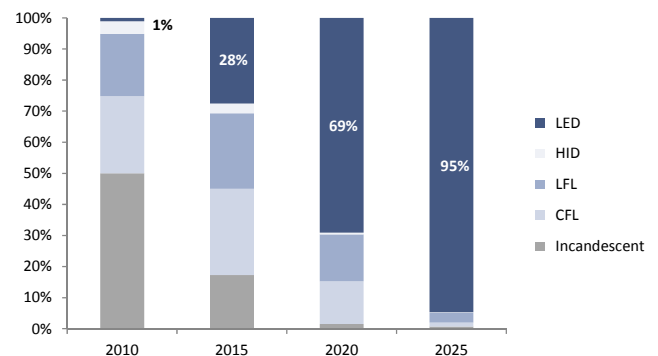
Sharp cost declines make LEDs increasingly competitive with alternatives such as CFLs and LFLs



Source: Goldman Sachs Global investment Research.

Exhibit 30: ...drives rapid gains in market share for LEDs

Market share by technology in the global lighting market



Source: Goldman Sachs Global Investment Research.

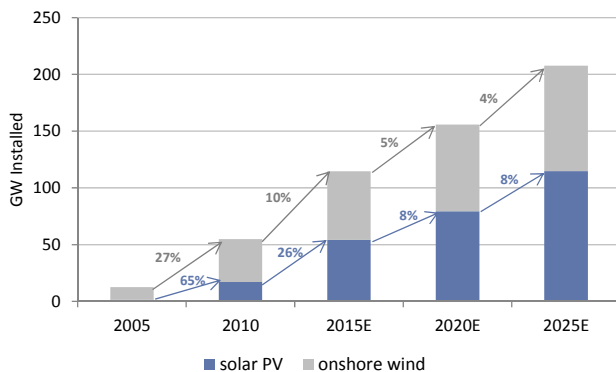
In addition, today’s LED can last for as long five years of continuous use, or up to 50x longer than incandescent bulbs and 3-7 longer than fluorescent lamps. Rapid performance improvements in terms efficacy, light quality and lifetimes have come with sharp cost reductions. LEDs are now retailing for \$10 or less.

Onshore wind & solar PV: Rewiring the global power sector

Onshore wind and solar photovoltaics (PV) have expanded rapidly, with 2015 shaping up to be another record-breaking year. Between 2010 and 2014, over 1 trillion dollars has been invested to install over 300 GW of onshore wind and solar PV power. In 2015, c.110 GW in nameplate capacity was installed according to our Clean Tech team, breaking the 100 GW mark for the first time. This is roughly double the amount that was installed in 2010 and the equivalent of building over 50 thermal power plants a year.

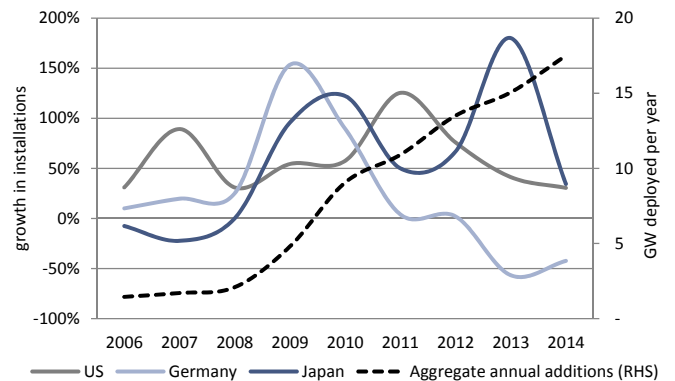
We see continued growth ahead, although the pace is slowing as the industry is attaining scale and the most generous subsidies are being pared back. During the breakthrough periods for solar PV (2010-15) and onshore wind (2005-10), installations grew at 26% and 27% CAGRs respectively. With maturing scale (investment approaches \$250 bn pa) and cut-backs in the most generous subsidies (see Section 2) growth is now normalizing. Based on our analysts’ forecasts, we expect installed capacity to increase 3.4x to 2.3 TW by 2025 (CAGR of 8% for solar PV and 4% for onshore wind). Installation rates rise above 150 GW pa by 2020, and 200 GW by 2025.

Exhibit 31: We expect steady growth in global installations, which could exceed 200 GW by 2025...
Annual solar and wind installations, 2005-2025 and 5y CAGR



Source: Goldman Sachs Global Investment Research.

Exhibit 32: ...although a regulation-driven boom-bust pattern is likely to continue at the country level
Growth rates in annual installations and aggregate annual deployment of solar PV in the US, DE, and JAP 2006-2014



Source: Goldman Sachs Global Investment Research.

Deployment remains uneven across the world, and despite steady global growth we see continued, regulation-driven volatility at the national level. Wind power deployment remains concentrated in China, the US (particularly in the Midwest; in Iowa c.28.5% of electricity in 2014 was generated by wind power), and Europe (in Denmark over 40% of electricity is generated from wind). Changes in policy can trigger big changes in national growth trajectories (see Exhibit 32). In the US, our analysts expect solar to contract by over 10% between 2016 and 2017, as companies rush deployments to take advantage of expiring investment tax credits.

We expect wind and solar to account for over half of (capacity-adjusted) new installations in electricity generation capacity by 2025. In capacity-adjusted terms, solar PV and wind now make up almost a quarter of gross additions to power generation. Assuming continued rapid growth, this share could grow to over half by 2025. Given the long life

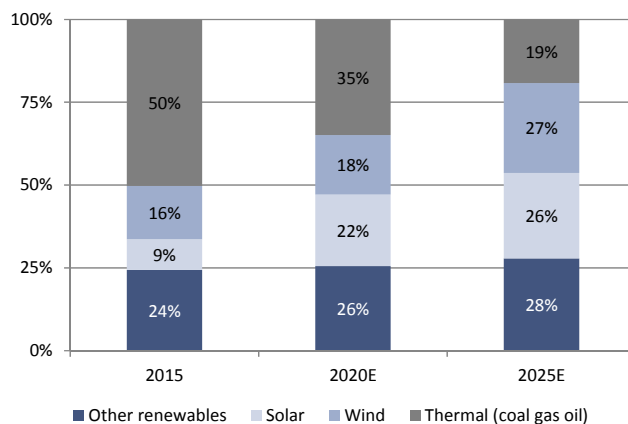
times of power plants and relatively slow growth in global electricity consumption, we expect their share in the installed base to be considerably lower.

In energy terms, this now puts the phenomenon of solar PV and onshore wind on par with US shale oil production. The energy harvested per year from wind power and solar panels installed just in 2015 is equivalent in energy terms to 842 thousand barrels per day (kbpd) of crude oil (conversion according to BP data). Based on our analysts' forecasts, we expect that solar and wind will add the equivalent of 6.2 million barrels of crude to global energy supply between 2015 and 2020 – more than the 5.7 million barrels US shale oil added to global oil supply in 2010-15, and comparable with the combined 2014 production of Iran and Iraq (6.1 million barrels).

Improving costs and performance underpin this growth, with unsubsidized wind and solar becoming increasingly competitive with incumbent technologies. Between 2010 and 2015, costs have dropped by three quarters for solar PV and over half for onshore wind, driven by lower manufacturing costs, capacity factor improvements, and reductions in installation costs. In many parts of the world, unsubsidized onshore wind farms are now among the cheapest forms of expanding electricity generation. In favourable locations, latest technology utility-scale solar can now also compete with fossil fuels and without requiring any subsidies. Growing competitiveness has also contributed to continued growth despite falling fossil fuel prices.

Exhibit 33: By 2025, solar and wind will account for half of capacity-adjusted gross additions in the power sector

Market share of solar PV and onshore wind in gross capacity additions (capacity factor adjusted)



Source: Goldman Sachs Global Investment Research.

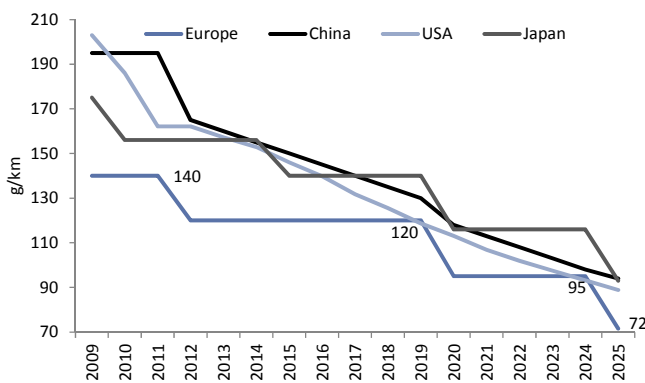
Advancing battery technology could significantly enhance the economics of wind and solar, further accelerating their deployment. With growing renewables penetration rates their inherent intermittency can create challenges from involuntary curtailment to grid instability, which could impact project economics and undermine future regulatory support. Rapid cost reductions and performance improvements in batteries could lead to growing co-deployment with renewables, with the potential to significantly reduce intermittency problems through so-called peak shaving (see our clean tech team’s recent deep dive, *The Great Battery Race: Framing the next frontier in clean technology*, October 18, 2015).

Solar PV installations are growing particularly rapidly, with solar overtaking wind installations in GW terms in 2018. High flexibility in deployment and potential for further cost and improvements in the semiconductor-based technology drive particularly rapid growth for solar PV. We expect solar installations to exceed wind installations for the first time in 2018, with an installed base of almost equal size by 2025.

Grid connected vehicles: A driver of change in automotives

Among our four front-runner technologies, hybrid and electric vehicles are growing particularly rapidly, although from a relatively low base. Over the next ten years, our sector analysts forecast sales to increase by a CAGR of 26%, expanding market share from 3% today to 22% in 2025E, amounting to almost 25 mn vehicles. Hybrids will account for the lion’s share of sales. However, grid-connected vehicles (EVs and PHEVs), growing at a 37% CAGR, will increasingly account for a considerable share in their own right (8 mn vehicles).

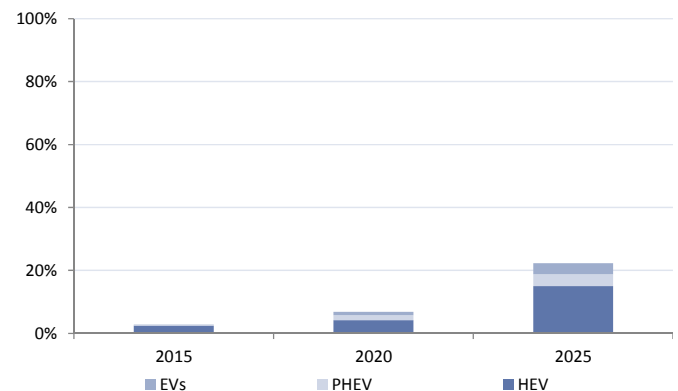
Exhibit 34: Regulation driving innovation...
CO₂ emissions (gCO₂/km) regulations



Source: Japan Automobile Manufacturers Association (JAMA), US Department of Energy (DOE), Goldman Sachs Global Investment Research.

Exhibit 35: Rapid market share gains for hybrids and electric vehicles...

Hybrids and grid-connected vehicles as a share of global car sales



Source: IHS, Goldman Sachs Global Investment Research.

Mounting regulatory pressure will continue to force OEMs to invest considerable resources in low emission technologies. China’s fleet emission target in 2020, for instance, will be lower than Europe’s target today (Exhibit 34). Until now OEMs have been able to comply with regulation by improving the efficiency of the internal combustion engine. In future, however, ever stricter rules will require a continued shift towards alternative drive trains.

Electric vehicle technology will depend on significant cost reductions and performance improvements in order to gain consumer acceptance. In a recent report (*Autos 2025 vol. 2: Solving CO₂*, August 5, 2015) our Autos analysts forecast the battery range for lower performance EVs to increase by over 70%, while battery costs are expected to fall by more than 60% over the next five years (Exhibit 37). Although technological advances play a significant role, growing economies of scale are the key driver of cost reductions. Led by Tesla and Panasonic’s 35GW Gigafactory, battery manufacturers have committed to approximately triple current production capacity over the next five years (Exhibit 36).

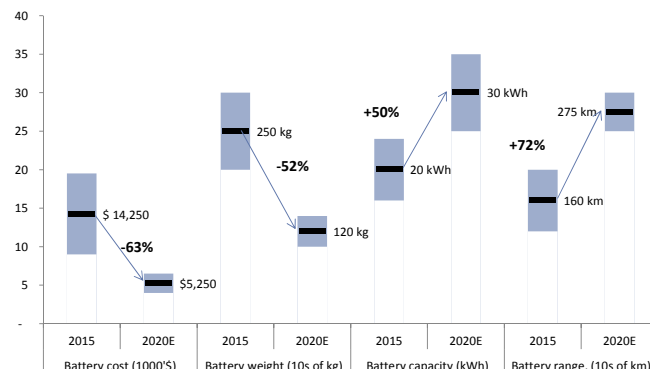
Exhibit 36: Extensive investment in battery production...
 Battery capacity additions by manufacturer

Company	Capacity	Evs equivalent capacity (@70kWh)	Production start	Location
Panasonic/ Tesla	35GWh	500k	2016	Nevadam US
LG Chem	7GWh	100k	2016	Nanjing, China
	1.6 GWh	22.8k	Expansion	Michigan, US
Foxconn	15GWh	214k	2016	Anhui, China
BYD	20GWh	286k	2020	various, China
Boston Power	10GWh	143k	2020	various, China
Samsung	1.5GWh	21.4k	Expansion	Ulsan, South Korea
	Combined		Expansion	Xian, China

Source: Company data.

Exhibit 37: ...is driving cost reductions and performance improvements

Battery costs, weight, capacity and range (2015 vs. 2020E)



Source: NEDO, Goldman Sachs Global Investment Research.

In our view, sub-nation regulatory support could drive an accelerated market share shift away from hybrids and towards grid-connected vehicles, if battery technology can deliver. In London, for instance, the Ultra-Low Emission Zone will from May 2016 onwards no longer exempt hybrid vehicles from the Congestion charge. Similar policies, favoring grid-connected vehicles over hybrids have recently been put in place in California and Beijing.

Low carbon regulation: Tipping the scales

Low carbon regulation: Tipping the scales

Policy support will remain a key factor in determining the speed and scale of the growth in the low carbon economy over the next 5-10 years. On aggregate, we expect regulation to intensify across major advanced and emerging economies. This will drive up compliance costs for carbon intensive business models and incentivize the continued rapid deployment of low carbon technologies.

At the same time however the global regulatory landscape for low carbon technologies will remain fragmented and volatile. On a 2015-25 timeframe key incentives are likely to continue to:

- be set at the national, and in some cases subnational level, rather than being agreed on in international negotiations;
- be often sector- and technology-specific, rather than consisting of more general measures such as carbon pricing; and
- change frequently as support for low carbon technologies remains politically controversial in many countries, and policy-makers respond to changing technology and market conditions.

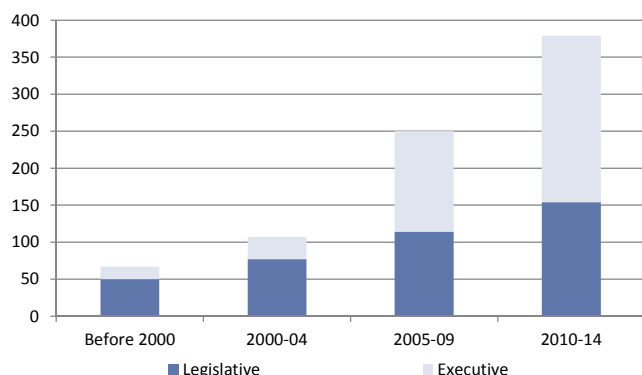
We also survey key trends in regulation that will shape the deployment of low carbon technologies from 2015-25 (see p.33).

Policy pressure to cut emissions remains a secular trend...

Policies for cutting carbon emissions and promoting low carbon technologies remain mired in controversy. In the run-up to the Paris Summit, the issue continues to define political fault-lines and polarize the debate between those that caution against the adverse impacts of heavy-handed emissions regulation, and those that demand urgent government action.

Exhibit 38: National emissions regulation increases rapidly

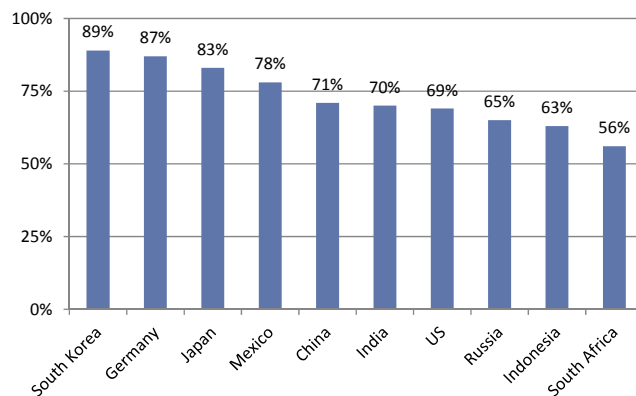
Number of national laws enacted on climate change mitigation and low carbon technologies



Source: LSE, Goldman Sachs Global Investment Research.

Exhibit 39: In the largest emitter countries, the public is broadly supportive of measures to cut emissions

Share of respondents supporting their country limiting greenhouse gas emissions as part of an int'l agreement, 2015



Source: Pew Research Center, Goldman Sachs Global Investment Research.

We believe investors need to focus on the bigger picture. Growing regulatory pressure to rein in carbon emissions will remain a secular trend against the backdrop of mounting concerns over global climate change, and broad public support for cuts to emissions in major advanced and emerging economies (a theme we have highlighted for several years, see GS SUSTAIN *Change is coming: A framework for climate change*, May 21, 2009; GS SUSTAIN *What is the climate for change?* October 2, 2013).

A recent academic study by the Grantham Institute at the London School of Economics counted over 800 policies and pieces of legislation worldwide that aim to reduce carbon emissions or promote low carbon technologies, with 46 new measures passed in 2014. The impact of these rules on industries varies from inconsequential to game-changing. However, we note that meaningful regulatory incentives to reduce emissions and promote low carbon technologies are now in place in almost every major economy – advanced and emerging.

There are many examples of incentives that have been scaled back or removed; but on balance we see little indication that global regulatory pressure is abating. Political debate focuses mainly on the speed and the choice of instrument rather than on the direction of travel. For example, the same government that prominently repealed the Australian Carbon Tax in 2014, committed a year later to reduce Australia's CO₂ emissions by over a quarter compared to 2005 levels by 2030 (see also *GS SUSTAIN: Paris climate conference - Evaluating Australian corporates' exposure to policy change*, November 30, 2015). The UK government, which has announced plans for scaling back subsidies for wind and solar, has also introduced one of the world's toughest carbon pricing schemes and decided to phase out coal by 2025.

Indeed, there are some indications that the degree of regulatory pressure could increase faster than anticipated. The cost calculation for regulators changes rapidly as low carbon technologies come closer to full commercialization. The marginal cost of incentivizing solar or wind deployment through reverse auctions and other measures has fallen sharply, making cash-strapped governments less reluctant to support them at the expense of incumbent technologies. Benefits are increasing too as low carbon industries are growing in scale. Tesla's plans for a battery factory, for example, set off a fierce competition among five US states for the \$5 bn+ investment with an estimated 6,500 jobs. Nevada, where the factory was eventually located, passed four laws and offered the company \$1.3 bn in incentives, including a 20-year sales tax exemption, with a lawmaker referring to it as the biggest prize for the state "since the Hoover Dam".

...but we expect global rules to remain an uneven patchwork

Looking forward, there is little indication that the complex patchwork of fast-changing incentives across different countries and industries will be replaced by a consistent set of global rules. Regulation will continue to come in a piecemeal fashion as the most important incentives: (1) are set at the national or even subnational level; (2) target specific sectors and technologies; and (3) are adapted continuously as market and political conditions evolve.

(1) All eyes are on Paris – but domestic rules will continue to set the pace

Global climate negotiations are once more in the limelight, but the most significant decisions on emissions and low carbon technologies will continue to be made at the national, and in some cases subnational level, regardless of the Paris outcomes. In many ways the summit has already produced its most important results, with the governments of most major economies announcing new, relatively ambitious plans to cut emissions and promote low carbon technologies, and some countries making formal pledges for the first time (see box).

Paris will not produce a global rulebook on how or to what extent countries have to cut emissions and what happens when they fail to live up to their commitments. Instead, the summit will mainly focus on the review process for voluntary and non-binding national targets, and mechanisms to support developing countries in implementing their commitments and coping with the impacts of climate change. New multilateral mechanisms to reduce emissions are likely to play a marginal role on the agenda.

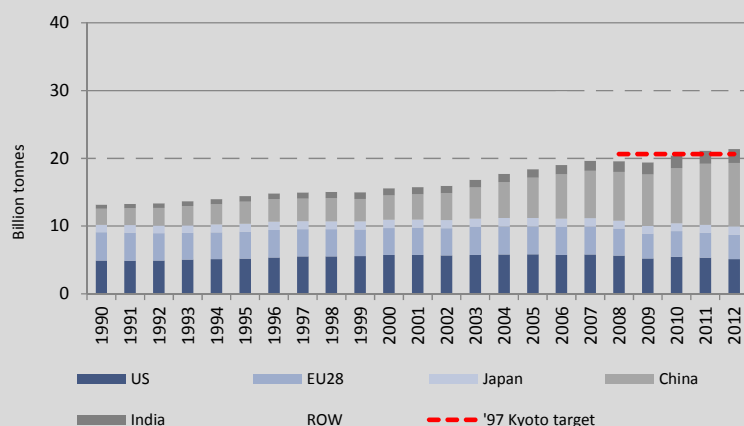
Paris in perspective – 25 years of global climate diplomacy

The significance of the 2015 UN Climate Change Conference in Paris can only be understood in the context of over a quarter century of near-continuous international negotiations on how to cut emissions. Global climate diplomacy began in earnest in 1990, with the publication of the first “Assessment Report” of the Inter-governmental Panel on Climate Change (IPCC). In response, over 150 countries signed off the United Nations Framework Convention on Climate Change (UNFCCC) in 1992 and vowed to work towards a “stabilization of greenhouse gas concentrations”. The Paris Summit is indeed “COP21”, or 21st ‘Conference of the Parties’ – the 196 signatories of the Convention.

To implement the Convention, negotiators from 193 countries agreed in 1997 to the Kyoto Protocol, which mandated a reduction global emissions by at least 5% compared to 1990 levels by 2008-12. The Protocol however did not succeed in reducing global emissions; in fact, by 2012 they had increased by 55% above 1990 levels. Advanced economies, which had agreed to cut their emissions by 6%-8%, were slow to implement the agreement, withdrew eventually, or declined to ratify it altogether. Emissions from the EU, the US and Japan peaked in 2007, and by 2012 were only 2% below 1990 levels. At the same time, emissions from emerging and developing countries – which were not required to meet targets under Kyoto in reflection of the principle of ‘common but differentiated responsibilities’ – tripled by 2012 from 1990 levels. China accounted for over half of this increase, and overtook the US as the largest emitter in 2005.

Exhibit 40: Kyoto targets were not met

CO2 emissions (excl. land-use change and forestry), 1990-2012



Source: World Resources Institute, Goldman Sachs Global Investment Research

As the shortcomings of the existing framework became increasingly apparent, efforts of international negotiators shifted to striking a new ‘grand bargain’ to replace the Kyoto Protocol. The goal was to create a new framework with binding commitments on advanced economies, in return for commitments by China and other major emerging economies to slow the pace of their emissions growth. The efforts ultimately failed at COP15, the Copenhagen Summit in 2009. The summit produced only an accord in which governments emphasized “strong political will to urgently combat climate change” and agreed that “deep cuts in global emissions are required”. How and when these cuts would be achieved was not specified.

These setbacks have forced international negotiators to re-evaluate their strategy. The 2015 Paris Summit is officially tasked to agree the successor regime to the Kyoto Protocol, which is supposed to come into force in 2020. However, in the aftermath of Copenhagen, the establishment of a Kyoto-like global framework of binding national quotas for emission reductions – the focus of global climate diplomacy for over two decades – appears increasingly unrealistic.

Instead negotiations in Paris are focused on more flexible mechanisms to support and accelerate voluntary national efforts to reduce carbon emissions. At the center is the attempt to formalize a ‘pledge and review’ approach, in which countries set their own reduction goals which are then collectively monitored and reviewed. In a first step, governments agreed in 2013 to put forward so-called INDCs in the run-up to the summit. These “Intended Nationally Determined Contributions” are voluntary (‘nationally determined’), non-binding (‘intended’), country-by-country goals for emission reductions (‘contributions’).

Exhibit 41: Overview of emission reduction targets pledged in INDCs by G20 countries
 'Intended Nationally Determined Contributions' (INDCs) pledges by G20 countries ahead of the Paris Summit

DMs	EU	Binding target of an at least 40% domestic reduction in greenhouse gas emissions by 2030 compared to 1990.
	US	Intends to achieve an economy-wide target of reducing its GHG emissions by 26-28% below its 2005 level in 2025; and 'best efforts' to reduce its emissions by 28%.
	Japan	A 25.4% reduction of GHG emission compared to 2005 by 2030.
	Canada	Economy-wide target to reduce its greenhouse gas emissions by 30% below 2005 levels by 2030.
	Australia	Reduce greenhouse gas emissions by 26-28% below 2005 levels by 2030.
EMs	China	Peaking of CO2 emissions around 2030 and 'best efforts' to peak early; lower emissions per unit of GDP by 60-65% from 2005 level; increase share of non-fossil fuels in primary energy consumption to around 20%.
	Brazil	Reduce greenhouse gas emissions by 37% below 2005 levels in 2025.
	India	Reduce emissions intensity of GDP by 33-35% by 2030 from 2005 level; 40% of electric power installed capacity from non-fossil fuel resources by 2030.
	Russia	Limiting GHG emissions to 70-75% of 1990 levels by the year 2030 might be a long-term indicator, subject to the maximum possible account of absorbing capacity of forests.
	South Korea	Reduce GHG emissions by 37% from the business-as-usual (BAU, 850.6 MtCO ₂ e) level by 2030 across all economic sectors.
	Mexico	Reduce GHG emissions unconditionally by 25% below BAU scenario by 2030. Net emissions peak starting from 2026; emissions intensity per unit of GDP will be reduced by around 40% from 2013 to 2030.
	Indonesia	Reduce 26% of its GHG emissions by the year 2020 and by 29-41% by 2030 compared to the business as usual (BAU) scenario.
	Turkey	Up to 21% reduction in GHG emissions from the Business as Usual (BAU) level by 2030.
	Saudi Arabia	Up to 130 mn tonnes of CO ₂ e pa by 2030 achieved through mitigation co-benefits.
	Argentina	Reduce GHG emissions by 15-30% in 2030 with respect to projected BAU emissions
South Africa	South Africa's emissions by 2025 and 2030 will be in a range between 398 and 614 Mt CO ₂ -eq, as defined in national policy.	

Source: World Resources Institute, Goldman Sachs Global Investment Research.

The shift from trying to agree binding quotas to asking countries to define what they are willing and able to deliver has led to a significant change in the negotiations dynamics. To date, 176 states, collectively accounting for over 95% of global carbon emissions, have submitted their INDCs, with many making formal pledges to reduce emissions for the first time. The targets are not easy to compare as countries have had significant leeway in formulating their goals and have chosen different metrics and baselines. It is clear however that they contain significant new commitments, even if they collectively continue to fall short of the so-called 2 degree target (the level of emissions which scientists have agreed would limit the risk of dangerous climate change and that governments agreed to aim for in 2010).

In the INDCs, advanced economies have agreed to substantial absolute cuts from current emission levels by 2030, ranging from the high teens in the US to 30%+ for the EU. Perhaps even more significantly, a number of major EMs have for the first time committed to tangible emission reduction efforts. China, the world's largest emitter, has agreed that its emissions will peak 'around 2030'. Both China and India have also pledged to reduce their emissions per unit of GDP significantly by 2030, respectively by 60%-65% and 33%-35% compared to 2005 levels. Both have also included high renewables targets: China has committed to source c.20% of primary energy consumption by 2030 from renewables, while India has pledged that non-fossil fuels will account for 40% of electricity generation capacity by 2040.

While there will be no formal enforcement mechanism, governments have agreed that countries' progress in meeting their INDCs will be monitored collectively. Negotiators hope that governments will be held to account by a combination of the 'naming and shaming' of countries that fail to live up to their self-set targets and pressure from national constituencies. The specifics of the monitoring and verification mechanisms and the format and frequency of these reviews is among the major items on the agenda for Paris. The other major issue will be the extent to which advanced economies will commit to support poorer countries in coping with the impacts of climate change, as well as in implementing their emission reduction targets through financing and technology transfer.

Against the backdrop of the deadlocked negotiations in Copenhagen, the fact that many major emitters have submitted relatively ambitious INDCs constitutes a significant success. If negotiators are able to clear the remaining hurdles and sign an agreement, Paris will be hailed as a milestone in the history of global climate diplomacy.

The Paris Summit should nonetheless not be dismissed for a lack of substance. Negotiators are recognizing that international legal obligations to cut emissions remain an anathema to many governments, while many major emitters at the same time have increasingly ambitious emission reduction strategies. Rather than risking another negotiations breakdown similar to Copenhagen in 2009, the summit aims to catalyze national action in key countries through a more informal process.

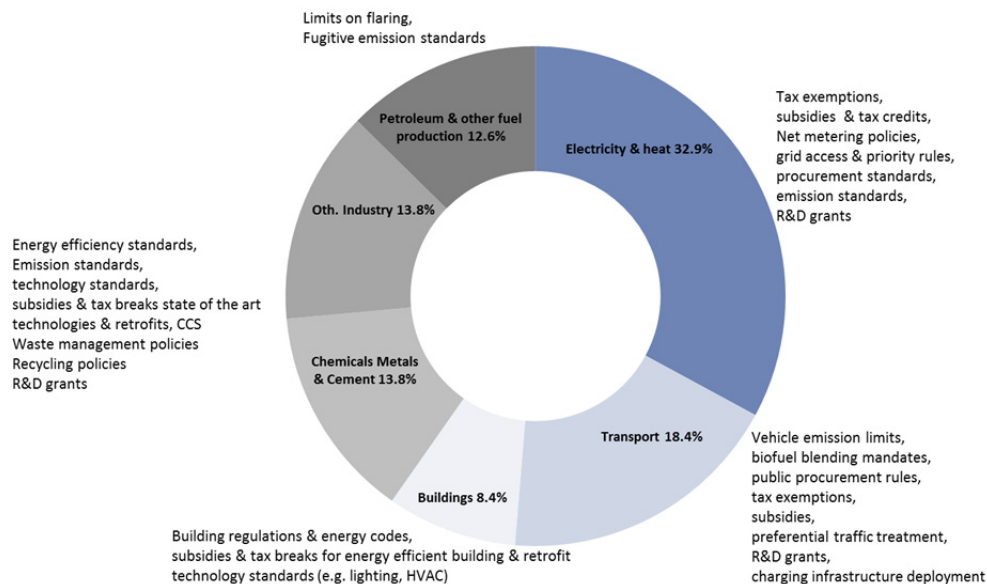
The key question is whether negotiators are indeed able to codify this compromise approach in an international agreement. For this, negotiators would have to overcome differences about its ultimate legal status (with US negotiators particularly keen to avoid a treaty status that would require approval by the Senate); as well as reservations from many developing countries that demand firmer commitments for emission cuts and financial aid by advanced economies. A collapse of the negotiations, a less likely but possible outcome, would be interpreted as a blow to global regulatory momentum.

(2) Sector-by-sector approaches rather than carbon pricing continues to dominate the picture

Governments will continue to rely on a broad array of sector- and technology-specific policies and regulations, with carbon pricing remaining one instrument among many. Despite its inherent advantages, the likelihood that a meaningful global carbon pricing framework replaces piecemeal, sector-by-sector regulation in the near future, appears limited. We see some progress towards carbon pricing for the power sector and heavy industries in countries such as China, where regional pilots will be extended to a national carbon pricing system by 2017. Most existing carbon pricing frameworks, however, suffer from shortcomings such as relatively low price levels and limited emissions coverage (see box).

Exhibit 42: In the absence of carbon pricing, governments have opted for a sectoral approach

Share of different sectors in global emissions (CO₂e) excl. agriculture, forestry and land-use change, with examples of emission reduction policies



Source: IPCC, Goldman Sachs Global Investment Research.

Carbon pricing

Economists and business leaders have long argued that a meaningful price on carbon emissions could be among the most effective and economically efficient means to cut emissions and promote low carbon technologies. The two principal forms of carbon pricing are (1) a carbon tax (i.e. determining the price of emissions) or (2) a cap on overall emissions (i.e. determining the quantity) with allowances being allocated to businesses (either for free or through auctions) and subsequently allowing market participants to trade these freely. Compared to other forms of emission regulation, carbon pricing could help to minimize distortions, avoids picking winners, and allows market mechanisms to determine the most cost-effective means to reduce emissions across the economy.

According to a recent World Bank study, 39 countries and 23 subnational jurisdictions including the EU, China, Japan, and several US States and Canadian Provinces are now using or are in the process of implementing carbon pricing. The impact on investment and emission reductions however has been relatively limited as a result of several factors:

- **Carbon pricing typically applies only selectively to emissions.** Carbon pricing schemes exist in countries accounting for over half of global emissions, but existing schemes collectively cover only c.12%. In Sweden, the country with the world’s highest carbon price at c.\$130, the tax applies only to the use of specific fuels in specific industries – a fraction of the country’s carbon emissions (other parts of Sweden’s emissions are also priced under the European cap and trade scheme, however at much lower price levels).
- **Prices in existing schemes are too low to drive significant impact.** 85% of emissions in existing schemes are priced at levels below \$10 and 99% are priced below \$30 per ton. Experts argue that much higher price levels would be needed to drive large-scale emission reductions. In the EU, where the most sophisticated cap-and-trade scheme has operated for a decade, carbon allowances have traded at prices below €20 since 2009.
- **Political uncertainty about controversial pricing schemes reduces their impact.** The Australian government, for example, repealed a carbon tax in 2014, which had only been introduced two years earlier. In 2013, the UK introduced a carbon price floor of £16, which was intended to rise to £30 by 2020. In 2014, the government announced that it would freeze the price at £18, with post-2020 pricing remaining uncertain.

Exhibit 43: Carbon pricing mechanisms vary across the world

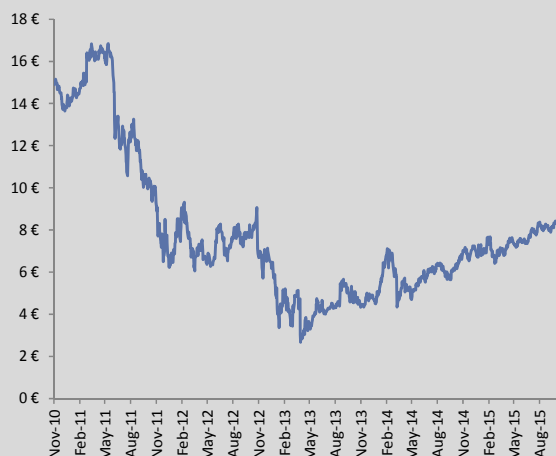
Examples of carbon pricing mechanisms in major economies

Cap-and-trade & carbon tax schemes	implied carbon price per ton	% of emissions covered	Comments
EU emission trading system	currently trading in the range of 5\$-10\$	45%	Since introduction in 2005, prices have declined rather than increased. Reforms to curtail the oversupply of emission allowances are currently being discussed.
Joint California/Quebec Cap and Trade	13\$	85%	California and Quebec Province recently agreed to link their emission trading systems. Ontario recently announced it would join the scheme.
China’s national emissions system	2-9\$ dollars in subnational pilots	35-60% in subnational pilots	After subnational pilots in 7 major cities and provinces, a national trading system will be implemented by 2017, initially covering utilities and heavy industry.
South Korean emission trading system	c. 9\$	66%	The scheme was introduced in January 2015, with free emission allocations, which are to be replaced with auctions.
British Columbia Carbon Tax	c. 23\$	70%	Mandated to be revenue neutral, i.e. all revenues recycled into personal and corporate income tax cuts and credits
UK Carbon Price Floor	c. 28\$	45%	Linked to the EU ETS, emitters are required to pay the difference to the floor price as a tax, as long as EU allowances trade below the floor price.

Source: World Bank, Goldman Sachs Global Investment Research.

Exhibit 44: EU ETS carbon spot price remains low despite a modest upwards trend

Price of EU carbon emission allowances

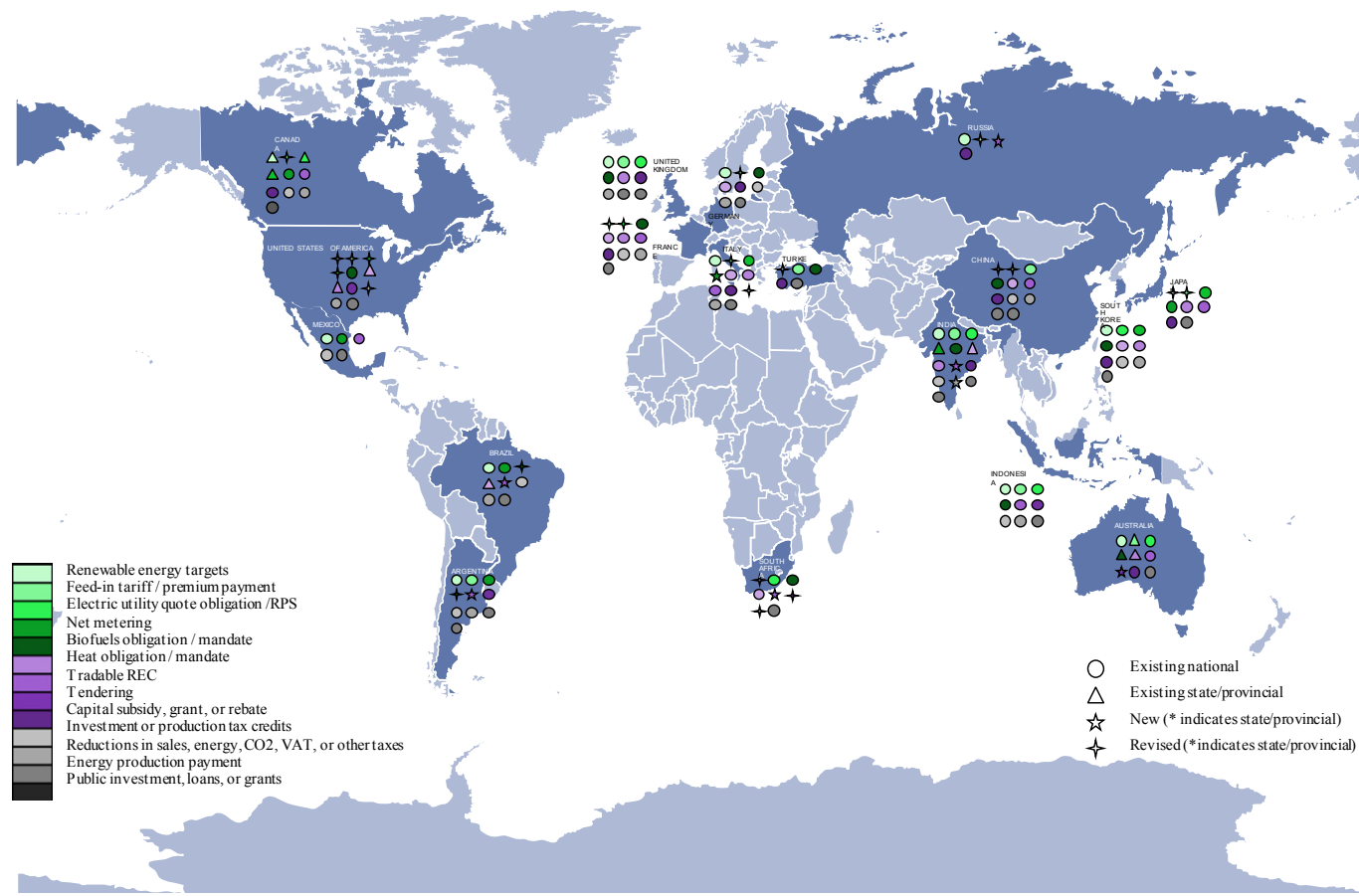


Source: Datastream, Goldman Sachs Global Investment Research.

An increasing number of businesses have introduced internal carbon pricing as a tool to guide long-term investment decisions and mitigate future regulatory risks. According to a recent study by the World Bank, 435 companies, including some of the world’s largest companies now use internal carbon pricing, with another 583 indicating their intention to introduce carbon pricing in the next two years.

Exhibit 45: Overview of support policies for renewables in G20 countries

Policy instruments in G20 countries to promote renewable electricity



Source: REN21, Goldman Sachs Global Investment Research. Data for Saudi Arabia is not available.

(3) Regulation will remain unstable as it adapts to evolving markets and politics

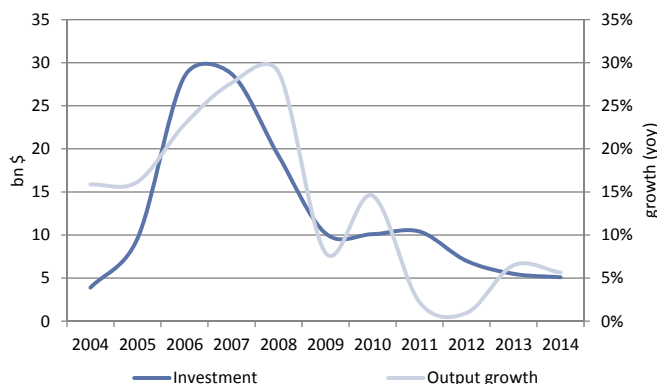
Not only will differences in regulations and support for low carbon technologies persist across geographies and industries – we also expect the regulatory landscape to remain inherently unstable. We see three key drivers of instability: (1) Shifting politics lead to discontinuities in regulation. (2) Regulation will adapt to changing technologies and market conditions. (3) Continued regulatory learning and innovation.

Shifts in political power are an obvious source of policy instability. The impact of changing political fortunes on Australia’s emission policy illustrates this point. Measures to rein in emissions have been among the most contentious issues in Australian politics and frequent changes in the political leadership of the country have contributed to repeated changes in policy. The carbon tax that the Australian government introduced in 2012 was removed only two years later following the election of a new government.

Policy-makers are also regularly adjusting targets and regulations to changing technologies and market conditions. Wind and solar energy have scaled up much faster and seen larger cost-reductions than experts and policy-makers anticipated. This has led to a rapid increase in volume dependent subsidies such as feed-in-tariffs and tax credits, triggering reforms in countries that heavily rely on such measures, including retroactive removals of subsidies, e.g. in Spain. Similarly, policy-makers have become much more cautious in their support for biofuels as experts have highlighted their adverse impact on global food security and research has pointed to a much more limited emission reductions potential than originally anticipated.

Exhibit 46: Biofuels growth has slowed as policy support has faded

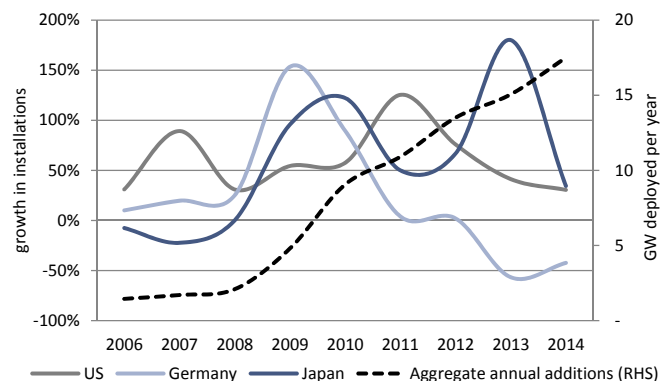
Investment in new biofuel capacity and growth rate in global production, 2004-14



Source: OECD, FAO, UNEP, Goldman Sachs Global Investment Research.

Exhibit 47: Volatile regulation drives a boom-bust pattern in the growth of low carbon technologies

Growth rates in annual installations and aggregate annual deployment of solar PV in the US, DE, and JAP 2006-2015



Source: Goldman Sachs Global Investment Research.

Regulatory innovation and learning is another powerful driver of policy instability. Policy-makers experiment with different types of policy instruments, and frequently adopt elements of policies that appear to be successful in other countries. Modern feed-in-tariffs, which were pioneered in Germany in 2000, were for example copied in 50 other countries over the next decade – but have become less popular as lower costs and rapid deployment have made them seem overly generous. Since 2010, 19 countries, including Germany, have decided to phase out or reduce feed-in tariffs in favor of reverse auctions, emulating the example of emerging economies such as Brazil that have successfully used competitive bidding processes to achieve rapid deployment at low subsidy cost.

Key markets act as regulatory pressure points

Regulatory changes in a small number of key markets continue to trigger change across global industries. Once compliance and R&D costs are incurred in such a lead market, the resulting solutions can rapidly spread across global industries, even if the same regulatory pressures do not exist in other markets.

In California, car manufacturers are for example under pressure to accelerate the development of plug-in hybrids and fully electric vehicles, in order to comply with new zero-emission vehicle (ZEV) sales quotas that come into force in 2018. As global carmakers can ill-afford to stay out of the single largest vehicle market in the US, this is likely to accelerate the commercialization of plug-in-hybrids and EVs, despite the fact that such mandates do not exist in most of the rest of the United States or in many other countries. Similarly, subsidies such as feed-in-tariffs in China and the EU, or tax credits and renewable portfolio standards in many US States have been the key to driving the continued global cost reductions in renewable energy, such as wind and solar.

Navigating global regulation – focus on structural trends

Navigating this complex regulatory landscape will continue to pose a considerable challenge for investors and companies. On the one hand it is clear that governments will continue to increase regulatory pressure on emission-intensive business models and further amplify their support for low carbon technologies. On the other hand, rules and regulations are likely to remain unstable and fragmented across sectors and geographies, creating significant risk and uncertainty for markets.

With respect to the low carbon technologies we are focusing on in this report, we believe long-term investors with a global outlook should focus on a number of key trends, which are likely to shape the regulatory landscape over the next 5-10 years.

LEDs

For LEDs lighting is a solution that is affordable; and with recent developments, can be used for almost every lighting need whether residential, commercial or outdoor. In this regard, policy increasingly takes a back seat as consumers and commercial drivers dominate LED deployment.

Continuing policy contagion could however offer incremental upside in low penetration markets such as India and Malaysia. The Indian government has developed policies to stimulate the LED adopting process in the country. In January 2015, the Prime Minister of India launched a scheme for LED bulb distribution under a domestic efficient lighting programme in the capital city, Delhi and a national programme for LED-based home and street lighting. Malaysia has rolled out a nationwide LED lighting project, aimed at fully replacing conventional lighting projects. The Malaysian government estimates by 2020 street lights nationwide will be switched to LED (currently only 5%).

Policies to disadvantage other lower efficiency lighting could also provide incremental support for continued rapid growth towards the end of the decade. Member States of the EU agreed in 2009 that such inefficient halogen lamps should be phased-out from September 1, 2016. The Commission has decided that the phase-out would be delayed until 2018.

Onshore wind and solar PV

Policy-makers and regulators around the world are in the process of adjusting to performance improvements and rapid cost declines in onshore wind and particularly solar PV. We see three key trends shaping regulation in the space:

(1) Policymakers will continue to move the goal posts on solar and wind targets, creating upside risks for deployment rates. As onshore wind and particularly solar PV are being deployed faster and at a lower cost than anticipated, policy-makers and regulators around the world are responding with increasingly aggressive deployment targets.

(2) This trend is particularly pronounced in many emerging economies, where incumbent technologies are struggling to meet growing energy needs. In countries such as India, Brazil, Turkey, South Africa, and Thailand policy-makers see wind and solar power as an increasingly attractive, rapidly deployable complement to conventional power generation. China for example recently increased its 2020 solar by 50% to 150 GW. India similarly increased its 2022 target 5x to 100 GW. Thailand also updated solar PV targets and wind targets from 0.5 GW and 0.8 GW in 2022 to 3 GW and 1.8 GW in 2021 respectively.

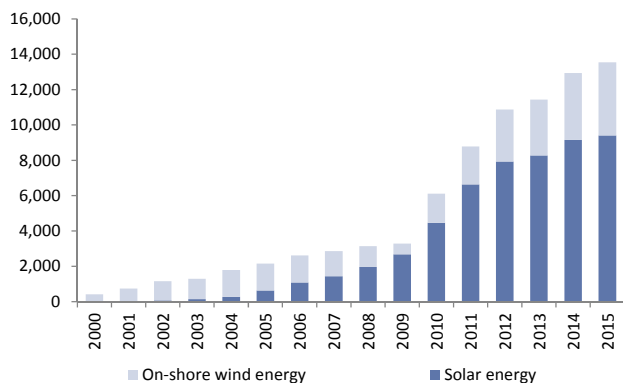
We see this as a positive particularly for solar PV, with potential for a positive feedback loop, as faster than anticipated scaling of supply chains accelerates cost reductions. While countries may not attain their deployment goals in all cases, we believe ambitious targets act as a catalyst for fast-tracking deployment and attracting investor attention. In response to new targets, India private sector players have made significant new commitments. Japan's Softbank for example has announced a new JV with FoxConn and Bharti Enterprises to deploy 20 GW of solar power in India at an estimated cost of \$20 bn.

(3) Policymakers face a difficult balancing act as they try to wean solar PV and onshore wind off state support, creating downside risks for the industry. On aggregate, we expect policy-makers to continue to reduce subsidy rates for wind and solar power, as generous subsidies in combination with high deployment rates create considerable fiscal burdens and cost reductions mean that less subsidies are needed to incentivize deployment.

We see this trend already playing out in a number of key markets. Feed-in tariffs have for example been reformed in Germany, where they will decline incrementally and increasingly be replaced by competitive auctions, as the governments seek to reduce the substantial subsidies for the sector. China similarly decided in January 2015 to reduce feed-in tariffs for onshore wind. In the US, generous tax credits for investors in solar and wind power are scheduled to expire at the end of 2016. While they may be extended (as they have been several times in the past) they are unlikely to become a permanent feature in the US.

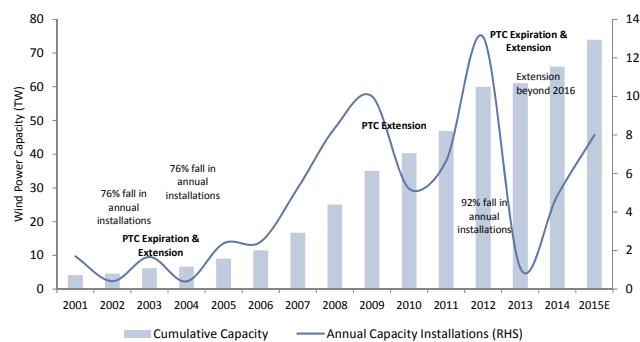
Exhibit 48: Subsidies under Germany’s feed-in tariff scheme have escalated with the rapid build out in wind and solar

EEG differential costs and apportionment amount in € mn



Source: bmwi, Goldman Sachs Global Investment Research.

Exhibit 49: PTC expiry impact
Impact of PTC expiry in the US



Source: American Wind Energy Association.

Gradual subsidy reductions are unlikely to materially slow the trajectory of capacity additions, but sharp reductions or prolonged policy uncertainty in key markets could create material risks for solar and wind companies. Risks are the largest where subsidy levels are set by regulators rather than determined through competitive bidding processes.

Efforts to pass on a greater share of the costs for maintaining the grid and back-up capacity in high penetration markets could become an incremental negative for solar and wind deployment. While this remains the exception rather than the rule (such charges exist, e.g. for solar PV in Arizona), such charges could become more common as deployment continues to increase.

Electric and hybrid electric vehicles

We see hybrid and electric vehicles as the technology with the greatest potential upside from government regulation. In the near term, they are likely to benefit as regulators step up the enforcement of emission rules in the wake of the VW scandal. In the medium term, we also see a growing trend towards incentivizing electric vehicles and plug-in hybrids at the expense of ordinary hybrids, something we already see playing out at the subnational level (e.g. in Beijing, London, California).

We also see electric vehicle incentives as a potential hotspot for regulatory innovation/contagion. We expect policy-makers to continue to experiment with new types of rules and regulations to support faster electric vehicle adoption. This could include the deployment of charging infrastructure, benefits such as free parking and the right to use bus lanes, as well as further tax exemptions and subsidies. Measures that prove effective in incentivizing accelerated deployment in some countries could be copied widely by other countries, as has been the case for policies driving the adoption of LEDs (incandescent phase outs) and solar and wind power (feed-in-tariffs, reverse auctions).

Exhibit 50: California ZEV regulations heading for a new phase in 2018...

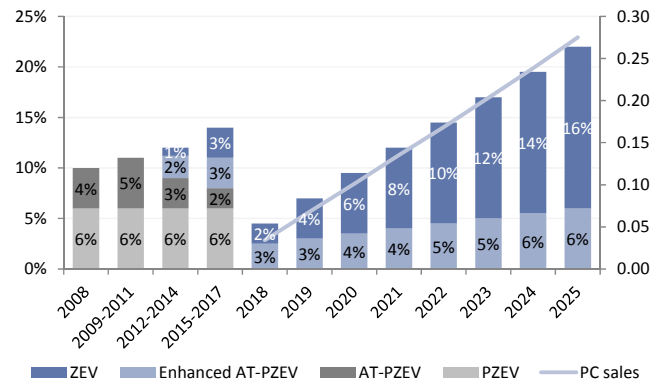
California credits by category

Category	Requirement (UDDS range)	Credit	
		MY2012-17	MY2018-
Type I	50-75miles	2	2
Type I.5	75-100miles	2.5	2.5
Type II	Over 100miles	3	3
Type III	Over 100miles + Fast refueling* or over 200miles	4	3
Type IV	Over 299miles + Fast refueling	5	3
Type V	Over 300miles + Fast refueling	7	3
Fast refueling requirements			
Type III	Must be capable of replacing 95 miles (UDDS ZEV range) in < 10min		
Type IV	Must be capable of replacing 190 miles (UDDS ZEV range) in < 15min		
Type V	Must be capable of replacing 285 miles (UDDS ZEV range) in < 15min		

Source: CEPA, Goldman Sachs Global Investment Research.

Exhibit 51: ...requiring car manufacturers to increasingly shift to grid-connected vehicles

California ZEV regulation schedule



Source: CEPA, Goldman Sachs Global Investment Research.

Norway's electric vehicle market

Like many low carbon technologies, EV will need a combination of technological development, regulatory support and incentives as well as genuine customer demand to reach widespread adoption. EVs' increase from near zero five years ago to 16% (40x global average) of new car sales in Norway illustrates this dynamic.

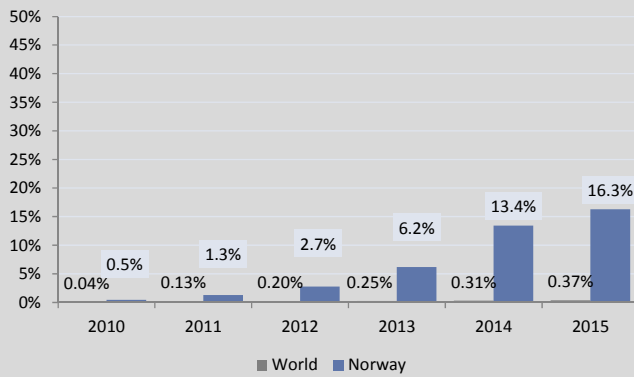
The Norwegian government promoted this development in several ways:

- Already in the mid-1990s Norway started to put in place subsidies and other extensive incentives to instill consumer demand. Electric vehicles offer consumers considerable cost reductions as well as attractive privileges. Customers are incentivized by effective subsidies such as the exemption from purchase tax, VAT, toll road charges, registration tax, and annual circulation tax, free parking and, last but not least, the privileged permission to use bus lanes.
- In 2008, the Norwegian government followed up with the launch of a municipal EV charging infrastructure program, unleashing a rapid build-up. Nationwide Norway has jumped from under 500 charging stations in 2009 to just under 8,000 in 2015 (Exhibit 53).

Regulatory incentives were in place since the 1990s, but it was not until the technological advancement of EVs made them acceptable as an alternative for end users that Norway's EV market share took off. Is this replicable across the global car market? Currently, no. Tax of various sorts make up c.50% of the price of a new car in Norway, i.e., in addition to "perks" such as free parking consumers effectively benefitted from a 50% rebate. This, however, will decline relatively rapidly as the difference between an EV and an equivalent ICE car is shrinking fast.

Exhibit 52: Norway's EV penetrations is 40x the global average

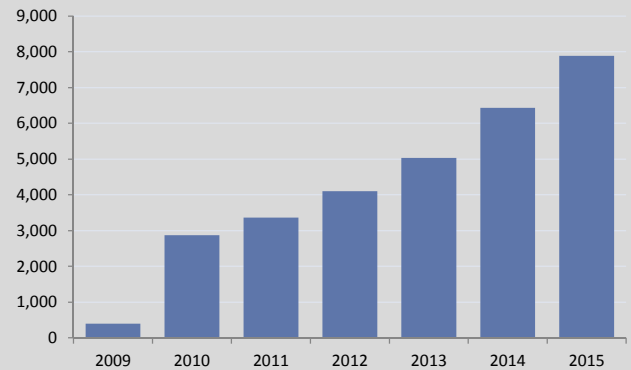
Global market share of EVs vs. market share in Norway



Source: Nature, IHS, Goldman Sachs Global Investment Research.

Exhibit 53: A rapid government-led build-up of charging infrastructure has been a key contributor

Number of charging stations in Norway



Source: NOBIL, Goldman Sachs Global Investment Research.

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Emissions: Beginning to bend the curve

Emissions: Beginning to bend the curve

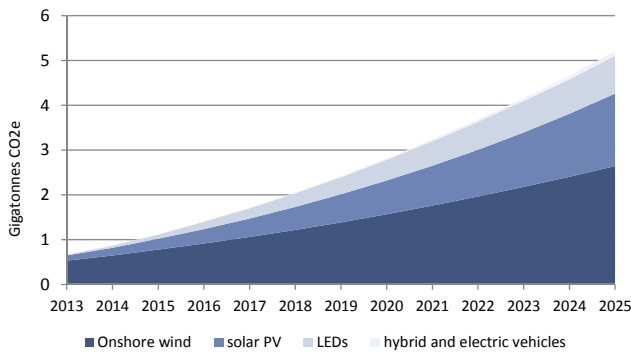
Until very recently, the impact of onshore wind, solar PV, LEDs and grid-connected vehicles – our front-runner technologies – on global emissions has been fairly marginal. Emission savings have come mainly from hydro and nuclear power and boosting the efficiency of incumbent technology, from better fuel mileages for combustion engines and from building cleaner power plants and switching from coal to gas.

Emission savings from solar, wind, LEDs, and hybrids & EVs are now in Gt territory...

As these front-runner technologies continue to scale, emission savings become material, and in 2015 crossed into gigatonne territory for the first time. For these technologies we estimate that the installed base at the end of 2015 will help to save roughly 1.1 Gt of CO₂e emissions per year – up from 0.87 Gt at the end of 2014. This is largely attributable to onshore wind (79%) and, to a lesser extent, solar PV (17%). This oversized impact of wind is explained by the relatively large installed base, higher capacity factors compared to solar PV, and the high emission intensity of the power sector.

Exhibit 54: Wind and solar power deliver the lion's share of 5+ Gt CO₂e savings by 2025

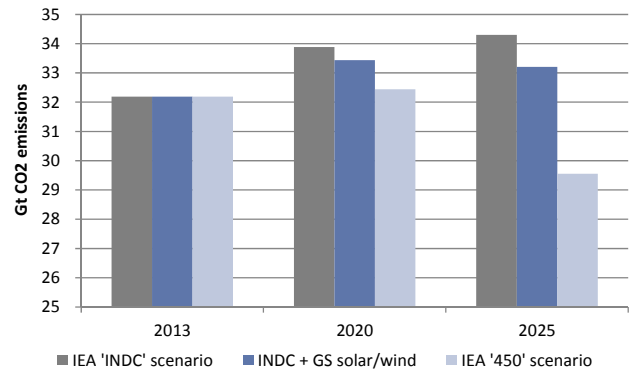
Emissions savings from four low carbon technologies, 2013-2025



Source: Goldman Sachs Global Investment Research.

Exhibit 55: We see low carbon technologies beginning to 'bend' global emission trajectories

CO₂ emissions in IEA 'INDC' and '450' scenarios, and INDC scenario with our solar/wind forecasts



Source: IEA, Goldman Sachs Global Investment Research.

As low carbon technologies take market share they will become a significant source of emission savings over the next decade. We forecast that emission savings will increase to 5.3 Gt CO₂e per annum by 2025. Onshore wind will still dominate, providing almost half of these savings, but the share of solar PV will increase rapidly to 30%, and LEDs and hybrid and electric vehicles together will save slightly over 1 Gt of CO₂e per annum.

How do we calculate emissions savings?

Modelling emissions savings poses significant challenges given the complexity of energy systems and the uncertainties surrounding key parameters, such as future capacity factors for different energy technologies. We derive basic global savings estimates based on a set of simplified assumptions rather than detailed modelling. Although these estimates are rough approximations, we believe they provide relatively robust, conservative estimates for the scale of potential emissions savings available from key low carbon technologies.

Onshore wind: We assume an average capacity factor of 23% for the installed base until 2013 (in line with IEA data). We assume capacity factors for new installations in 2014 to average 30%, increasing in a linear fashion until 2025 to 35%. In line with IEA models we assume average capacity factors of 58% for coal and 37% for gas for 2013; and assume they remain constant until 2025. We assume electricity generated by wind turbines replaces electricity generated by gas and coal in equal amounts. In line with IEA data, we estimate a TWh of electricity generated from coal/gas on average to be associated with 1.03/0.54 mn tonnes of CO₂ emissions.

Solar PV: We assume an average capacity factor of 11% for the installed base until 2013 (in line with IEA data) and of 18% (based on IRENA data) for new installations in 2014, increasing in a linear fashion until 2025 to 25%. All else is equal with onshore wind.

LEDs: We use the GS global lighting model (incl. sub-models for residential, commercial & industrial, and outdoor) to estimate LED penetration and replacement of incandescent, fluorescent and HID lamps. Key assumptions include lifetimes (50k hours) and efficacies for LEDs (increasing from 121 lm/W in 2015 to 196 in 2025). We estimate an alternative no LEDs scenario, assuming that light output is replaced by incumbent technologies in line with their relative market share. This allows us to estimate mounting electricity savings from introduction of LEDs. We convert electricity savings into emissions savings assuming average grid emission intensity of 0.57 mn tonnes of CO₂ emissions per TWh (estimate based on IEA data for 2013) and 10% higher energy use at source than at site owing to transmission and distribution losses.

Hybrid and electric vehicles: We assume 2015 average emissions of 140 g/km driven for internal combustion engines (ICE), and 90 g/km for hybrids. We assume they decline in a linear fashion to 130 g/km for ICEs and 80 g/km for hybrids by 2025. For PHEV and EVs we assume stable emissions at 60 g/km and 0 g/km respectively. We model four markets (US, EU, China, and ROW) with proportional uptake of EVs, PHEVs and hybrids. Based on ICCT data, we assume vehicle km driven per year of 19.8 k for the US, 12.8 for the EU, 19.3 for China and 12.6 for the rest of the world.

...and begin to shift global emission trajectories

Low carbon technologies could start to shift global emission pathways earlier and more significantly than is assumed in mainstream scenarios. We compare our projections to two IEA scenarios, the "INDC" scenario (modelled on the assumption that countries will achieve their self-set Paris targets) and the "450" scenario (assuming more ambitious policies including carbon pricing to limit emissions to levels that will keep temperature rises below 2°C). We find that, relative to our forecast, both scenarios considerably underestimate the speed of wind power deployment (42% and 24% below our estimate by 2025 in the INDC and 450 scenarios respectively) and particularly solar power (76% and 70% below our estimates).

These technologies present no 'silver bullet' to rein in CO₂ emissions; they could help global emissions to peak around 2020 – rather than continuing to increase slowly over the next decade. In the IEA's 'INDC' scenario, emissions keep rising slowly as gradual reductions in carbon intensities are more than offset by growing global GDP. All else equal, our solar PV and onshore wind assumptions would reduce emissions by 2025 by 8%, and contribute to an overall decline in emissions in the 2020-25 period. By themselves, these reductions are not large enough to move global emissions into a '2° scenario', but policy support, particularly for onshore wind and solar PV, could increase further as their near-term emissions reduction potential becomes increasingly apparent. Emissions savings from LEDs and hybrid and electric vehicles could contribute to additional emission reductions (we do not model their impact in the scenarios as the specific assumptions on LEDs and hybrid/electric vehicles are not detailed by the IEA).

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The low carbon economy: Reshaping competitive dynamics

The low carbon economy: Reshaping competitive dynamics

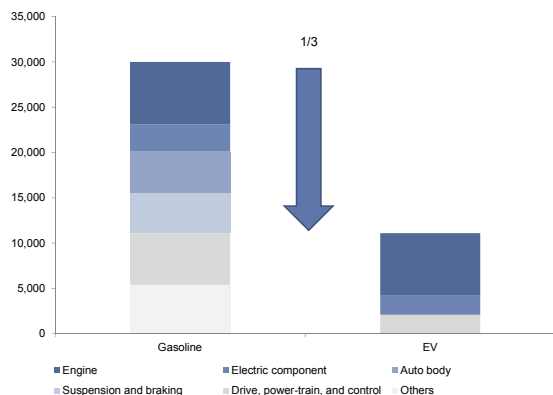
The evolution of low-carbon technologies and mounting regulatory pressure to curb emissions are driving structural change across global industries. In lighting, power generation and autos, we see low carbon technologies shifting competitive dynamics in a variety of ways, from reducing barriers to entry and attracting new entrants, to the proliferation of new business models. We also see growing knock-on effects across supply chains and mounting reputational and compliance risks across our global coverage.

Most obviously we see this in the three sectors we highlight throughout this report – lighting, power generation and increasingly autos – where low carbon technologies are beginning to replace carbon-intensive incumbent technologies at an accelerating rate. The drivers may be different, but we see many parallels to symptoms in other industries in the grip of fast-paced technological paradigm shifts, from retail (e-commerce) to oil E&P (shale technology). These include lower barriers to entry and changing business models as well as market fragmentation and growing pressure to make large and risky investments.

Low carbon technologies can (1) lower barriers to entry...

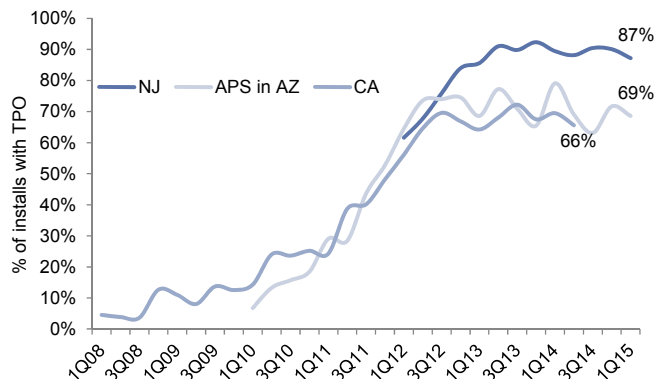
A paradigm shift in technology often lowers barriers to entry and creates openings for new business models. In autos, fewer parts in electric vehicles compared to cars driven by combustion engines could help to erode the competitive advantages of incumbents and make it easier for start-ups or companies from other industries to enter the sector. An EV includes only about one-third of the number of components of on board vehicles powered by a gasoline engine (see Exhibit 56). As a result: (1) there is the ability to coordinate and integrate production across several fronts, which is a key strength of conventional automakers, as well as; (2) their supplier management practices, which are not necessarily as big a competitive advantage as they have been in the past.

Exhibit 56: Electric vehicles have fewer parts
Number of parts in a gasoline vehicle vs electric vehicle



Source: Goldman Sachs Global Investment Research.

Exhibit 57: ...Leasing is increasingly popular in US solar
Percentage of installs with third party ownership



Source: APS, New Jersey Clean Energy Program, BPU, Goldman Sachs Global Investment Research.

... (2) create openings for new business models...

Innovative leasing and finance models in the solar sector have also allowed retail customers to participate in the notoriously capital incentive power generation sector.

Rather than facing upfront costs between \$24,000-\$30,000 dollars, “Solar-as-a-Service” enables homeowners to lease panels at little upfront cost. Rooftop installation companies in turn have to be able to tap into large scale funding from financial institutions through innovative financial arrangements, such as tax equity products.

In lighting we see a similar trend towards innovative business models, even if “Lighting-as-a-Service” is still less developed. Acuity Brands, with 46% of its total sales in LEDs, recently announced a partnership with Key Equipment Finance to provide flexible financing options for customers (often for larger commercial or municipal clients) looking for transition to LED-based lighting solutions. In the fragmented lighting industry, such new business models could prove important to companies’ ability to reach higher market shares.

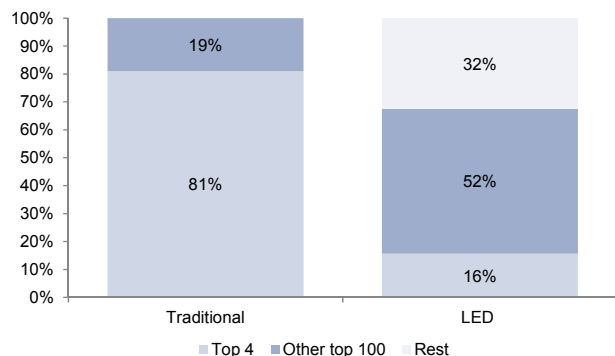
... (3) can contribute to market fragmentation ...

The lighting case demonstrates how rapid technological change and falling barriers to entry can lead to market fragmentation and intensifying competitive pressures. For several decades, the lighting industry was a relatively stable industry, dominated by a handful of global companies. These incumbents were selling a premium product into a consolidated market with strong cost advantage achieved through significant economies of scale. LED technology eroded these advantages and allowed a large number of new entrants to challenge entrenched incumbents. While the latter managed to maintain their leadership in the sector, the market fragmented and competitive pressures resulted in significant margin compression.

The market for solar panels is similarly fragmented with global blue-chip companies that dominate thermal power generation equipment market playing an insignificant role. While engineering companies like Siemens and GE (both among the technology leaders in conventional power generation equipment markets) are significant suppliers of wind power generation equipment, they are two among many players in a market led by specialized equipment manufacturers.

Exhibit 58: Fragmentation in LEDs...

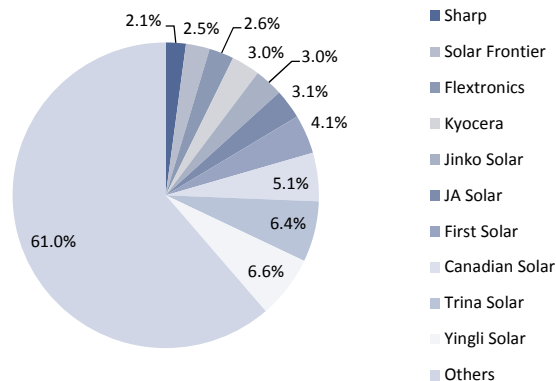
Market shares in the lighting industry



Source: CSIL 2011, Goldman Sachs Global Investment Research.

Exhibit 59: ...leading to declining margins

Market shares in the lighting industry (2013)



Source: NREL, Company data.

... (4) and often force incumbents into large and risky investments.

Incumbents do not only have to adapt to the proliferation of new business models, but in many cases also make large and risky investment in new low-carbon technologies to

Carbon concerns reflected in the Competitive Positioning (CP) frameworks

In the wake of increasing regulations, carbon emissions and their impact on the competitive landscape are gaining more importance. One of the ways in which our analysts reflect these concerns through integration in our Competitive Positioning frameworks. These are a set of positioning frameworks that aim to appraise the strength of companies' operations and identify those best placed to tackle the challenge of a fast-evolving operating environment. Below we highlight the way in which competitive pressures from carbon regulation are reflected in Automobiles and Utilities – two sectors where this is particularly relevant.

Automobiles

"The single biggest challenge we see to the global automotive industry and its profit pool is increasingly stringent global emissions regulations. The biggest global automotive markets, North America, China and Europe are all progressively tightening emission regulation thresholds. To comply with these targets constitutes significant headwinds to industry profitability, both through higher research and development requirements and significantly higher variable costs. While regulation is a significant headwind to OEMs (given their lack of pricing power) it can also present opportunities; for example for technology suppliers who stand to benefit from supplying the requisite technical solutions."

- *Upward mobility: The rise of global autos – Competitive positioning in a growing, evolving autos industry, May 2014*

"Major developed nations are under pressure to reduce vehicle CO₂/kg 30%-40% by 2025. We estimate the ratio of Electrified Vehicles, which includes EVs, PHEVs and HVs, will increase to 25% from the current 5%. In addition, further improvements in the thermal efficiency of internal combustion engines (ICE) will be needed and can yield significant benefits as a 1% improvement in thermal efficiency cuts fuel consumption by 2%-3%."

- *A disruptive new era of the Automotive Age – Technology accelerating a rapid shift in the future of mobility, May 2015*

Utilities

"We believe global governments' growing focus on environmental issues is likely to have significant implications for the industry through increasing emphasis on low emissions generation such as renewables and clean water/air and waste management as well as higher carbon prices. This focus increases and directs capex as well as driving dispersion in returns (cleaner power generation/assets are likely to benefit)."

"Over the next 5-10 years, we expect higher costs for emissions in all parts of the world. Power generators with lower emission technology (nuclear, hydro, renewables) will fare better in this environment than coal-fired generators in particular." "We forecast high levels of capex for the global sector, driven by the need to replace existing power generation/network facilities, lower carbon emissions, improve interconnections and satisfy growth in demand."

- *Illuminating value drivers – Analysis of 148 utilities to identify best-positioned assets, December 2014*

Exhibit 60: Environmental focus in our Global Utilities framework

Themes shaping industry (next 5-10 years)	Need for investment	Environmental focus	Evolving regulation	Commodity cycle
	Driven by replacement, to provide better interconnectivity between markets and for new renewable capacity, and to satisfy growth in electricity/gas demand	Increasing emphasis on low emission generation, clean water/air, waste management and an environment of higher prices for emissions	Declining returns for regulated activities reflecting lower interest rates (and pressure on tariffs) as well as more intervention in "unregulated" markets of power generation/supply	Changes to commodity prices (coal, gas and carbon) can have a significant impact on returns for power generation activities
Drivers of corporate performance	Competitive Positioning			
CP Category	Access to Growth	Pricing Power	Cost Advantage	
CP Metrics	Geography-specific measures		Company-specific measures	
	Growth outlook	Regulatory risk	Cost efficiency	
	Expected growth in power demand	Retail tariffs (as % of mean income) and industrial tariffs (absolute) – indication of political sensitivity of tariffs	Cost of generation (/MWh) vs. marginal cost in region	
	Expected evolution of electricity reserve margins	World Bank regulatory quality score	Emission intensity (tn/MWh)	
	Growth in renewables	Gov't financial health: govt debt/GDP; net borrowing/GDP, inflation	Regulated return vs. 10-yr government bond yield	

Source: Goldman Sachs Global Investment Research

secure a foothold in a fast-evolving sectors. Autos companies for example are forced to make risky bets on alternative drive train technologies with an uncertain future, while at the same time investing in reducing emissions from combustion engines to comply with ever stricter regulations to sustain their existing businesses.

Since 2011, Nissan has invested c.\$5 bn in vehicle development and battery production. Nissan’s initial projection estimated that EVs would account for 10% (around 10 mn units) of total vehicle demand by 2020. While the Nissan Leaf is among the best-selling EVs, sales have remained relatively constant at around 2,000-3,000 vehicles per month. Other car makers have similarly made significant investments in electric vehicles (e.g. BMW, General Motors, VW) or other alternative drive train technologies such as fuel cell vehicles (Toyota).

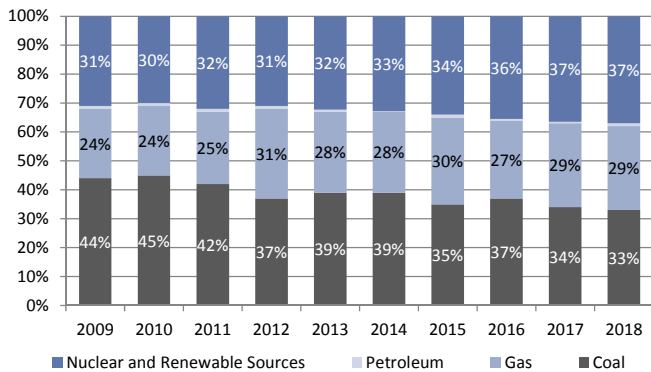
We also see significant knock-on effects across supply chains...

We see low carbon technologies creating significant knock-on effects across supply chains. As low-carbon technologies shift competitive dynamics and material footprints in upstream industries, the reverberations in the upstream supply industries can be significant.

These effects are for example visible in basic materials, particularly seaborne coal. Like many commodities, seaborne coal prices have declined significantly from a combination of slowing demand growth and oversupply problems. However, with governments around the world making increasing efforts to replace thermal power generation with other cleaner and less carbon intensive energy sources, our analysts believe that demand for the commodity will face structural long-term decline (see *Heat Sensors: Thermal coal reaches retirement age*, January 23, 2015).

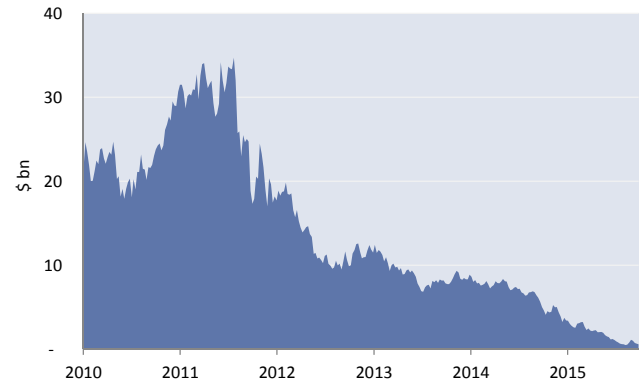
The impacts of mounting regulatory pressure and market share losses to cleaner sources from gas to renewables are nowhere more visible than in the US. Coal still accounts for 35% of energy generation, however has lost 9 percentage points of market share since 2009. Our analysts project further declines to 33% by 2018E as many aging coal-fired power plants face accelerated retirement due to tightening emission regulations and growing competitive pressures from cheap gas and rapidly growing renewable sources. In conjunction with low world market prices and weak export demand, this has had significant adverse consequences for the US coal industry, with the largest four companies losing over 90% of their market caps in 2015.

Exhibit 61: The US electricity mix is shifting, with coal on the losing side
US electricity mix



Source: International Energy Agency, McCloskey, Goldman Sachs Global Investment Research.

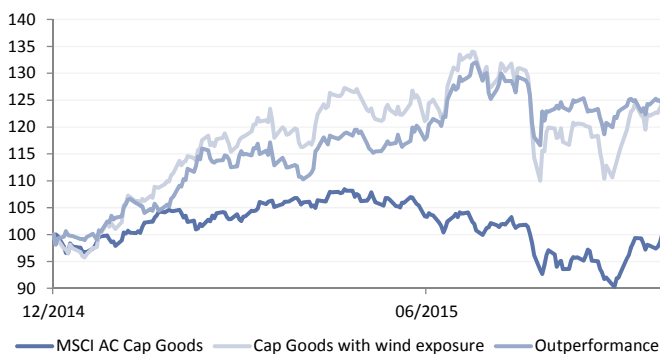
Exhibit 62: The combined market cap of the four largest US coal producers has declined by over 90% since 2011
Combined market capitalization,



Source: Datastream, Goldman Sachs Global Investment Research.

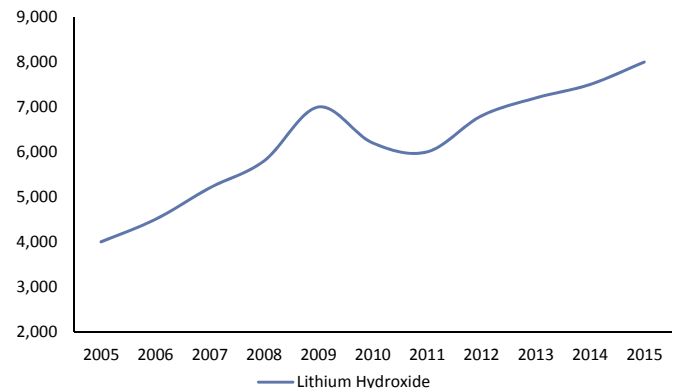
Other industries have been beneficiaries of the growing importance of low-carbon technologies. The price of lithium, for example has defied the downward trend in global commodity prices, with prices on a steady upward trajectory since 2011. The material is a critical raw material for the fast-growing global battery-supply chain. Wind-exposed capital goods companies have similarly managed to defy the broader downturn in capital spending across our coverage (see *Fortnightly Answers Questions: Where are the capex hotspots?* November 23, 2015).

Exhibit 63: Wind makes the difference
Cap goods companies with wind exposure vs. the sector



Source: Datastream, Goldman Sachs Global Investment Research.

Exhibit 64: Lithium continues to be in demand
Lithium price trends (USD/metric tonnes)



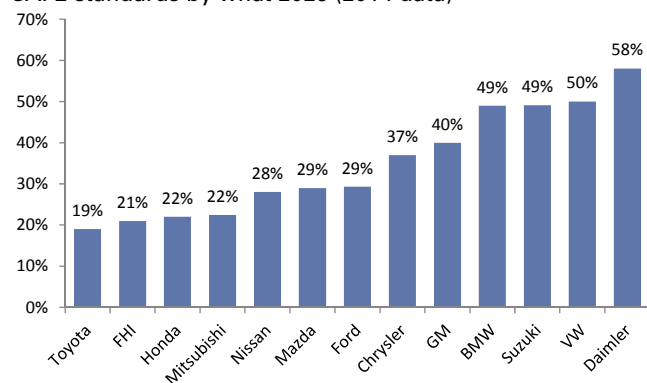
Source: Benchmark Mineral Intelligence, Goldman Sachs Global Investment Research.

...and mounting regulatory & reputational risks

Apart from the impacts of low-carbon technologies on competitive dynamics, we also see increasing compliance costs and reputational risks in many industries across our coverage (reflected in our GS SUSTAIN Governance and Risk Management metrics see *Governance and Risk Management – expanding coverage, narrowing focus*, March 1, 2015). This is particularly relevant in carbon-intensive heavy industries such as cement, steel, chemicals, and paper & pulp, where public scrutiny and compliance cost are increasing. We also see this as an increasingly important factor in consumer-facing businesses with large carbon footprints such as airlines, where reputational risks can be material.

Exhibit 65: Compliance and reputational risks in the autos sector increasingly linked to emissions...

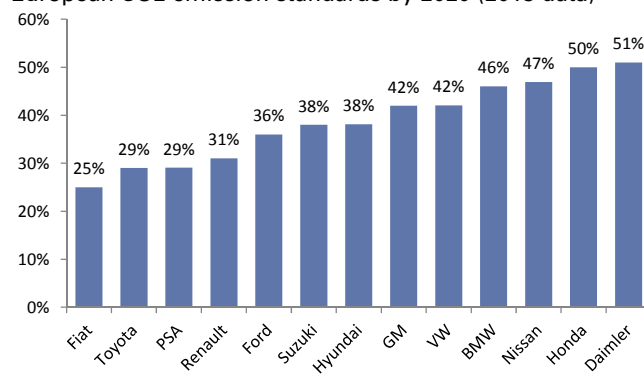
Degree of fuel economy improvement required to meet US CAFÉ standards by what 2025 (2014 data)



Source: EPA, compiled by Goldman Sachs Global Investment Research.

Exhibit 66: ...with car makers exposure varying with the carbon intensities of their vehicle fleets

Degree of fuel economy improvement required to meet European CO2 emission standards by 2020 (2013 data)



Source: EU, compiled by Goldman Sachs Global Investment Research.

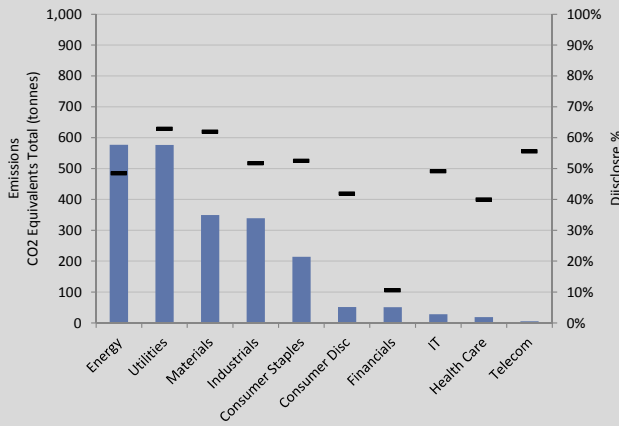
Such regulatory risk have been recently highlighted in the autos sector, where the “Dieselgate” scandal at Volkswagen illustrates the increasingly material compliance and reputational risks linked to emissions (see *‘Dieselgate’ shifts opportunity set towards suppliers*, September 29, 2015). We also see this as something potentially increasingly significant in other consumer-facing businesses with substantial carbon footprints such as airlines.

GS SUSTAINs Governance and Risk management (GRM) screening reflects emission concerns

Governance and Risk Management (GRM) is one of the three pillars of the GS SUSTAIN framework, and offers a unique tool for assessing environmental social and governance risks relative to global competitors (See *Governance and Risk Management – expanding coverage, narrowing focus*, March 1, 2015). We use a screening based on a wide variety of metrics to assess such risks, including an assessment of CO2 equivalent emissions relative to global peers. To make emissions footprints comparable across industry peers, we divide the total CO2 equivalent emissions by the gross cash invested. Companies in the lowest quintile are given the highest score and vice-versa for companies in the highest quintile. Companies that do not disclose the emissions data are also scored lowest.

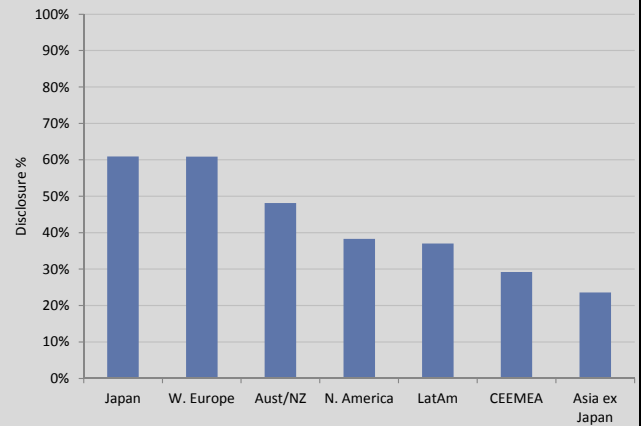
The exhibits below summarize the CO2 equivalent emissions and disclosure levels of MSCI ACWI constituents. Unsurprisingly resource-related industries have the highest CO2 equivalent emissions (Energy, Utilities and Materials) compared to services related sectors like IT, Healthcare and Telecom. Disclosure levels are relatively higher for the DMs vs. EMs with Japanese companies taking the lead; whereas companies in Asia ex Japan disclosing the least.

Exhibit 67: CO2 Equivalents Total emissions (tonnes)
Split by Sector



Source: Goldman Sachs Global Investment Research

Exhibit 68: ...higher disclosure for Developed countries
Split by region



Source: Goldman Sachs Global Investment Research

Disclosure Appendix

Reg AC

We, Jaakko Kooroshy, Aaron Ibbotson, CFA, Brian Lee, CFA, Derek R. Bingham, Warwick Simons, Justus Schirmacher, Gabriel Wilson-Otto, CFA, Gaurav Tandon and Juhi Malik, hereby certify that all of the views expressed in this report accurately reflect our personal views about the subject company or companies and its or their securities. We also certify that no part of our compensation was, is or will be, directly or indirectly, related to the specific recommendations or views expressed in this report.

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