Renewable Energy: a Route to Decarbonisation in Peril?

Paper prepared for the
29th Round Table on Sustainable Development
to be held at OECD Headquarters, Paris
4-5 June 2013

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ACKNOWLEDGEMENTS

This paper was prepared by Richard Baron (OECD Round Table on Sustainable Development). The author would like to thank Simon Upton for his critical guidance and constructive comments on earlier drafts, and the following for their suggestions and comments: Chris Kaminker, Nick Johnstone, Virginie Marchal, Ron Steenblik and Robert Youngman (OECD), Paolo Frankl, Uwe Remme, Markus Wrake, Marco Baroni, Laura Cozzi, Christina Hood, Laszlo Varro, Manuel Baritaud (IEA), Dominique Finon (CIRED), Michael Taylor (IRENA), Bart Stoffer (GE Energy), Dan Arvizu, Morgan Bazilian and Jeffrey Logan (NREL), Jean-Christophe Füeg (Swiss Federal Office of Energy), Sarah Eastabrook (Alstom), Maria Mendiluce (WBCSD), and Amelia Smith for thorough reviewing and editing.

The Round Table on Sustainable Development gratefully acknowledges financial support provided by the World Business Council on Sustainable Development.

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KEY CONCLUSIONS

Climate science continues to underscore the need for global energy needs to be met from sources that will progressively permit the elimination of carbon emissions to the atmosphere in the second half of this century. Without this transformation it will not be possible to keep global warming to below 2 degrees Celsius.

Under this constraint, the future energy system will plausibly have to rely on a much larger share of renewable energy technologies going far beyond the hydro-electricity and biomass energy that dominate renewables today, as well as embrace other zero emission options such as CCS. By 2050, solar and wind technologies alone may have to supply 30% of global electricity demand. That is more than the total electricity production of OECD countries today. These technologies accounted for less than 2% of global supply in 2010.

Most renewable electricity technologies are not generally competitive, even if examples to the contrary are no longer rare. The commercial viability of renewables remains hampered by market failures, especially the absence of a CO_2 price that reflects the global constraint on emissions. In the current second or third-best world, other policy instruments have had to be implemented to subsidise RE technology deployment; these have resulted in significant market growth and cost reductions.

Such policy instruments may be approaching their limits. Beyond this, barriers are emerging that could prevent the further deployment of renewable electricity:

- The financial crisis has hit investment in clean energy, including renewable electricity, although not in all regions. Rapid reductions in the prices of PV panels and wind turbines have led to an unexpectedly high number of projects coming forward, and increases in the cost of policy support measures and electricity prices. Abrupt changes to policy support measures have severely undermined the confidence of investors in this sector.

- The variability of the wind and solar resource raises challenges for electricity systems. Countries where deployment of is relatively high (above 10% of electricity generation) have coped with this either by extensive connections to other electricity systems, or maintaining excess capacity in flexible natural-gas plants. Even higher levels of renewable penetration will require broader inter-regional and international grid connections, demand response (including through smart grids) and electricity storage capacity to create much more flexible electricity systems.

- Today's electricity market arrangements were not designed with decarbonisation in mind. At present, the more renewable electricity (at high cost, covered by subsidies) coming onto the market the lower the electricity price. This paradox will have to be resolved in the future. New market designs may be required in the future. This experience may be useful to regions that have not adopted electricity markets but will seek to minimise the cost of the transition to low-carbon electricity systems.

- In the US, cheap unconventional gas lowers electricity generation costs and therefore increases the cost of supporting renewable electricity technologies. On the other hand, gas plants are well suited to follow the ups and downs of intermittent electricity, and can substitute to more CO_2-intensive coal-plants. The future of unconventional gas is uncertain in other regions of the world, but at a time when support measures to renewables are being re-evaluated, it is important to understand how the arrival of unconventional gas can be accommodated without locking electricity systems into an even longer period of dependence on fossil fuel. Policy makers will need to be careful to ensure that the availability of a new source of fossil fuel does not bring progress in renewables to a standstill but rather complements the transition to a zero-emissions world.

INTRODUCTION:
WHY LOOK AT RENEWABLE ENERGY AND DECARBONISATION NOW?

1. The threat of climate change, combined with increased volatility in fossil fuel markets, has seen strong policy support for the deployment of renewable energy sources over the last decade. Defined as having a very limited or benign impact on natural resources, renewables have also become synonymous with CO_2 emissions-free energy, even if their manufacturing and operations lead to some, often insignificant, emission of CO_2 or other greenhouse gases.

2. New renewable energy sources have recorded double-digit growth rates in the last decade. As of 2012, the installed capacities of wind and solar power generation combined approached that of nuclear. Even if nuclear still delivers much more power to the grid globally than these variable resources, it is a remarkable development. Renewables are also far ahead of fossil generation fitted with carbon capture and storage (CCS) technologies. While many CCS projects are underway, there are no full-sized power plants fitted with this technology in operation today.

3. However, renewables now seem to have entered a zone of turbulence. The debt crisis, the rapid, sometimes retroactive reduction of economic incentives in support of renewables and the collapse in CO_2 prices in Europe saw investment in renewable energy slow during 2012. With manufacturing capacities about twice as high as global demand for both wind and photovoltaic, some consolidation was warranted and is now underway. This combination of factors could be seen as an emerging barrier to the deployment of renewables at scale to mitigate climate change. This is of concern given that other solutions such as energy efficiency, nuclear energy, CCS and land-use change activities are not being deployed on sufficient scale to take up the slack.

4. Other challenges are increasingly raised in discussions about renewables at scale, especially wind and solar. It is feared that these variable resources will impose new strains on electricity transmission infrastructures designed to handle the dispatch of power from plants with more predictable electricity output rather than less predictable sources. Increasing quantities of power from variable renewable energy (VRE) will require both careful policy design and infrastructure planning.

5. Last, in the absence of adequate carbon prices, the penetration of VRE will need financial support to bridge the competitiveness gap with other power generation alternatives for some time to come. The recent development of cheap shale gas in the United States, and electricity prices hitting record lows as a result, is seen by some as putting into question the high level of support for VRE deployment at this stage. In this view, gas is seen as a preferable transition fuel until low-carbon technologies become fully competitive. Others view gas as a perfect complement to a high VRE scenario in which gas turbines would provide the needed extra flexibility to ensure a reliable electricity system. Still others worry that a widespread switch to gas will simply prolong path dependency on fossil fuel.

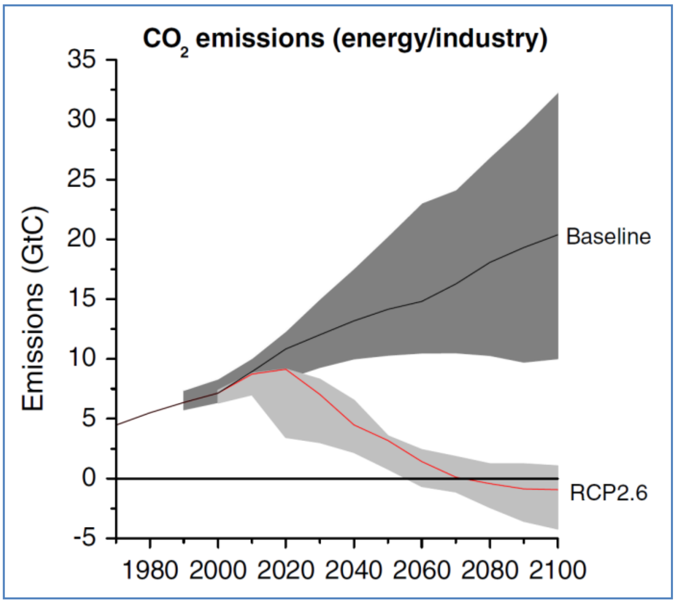
6. This paper summarises the current understanding of these challenges and the basis on which variable renewable energy in particular can contribute to secure, low-carbon, electricity generation. Section 1 presents the decarbonisation challenge and gives an overview of scenario results on the role of renewables in the decarbonisation of the electricity sector. Section 2 describes the current status of variable renewable energy sources and their relative competitiveness. Section 3 reviews support measures and financing issues. Section 4 focuses on the integration of VRE from both a technical and market organisation perspective. Section 5 asks whether the rise of unconventional gas supply will encourage or hinder the contribution of VRE to decarbonisation.

1. THE ROLE OF RENEWABLES IN GLOBAL CLIMATE MITIGATION

1.1 Meeting climate change goals requires full decarbonisation of energy

7. The international research community has updated its approach to future climate change scenarios to support the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). The forthcoming report will provide a range of emission scenarios that represent different climate policy responses and includes the elaboration of a policy mix designed to meet the aspirational 2°C climate change objective adopted at the UN climate conference in Copenhagen (2009).

Figure 1. CO_2 emissions from energy and industry to achieve the 2°C objective



Source: van Vuuren et al. (2011).

Note: Ranges reflect other modelling scenarios.

8. Van Vuuren et al. (2011) built this 2°C scenario (RCP 2.6)[1], taking into account emissions from energy production and use, land-use change and forestry, and non-CO_2 greenhouse gases and gases with a negative impact on temperature increase. The scenario envisages a range of renewable sources for electricity production including bioenergy along with carbon capture and storage technology (CCS) to produce electricity with negative emissions (*i.e.* a net capture of CO_2 from the atmosphere through photosynthesis into permanent reservoirs with CCS).[2]

9. In the absence of an energy technology with net negative emissions, zero-carbon options would need to penetrate more vigorously and earlier than already assumed in RCP2.6 – a scenario seen as

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[1] Representative Concentration Pathway for a global radiative forcing of 2.6 W/m^2, consistent with the 2°C goal.

[2] This negative-emission technology is in fact critical to the achievement of the 2°C objective. In light of other emission trends in land-use, RCP2.6 projects net *negative* emissions from the energy/industry sector by the end of the century, at about -1 billion tons of carbon or -3.7 billion tons of CO_2 ($GtCO_2$).

implausible by other modelling studies (see van Vuuren et al. 2011). In short, the energy sector must completely decarbonise and become a net absorber of CO_2 in the second half of the century if the world is to achieve the 2°C objective.

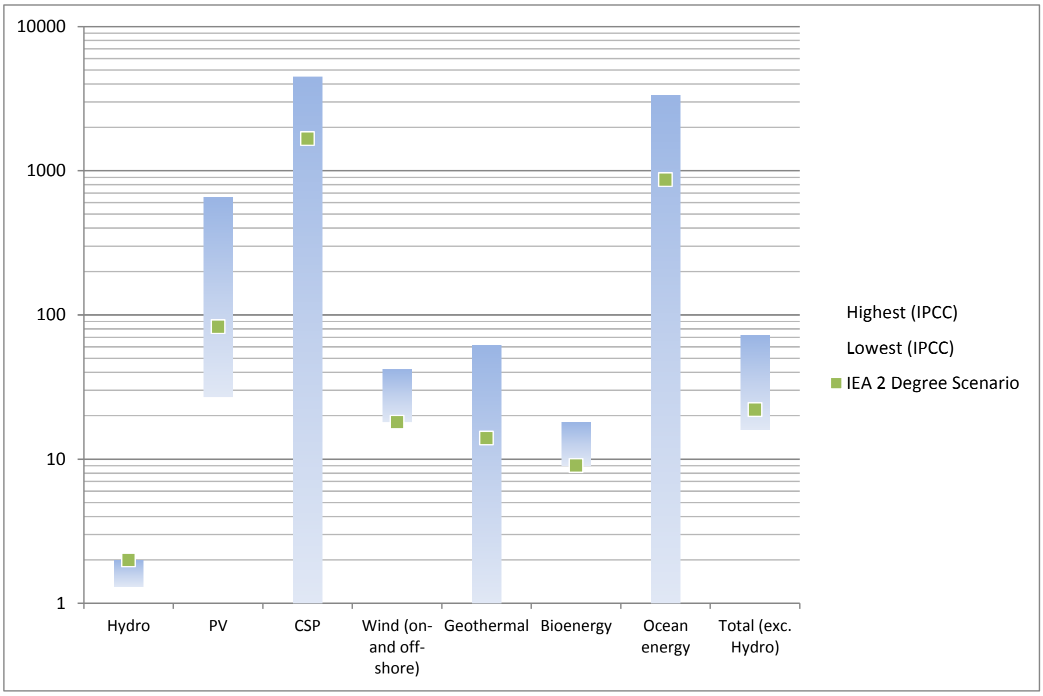
1.2 Renewable energy: the future challenge

1.2.1 Renewable energy deployment in low-carbon scenarios

10. Modelling scenarios abound on the future energy mix required to maintain the global temperature increase below 2°C. These scenarios work from a broad portfolio of energy technologies and their costs, as well as general economic growth assumptions. Their energy projections result generally from a minimisation of cost under a CO_2 constraint.

11. Figure 2. forecasts the growth factors of electricity output from renewable sources between 2010 and 2050. It includes the high and low estimates for all scenarios surveyed by the IPCC Special Report on Renewable Energy (IPCC, 2011), and point estimates from a recent, internally consistent scenario: the *2 Degree Scenario* (*2DS*) of the International Energy Agency (IEA, 2012.b).

Figure 2. Multipliers of renewable electricity output between 2010 and 2050



Sources: IPCC (2011), IEA (2012.b).

12. Hydroelectricity only doubles between 2010 and 2050 in IEA *2DS* but nonetheless produces one-sixth of the world's electricity by the end of the period. Other renewable electricity grows 22 times between now and 2050, amounting to 40% of total electricity production and adding up to more than all electricity produced by fossil fuels today. In this low-carbon scenario, variable renewable energy sources

alone (from PV panels, concentrated solar power plants, wind turbines and marine technology) would generate more than twice China's electricity output in 2012.[3]

1.2.2 Main assumptions behind the high penetration of new renewable energy sources

13. The significant growth in renewable energy supply described in the various scenarios reflects technical assumptions and policy assumptions necessary to move the global energy system away from low-cost fossil fuel use to a higher cost, low-carbon solution. They include:

- **A technology potential**, *i.e.* an upper bound can be put on hydropower developments based on existing dams, geographical constraints on rivers and flows, etc. By contrast, in spite of spectacular growth (especially for wind and solar-based electricity), the technical potentials of new renewables are very far from being fully exploited in the scenarios (see Box 1 on theoretical renewable energy potentials).[4]

- **A significant price on CO_2 emissions**, *i.e.* either a tax on emissions or a market-based instrument (emissions trading). The *OECD Environmental Outlook to 2050* projects an economy-wide global price of USD 325/tCO_2 in 2050. In the more technology-oriented *2DS*, the marginal cost of CO_2 is USD 160/tCO_2 by 2050 (OECD, 2012, IEA, 2012.b).[5]

- **Specific subsidies to renewable sources, evolving over the period**. Such subsidies are subject to two drivers. On the one hand, near term growth in renewable sources implies a growth in subsidies expenditures. On the other, a rising CO_2 price makes low-carbon technologies more competitive in the electricity market (where it exists). Further, learning effects and economies of scale lower the unit cost of renewables, reducing the need for subsidies.[6]

- **A significant improvement in end-use efficiency**. Low-carbon scenarios assume a lower level of energy demand than under business-as-usual conditions, driven by ambitious energy efficiency policies and rising energy prices – a result of the carbon price and the penetration of higher-cost supply sources.[7] The same amount of renewable energy in the mix goes further towards cutting carbon by displacing demand otherwise met by fossil fuels. More efficient end-uses would also facilitate social acceptance of the transition by decreasing end-users' exposure to rising unit costs.

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[3] China's output amounted to 4 900 TWh in 2012 (China Daily, 2013). In IEA *2DS*, variable renewables would generate 12 650 TWh by 2050.

[4] See IPCC 2011, p.12, for a summary of technical potentials in geothermal, hydro, ocean, wind, biomass and solar technologies. As an example, wind technologies could *technically* supply more than the current level of electricity use (provided that adequate storage and grid balancing issues can be managed). These potentials do not take costs into account, however.

[5] In the nearer term, the *450 Scenario* of the IEA assumes carbon pricing policies in OECD and emerging economies with a price range of USD2010 95-120 tCO_2 by 2035 (IEA, 2012.h).

[6] In the IEA *World Energy Outlook*, total renewable subsidy expenditures grow by a mere 5% between the *New Policies Scenario*, which assumes limited action on climate, and the low-carbon *450 Scenario*, for a 60% increase in renewable electricity other than hydroelectricity. This results from a higher CO_2 price and lower technology prices driven by learning and economies of scale in the *450 Scenario*.

[7] In the case of electricity, this general trend can be partly offset by the penetration of electric vehicles (Fulton and Trigg, 2011).

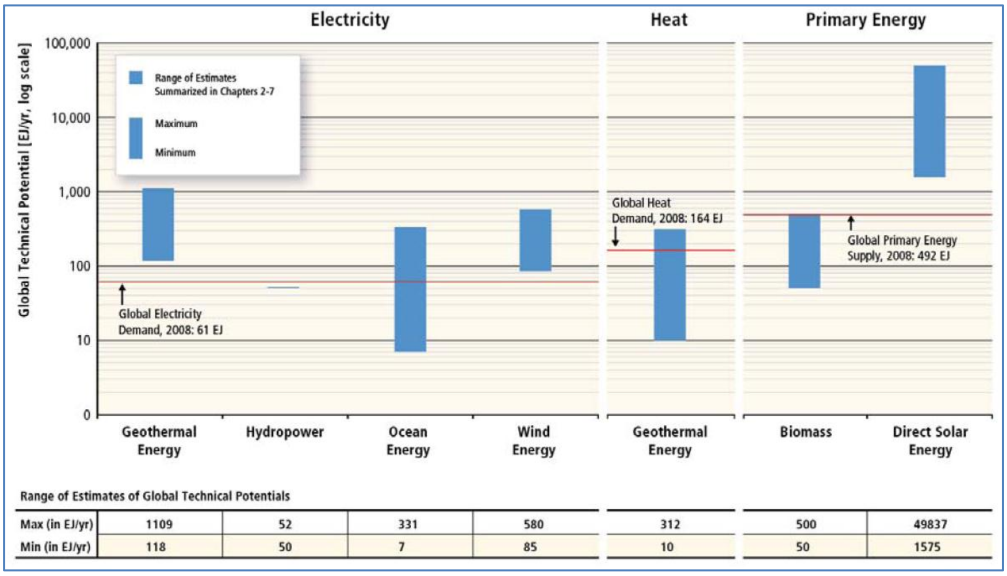
- **The removal of subsidies to the production and use of fossil fuels,** which, in some countries, have had some bearing on fuel choice in power generation.

- The availability and deployment of **other low-carbon technologies** (nuclear, CCS in power generation and industry, etc.).

Box 1. The global theoretical renewable energy potentials

The following figure, taken from the IPCC *Special Report on Renewable Energy Sources and Climate Change Mitigation,* compares renewable energy potentials with global levels of total electricity, heat and primary energy demand.

Ranges of technical potentials of renewable energy sources



	Geothermal Energy	Hydropower	Ocean Energy	Wind Energy	Geothermal Energy	Biomass	Direct Solar Energy
Max (in EJ/yr)	1109	52	331	580	312	500	49837
Min (in EJ/yr)	118	50	7	85	10	50	1575

Source: IPCC, 2011.a

Note: Logarithmic scales are used due to wide ranges. As biomass and solar could have multiple uses (electricity, heat, etc.), their potentials are indicated in primary energy use equivalent. IPCC adds that “Ranges are based on various methods and apply to different future years; consequently, the resulting ranges are not strictly comparable across technologies.” (p.8, IPCC, 2011.b)

These potentials are not the measure of all available energy from the sun, wind, hydro and biomass resources on the planet, which is orders of magnitude larger than reported. They reflect, rather, potentials through the use of specific technologies available today, even if not all are mature *nor commercially viable*. Overall, renewable energy can make a major contribution to meeting global energy demand, whether through electricity production, heat, or the production of fuels (through biomass).

1.2.3 Why focus on variable renewable energy

14. In addition to these policy and technology assumptions, the scenarios also assume that electricity systems will adjust to accommodate the growing deployment of variable energy technologies. This assumption is particularly important in respect of solar and wind. Geothermal and bioenergy electricity technologies can generate stable amounts of electricity without much uncertainty; solar and wind are inherently variable. Transmission and storage infrastructures – and associated costs – are mentioned in

IPCC as particularly important determinants of large renewable energy penetration in the medium run. And, indeed, the deployment of variable renewable energy (VRE) appears very significant: electricity from wind, solar and marine technologies could generate more electricity in 2050 than all the electricity consumed today by either OECD or non-OECD countries (IEA, 2012.b).[8] VRE would account for more than 30% of total electricity output, to be compared with very low levels observed today (see next section). All this assumes very significant adjustments that are not always spelled out in scenario analysis.

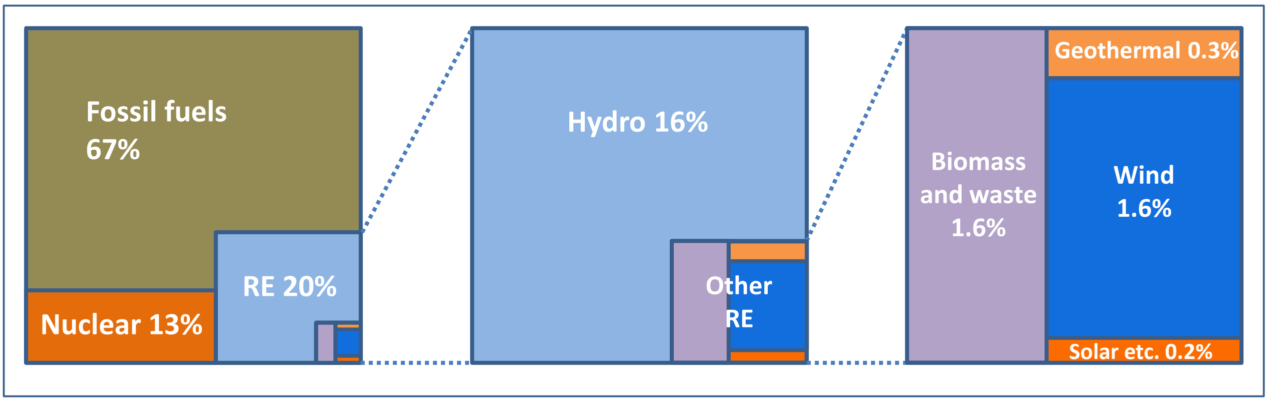
15. If these levels of penetration by VRE are to be achieved, much will need to be done to create the necessary conditions to inject these new, challenging forms of electricity into electricity systems worldwide. In what follows, special emphasis is given to variable renewable electricity, while acknowledging the rising contribution also required of biomass-based and geothermal electricity to achieve a global low-carbon energy mix.

1.3 Renewables in the global energy picture: biofuels, hydro, and others

16. Fossil fuels still dominate global energy supply -- 81% of the total -- notwithstanding the rather spectacular growth rates recorded by wind and solar photovoltaic power. Biofuels and waste lead the renewable energy supply due to the high level of non-commercial biomass use for heating and cooking in developing countries. Hydroelectricity is a distant second, and geothermal, third.

17. Renewable sources supplied 19.4% of the world's electricity in 2010, with geothermal, wind, solar and tide accounting for 2.1%, against 1.8% in 2009 (Figure 3). In total output terms, these 'other renewables' grew by 26% between 2009 and 2010. Wind, solar and tide electricity amounted to 375 TWh in 2010 – 1.8% of the world's electricity supply or equivalent of the United Kingdom's electricity consumption in that year.

Figure 3. Fuel shares in world electricity production (2010)



Source: based on IEA, 2012,f.

* Other includes electricity from energy sources not defined above such as non-renewable wastes, peat, and chemical heat.

** Other renewables includes geothermal, wind, solar, tide.

18. Despite spectacular growth, the share of renewables in electricity supply has remained unchanged since 1990 because of the fact that huge additional fossil capacity has also been created. The global picture

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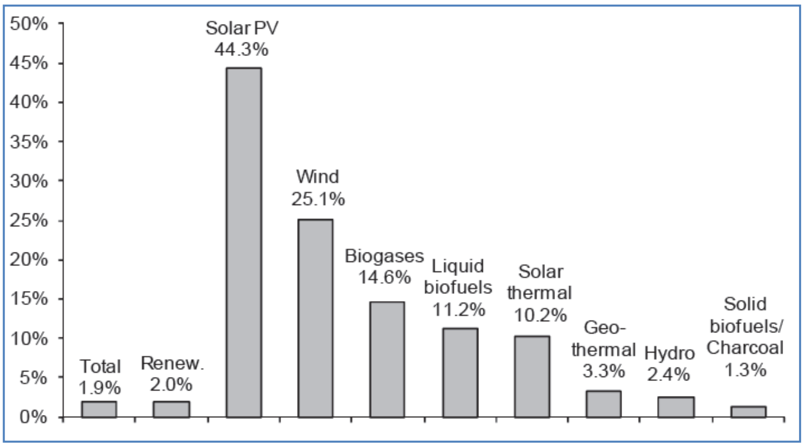
[8] Certain scenarios quoted by the IPCC (2011) show wind turbines, or solar PV panels, producing even larger amounts individually (see Annex I).

in 2010 presents very rapid growth in new renewables, especially wind and solar in power generation (Figure 4).

19. As of the end of 2012, the total installed capacity of wind was reported at 282 GW, and solar PV at about 100 GW. The two combined almost match the installed capacity of nuclear, but because of their variable nature they still account for a smaller share of electricity supply. Hydro, a more traditional resource, has recorded modest growth but nonetheless accounts for 16% of global electricity supply, *i.e.* the largest non-carbon electricity technology ahead of nuclear (13%). So while new renewable sources have made sizeable inroads, they still only meet a very small percentage of global electricity demand.

Figure 4. Annual average growth rates for world renewables energy supply from 1990 to 2010



Source: IEA, 2012,f .

2. RENEWABLES TODAY: DEPLOYMENT, COSTS, AND SUPPORT MEASURES

2.1 A more mixed (and encouraging?) picture at country level

20. The global picture indicates a very low penetration by renewables in the energy and electricity mixes. In sharp contrast, a few countries and regions have achieved a fairly high share of renewable energy penetration, including variable renewable electricity from both wind turbines and solar PV plants. These pose challenges from the standpoint of grid integration, which more steady geothermal and biomass-based electricity plants do not. Solar thermal technology coupled with storage capacity is also less problematic than PV technology. It is therefore interesting to see how countries with high penetration rates of variable renewable energy technologies (VRE) have coped with this problem.

21. Table 1 displays high penetration rates for VRE in a diverse set of circumstances. Denmark presents a very high share (28%), however, its electricity capacity is well integrated into a broader regional electricity system interconnected with Scandinavia (with its high share of hydroelectricity) and Germany, as illustrated by the electricity trade intensity indicator in the same table. Variations in wind output are more easily managed if connection to other countries allows the export of excess energy, or electricity imports if the wind doesn't blow (Bahar and Sauvage, 2013). The numbers for Ireland and Spain suggest that interconnection is, arguably, not a necessary condition with penetration rates lower than Denmark's (16-18% versus near 30%). However, both Spain and Ireland have flexible gas-fuelled power plants that facilitate the integration of variable electricity into the grid.

Table 1. Illustrating high annual penetration rates of variable renewable electricity

	Denmark	**Germany**	**Ireland**	**Spain**
Gross electricity production (2011.e)	34.9	614.5	27.4	292.1
Wind (TWh)	9.8	46.5	4.4	42.4
Solar (TWh)	0	19	0	9.1
Annual penetration of variable electricity (2011)	**28%****	**11%**	**16%**	**18%**
Trade intensity indicator (2010)*	**29%**	**8%**	**1.8%**	**3%**

Source: Electricity Information 2012, IEA, 2012.

* This indicator is equal to the average of each area's imports and exports, divided by gross electricity production.

** Annual wind penetration reached 30% in 2012 (Danish Energy Agency, 2013).

22. Benatia et al (2013) conducted an inquiry into conditions that enhance the productivity of wind plants, based on a sample of 31 countries or regions. Their statistical analysis considers what determines the effective capacity factor of wind plants in a country – *i.e.* the utilisation of installed wind capacity. The results stress the importance of certain components to effectively integrate wind resources in a country's electricity system. Conversely, they show how the absence of some of these components may lower wind turbine productivity, with frequent instances when wind generation is wasted because it cannot be absorbed by the grid. Grid enhancement, in these cases, can help to maximise the productivity of existing wind

capacity.[9] Beyond the obvious importance of each country's wind resource endowment, the following emerge as being of critical importance:

- The availability of **dispatchable generation** capacity, *i.e.* plants that can deliver electricity to the grid quickly to compensate for times when there is less wind.
- **Electricity transmission** capacity, *i.e.* the ability to move generated electricity over long distances inside a country.
- **Energy storage**, *i.e.*, hydroelectric pumped storage has an increasing positive impact when wind capacity grows.
- The possibility of **cross-border electricity trade**.[10]

23. Country-based experience indicates that high penetration rates of variable renewable energy can be achieved exceeding the global average of 1.76% of wind, solar and tidal power in electricity generation. It requires a set of accompanying measures and infrastructure, including maximising the productivity of VRE plants. The technical and economic challenges should not be minimised, but there is a track record, and much technical and policy experience (good and bad) that can be shared across countries and their respective electricity grids to increase the penetration of these renewable resources.

2.2 Can renewables compete?

24. Much-debated issues when it comes to renewables and climate mitigation are 1) their cost compared with other forms of electricity generation or energy savings and other options for reducing greenhouse gases; and 2) the costs borne by final end-users through electricity prices. The immediately following question is: when will they become competitive on a broad basis? The nature of the cost imposed by the integration of variable energy resources into the grid is another important and much debated element of this discussion.

25. Renewables have desirable attributes for policy-makers other than greenhouse gas mitigation, *e.g.* reduced local air pollution, enhanced energy independence and the development of an industry with global growth prospects. These must be factored into any appraisal of their economic attractiveness. For the sake of clarity these are not addressed here, but the extent to which such externalities are factored into energy prices will remain an important determinant of the competitiveness of renewables with other electricity supply technologies.

2.2.1 Fossil energy prices are not right

The lack of an adequate carbon price

26. The instrument of choice for environmental control in the case of a negative externality, like human-induced climate change, is to put a price on the externality in order to bring it back to a socially optimal level. Rational economic agents are then supposed to reduce their reliance on the source of the

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[9] A cost-benefit analysis is then necessary to identify those improvements that should be realised.

[10] This applies above a certain penetration rate, set at 3% of total output from wind, a level that has been exceeded by all countries in Table 1, among others (Benatia et al, 2013).

externality, and will all do so until the marginal cost of reduction equals the price placed on it.[11] In the case of climate change, this implies putting a price on greenhouse gas emissions, including on CO_2 emissions from fossil fuel combustion, at USD 100/tCO_2 or higher by 2030 or so.

27. Unfortunately, only a small share of the global electricity sector is currently subject to a CO_2 price. In the majority of cases where there is one, the actual price has been low. This is due to a variety of causes, including over-allocation of permits in the establishment of emissions trading systems, dampened electricity demand and demand for CO_2 emissions as a result of the economic recession and, mostly in Europe, an unexpectedly high growth in renewable energy supply driven by other policy incentives. It is fair to say that carbon pricing policies in electricity generation have not had a marked impact on emissions from electricity generation globally (Figure 5). In other words, renewables suffer from a first-order market failure: the non-pricing of CO_2 and the under-pricing of SO_2 and particulate matter emitted by fossil fuel-based technologies.

28. An additional complicating factor is the long-term nature of the climate change constraint. Although the required emissions path is well known, or at least the overall emission budget available between now and 2050, emissions rights or carbon prices are rarely set for periods extending beyond the next decade. In theory, longer-term allocations should lead to the formation of expectations about the future price of CO_2 emissions, thereby underwriting private investment in low-carbon technologies.

Other market failures affecting renewables

29. A second type of market failure relates to **learning effects** and the associated cost dynamics of new technologies. Wind and solar-based electricity, like most new technologies, have a track record of declining costs: as more experience is drawn from their production and their costs tend to go down. Unfortunately, individual investors have a more limited interest in pushing a technology along the learning curve than society as a whole. Indeed, lowering the cost of these new technologies avoids facing much steeper CO_2 reduction costs when other options will have been exploited (Finon, 2012).

30. The superiority of relying on a carbon price is in fact called into question by the dynamics of technological change. Recent work finds that an optimal solution to long-term CO_2 mitigation is the combination of a carbon price and R&D expenditures to reduce the cost of not-yet-competitive CO_2-saving technologies. It would take a much higher carbon price to encourage such R&D, which would impose a high burden on society for a technology improvement that can be achieved at lower cost with more directed R&D efforts.[12]

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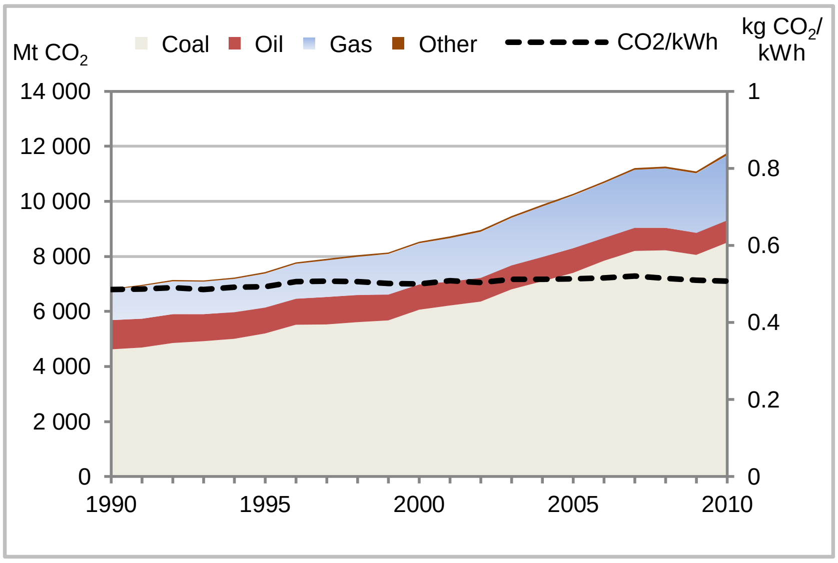
[11] In theory, the price put on an externality is set with full knowledge of its cost to society. The price should be set where the marginal cost of lowering the externality equates the resulting marginal benefit.

[12] Acemoglu et al. (2009). See also IEA (2012.b) and Hood (2011.b) for a detailed discussion of policy combinations and interactions.

Figure 5. CO₂ emissions from global electricity generation, by fuel



Source: IEA, 2013.a.

Far from a 'first-best' world: the need to support the deployment of low-carbon technologies

31. Carbon prices are not right, though if they were, they would need to be complemented by dedicated support to trigger learning effects and lower the cost of low-carbon technologies like renewables. In this 'second-best' world subsidies are justified, but at what level and of what kind? In countries where a CO_2 price exists, it is often not at the level projected to keep emissions in line with the collective 2°C goal. In parallel, countries have introduced a broad and often expensive array of support measures to bring renewable energy to the market (Box 2). The justification for these subsidies and their levels has generated much debate in the economics discipline.[13]

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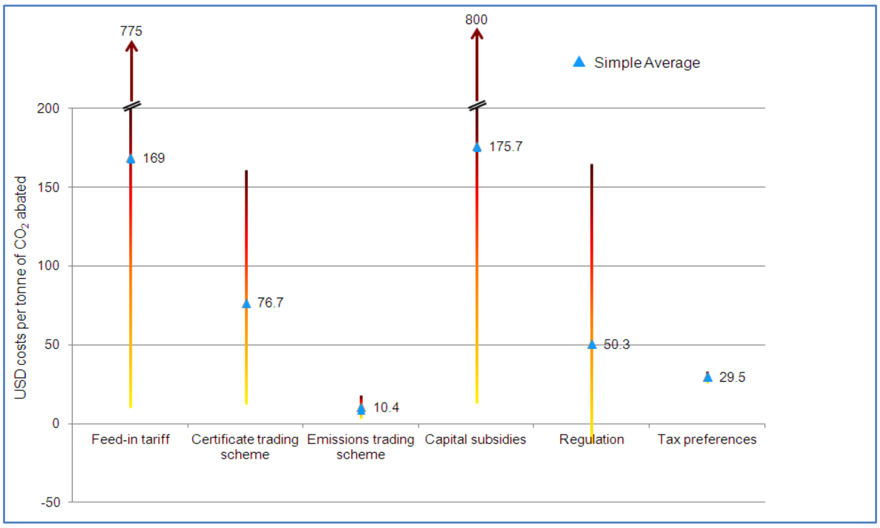
[13] See in particular Fischer and Preonas (2011).

Box 2. Effective carbon price for the main policy instruments used in the electricity sector

The following figure shows the ranges of effective carbon prices found for various types of instruments used for environmental policy in 14 selected countries (Australia, Brazil, Chile, China, Denmark, France, Germany, New Zealand, South Africa, Spain, the UK and US).



The studies assessed the amount of emissions reduction triggered by each instrument, the costs to society of implementing the policies, and (by dividing the latter by the former), the average cost to society per ton of CO_2. This shows large differences in the estimated carbon prices both within and across instrument categories, with some very high costs per tonne abated related to feed-in tariffs and capital subsidies – with clearly the lowest costs linked to emission trading schemes. At first sight, promoting renewables deployment appears to be an expensive way to address climate change.

Several caveats apply: 1) as argued previously, current carbon prices are inadequate due to market failures – today's cost to deploy clean technologies may be tomorrow's savings when these technologies must be deployed at scale; 2) some of the policies serve several policy objectives and their CO_2 price-equivalent does not provide the full picture; 3) the study is a "snapshot" of the situation in 2010 (financial incentives provided to renewables have been seriously reduced in the last couple of years, as mentioned below).

Source: OECD Effective Carbon Pricing study, *forthcoming.*

2.2.2 Costs of variable renewable energy technologies: generation and beyond

32. How large is the competitiveness gap between the pricing of new renewables and more mature power generation technologies? There is no universally valid answer to this question, for the following reasons:

- Without a price on fossil fuel externalities, the competitiveness of low-carbon technologies is hindered. Some technologies would be competitive if externalities were priced.

- Geographical circumstances that determine the productivity of VRE (wind speed, insulation) vary across regions. Wind turbines and solar PV are competitive without subsidies in some regions (New Zealand for wind, off-grid remote areas for PV, etc.).

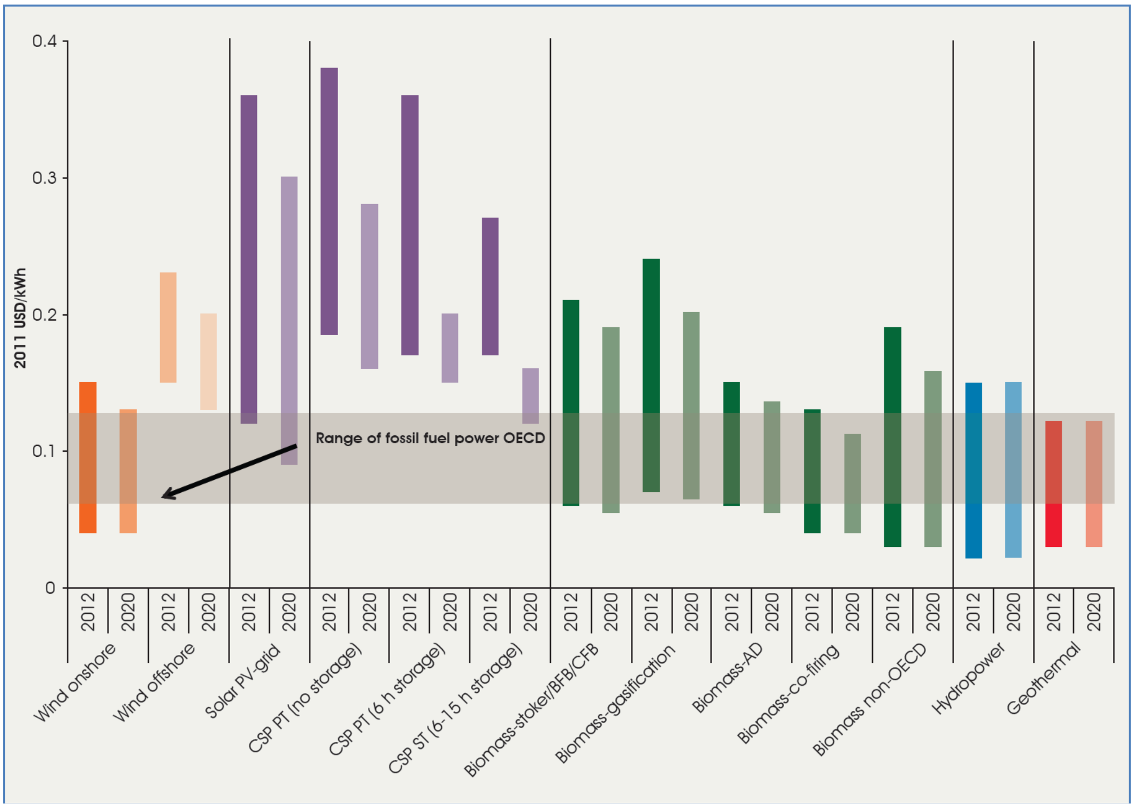
- Labour, materials or capital costs also differ. For an identical technology and technical potential, cost parity may be reached in some regions and not in others.

- The prices of wind turbines and PV equipment declined very rapidly in the last few years and are expected to continue to do so (IEA, 2012.e). The competitiveness gap between renewables and other generation technologies is narrowing.

Generating costs: favourable trends for variable renewable sources

33. IRENA (2012) gives an overview of renewable power generation costs in 2012, as well as projected 2020 costs. It uses the concept of the levelised cost of electricity (LCOE), *i.e.* the ratio of an installation's lifetime costs to lifetime electricity generation, discounted back to a common year using an average cost of capital set at 10% to facilitate comparisons. Figure 6 compares a range of technologies and regions for new capacity in 2012 and 2020. The range of OECD fossil-fuel basedx power is also for new capacity, with fuel contracts to secure future prices; the current price range for existing plants in the US and Europe is USD 0.05-0.06/kWh.

Figure 6. Typical ranges of levelised cost of electricity for new capacity of renewable power generation technologies, 2012 and 2020



Source: IRENA (2012).

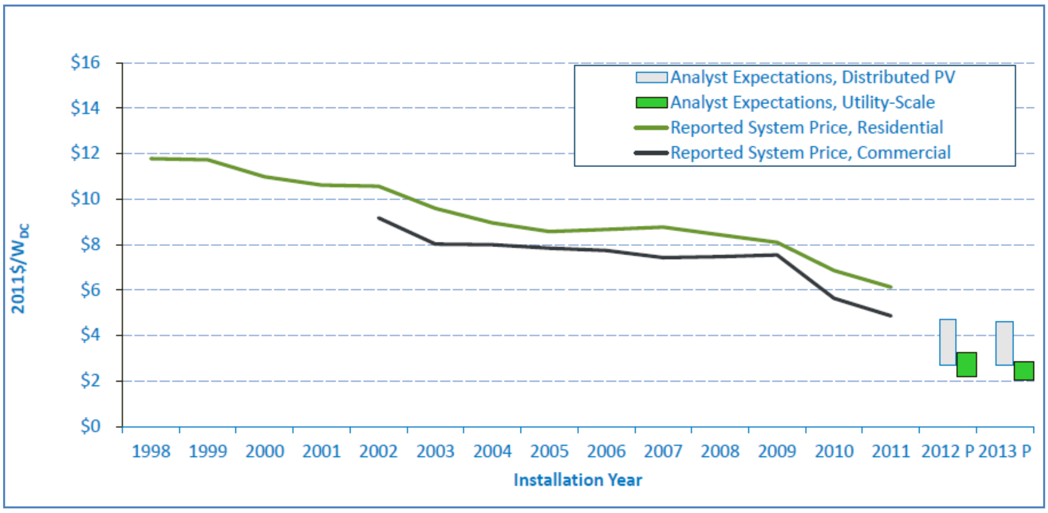
Note: PT: parabolic trough; ST: solar trough; BFB/CFB: bubbling fluidised bed/circulating fluidised bed; AD: anaerobic digestion. The lower estimates for biomass-based electricity are based on agriculture and forest residues with limited potential. Larger installations need dedicated energy crops, and are on the higher cost range.

34. The numbers shown in Figure 6 are only indicative. The degree of competition in the renewable energy sector, the cost of capital and natural endowments all affect local generation costs. Clearly, some

renewable generation technologies in some regions will be either competitive or close to competitive with fossil-fuel based generation, *when comparing their levelised cost* (other than from large hydropower; *e.g.* onshore wind plants and possibly large-scale solar PV installations). As explained below, the use of LCOE for such comparisons may be misleading, however. Further, any price of CO_2 would further tip the balance towards renewable technologies – assuming biomass-based technologies use resources that do not release CO_2.

35. The latest estimates tell only half the story, however. Learning effects and economies of scale have consistently driven the prices of these new technologies down. In the recent past, overcapacity in the production of wind and solar technology components has also contributed to spectacular price reductions (IEA, 2012.e), reflected in full system prices of PV installations in the US (Figure 7).

Figure 7. US photovoltaic system prices, 1998-2013



Source: Arvizu, 2012.

36. IRENA (2012) provides a similar range of prices for a sample of countries including Australia, China, Germany, Italy, Japan and the United States.[14] It is interesting to compare IRENA's 2012 cost data with assumptions used in low-carbon scenarios summarised by the IPCC a year earlier. The IPCC used a price range in 2020 of USD 2300-5800/kW. Latest statistics suggest that current prices are already equal to, or lower than, the prices that IPCC scenarios used for 2020 and after.

37. The drop in prices is confirmed by the growth of the market for PV panels, which broke a record in 2011 with 30 GW of additional installed PV capacity. The year 2012 was probably a close second, with newly installed capacity estimated between 25 and 31 GW (IEA, 2012.g). This has had an unfortunate effect going forward: the unexpectedly high deployment of PV installations, along with high subsidy expenditures, has led governments to drastically adjust their subsidies downward, sometimes even retroactively (see Annex 4), to the detriment of the manufacturing sector and interest of financiers.

38. A more favourable reading of recent history is that price trends point to a closing competitiveness gap for VRE in spite of the absence of a consistent price on CO_2. Several caveats apply, however, before policy-makers rush to further revise their policies.

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[14] See Figure 6.6 in IRENA 2012, page 54.

Cost parity in generation: the wrong metric to monitor; the need to look at electricity prices; system costs and grid parity

39. According to Joskow (2011) "levelized cost comparisons are meaningless because they ignore variations in the price of electricity at the actual time when supplies are forthcoming from intermittent technologies". For example, where high electricity demand occurs at mid-day (*e.g.* in locations with air-conditioning load), solar PV power is more competitive than when peak demand occurs in the early morning or late afternoon. As for wind, there is usually no systematic correlation between wind patterns and high levels of demands during the day. In temperate regions, however, wind turbines produce more in the winter, when demand levels and prices are higher.

40. The second important consideration in cost comparison relates to the integration of variable renewable energy into the grid (described further in Section 4). There are three main components to these so-called **systems costs** (IEA, 2012.g):

- Adequacy and flexibility costs. Adequacy refers to the need for generation that can produce when VRE is not available. Flexible plants are needed to ramp up and down as wind power and solar PV power vary.[15]

- Balancing costs, to address differences between VRE output planned a day-ahead and actual delivery.

- The costs of grid integration to connect generating units located far from electricity consumption.

41. Various estimates of these systems costs exist in the literature.[16] While not negligible (ranging from USD 6-25/MWh), these costs do not add much to the existing competitiveness gap of renewables today, and there is a debate over which part of the electricity system (generators, system operators, etc.) should carry the cost of connecting and integrating new renewable installations. The challenge is to ensure sufficient investment to guarantee a reliable electricity system with a high penetration of variable renewables.

42. Another common notion in the discussion of the competitiveness of renewables is **grid parity**. IRENA (2012) defines this as "the point where the LCOE of PV, without subsidies, is the same or lower than the residential electricity price, excluding taxes" (2012, p.49). At this point, the argument goes, it should be in end-users' financial interest to install PV panels on their roofs as a cheaper means of supplying electricity than the grid. That is, the subsidy will have become unnecessary.

43. For users connected to the grid, 'grid parity' does not mean that solar PV have become competitive without a subsidy. Users face an average electricity price that includes a fixed cost for access on top of the cost of generated electricity (access to the grid is crucial, as PV panels do not generate

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[15] Not all technologies can ramp up or down to follow VRE. Nuclear and coal plants are typically less flexible than gas turbines or hydroelectric plants. Nuclear plants can be operated flexibly, however. In France, nuclear plants provide grid services from frequency regulation to daily load-following (MIT, 2011).

[16] IEA (2012.g) estimate these systems cost in the USD_{2010} 6-25/MWh range – with grid integration costs accounting for USD 2-13/MWh. NREL (2012) reports estimates for balancing costs below USD 5/MWh, including in the case of Denmark, where wind power generates 24-28% its electricity annually. With transmission costs added, these estimates remain in the above-mentioned range. NEA (2012) provides much higher estimates for wind and solar PV power penetration rates of 30%, but under very conservative assumptions.

electricity at all times). So while households with PV panels save the costs related to grid-based power they no longer need, they still pay for access. Therefore; as grid parity refers to total cost of household electricity *including access* it an improper indicator of the competitiveness of PV in a grid-connected installation. [17]

2.2.3 Summary

44. The competitiveness of new renewable technologies is a complex issue. Several market failures disadvantage low-carbon technologies, including renewables, starting with the quasi-absence of a price on CO_2. Second, learning effects and the dynamics of the cost of new technologies argue towards combining CO_2 pricing and dedicated support to the development and deployment of low-carbon technologies. Comparisons of generation costs to gauge the competitiveness of renewables are therefore misleading without reflecting the cost of CO_2 associated with fossil-based generation. Variable renewable electricity also carries costs related to its integration into the grid; these costs appear manageable at present. The costs of wind turbines and solar PV panels have witnessed spectacular reductions, narrowing the gap to commercial viability and making these technologies competitive in certain areas. Overall, support measures still are and will be needed for some time if VRE is to be scaled up and make its full contribution to climate change mitigation.

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[17] Many thanks to Marco Baroni (IEA) who elaborated and shared the arguments on grid parity reflected here.

3. DEPLOYING RENEWABLE ELECTRICITY: LESSONS FROM THE RECENT PAST

3.1 Support measures[18]

45. Significant subsidies have been in place in developed and more recently in developing countries to support the deployment of electricity supply from renewable energy sources. The majority of wind and solar power installations in operation today were made possible by public support, provided through:

- Price support: feed-in tariffs (FIT) and variations on that approach.
- Quantity-based systems: quotas for renewable energy or general programming and long-term contract auctioning.
- Grants, tax preferences and government loan guarantees.

3.1.1 The key role of access rules

46. In addition to these policies, specific rules have been developed to ensure that variable renewable sources in particular have access to the grid despite supply being unpredictable. Grid operators have developed management procedures and mechanisms to accommodate more variable energy, without which their integration would have been impossible. This is an important learning effect of the early deployment of these technologies.

3.1.2 Price support (FIT)

47. Feed-in tariffs provide a guaranteed price for delivered electricity. The guaranteed nature of the return provides a high level of assurance to investors. Price systems also allow differentiating payments according to technologies, to reflect generation costs and other attributes (environment, social, industrial).[19] There are important variations in FIT systems that affect their efficiency and overall policy costs. Two main systems have been operated:

- A fixed-price FIT which guarantees a fixed revenue per kWh to an eligible project over a given period of time (typically 10-25 years). This type of FIT has been used in more than 50 countries, including most OECD countries or their sub-national units.
- A FIT premium which guarantees a fixed premium for each kWh on top of the electricity market price. This encourages the installation of projects where the best price can be secured (*e.g.* where locational pricing exists). The downside risk for investors is a drop in the electricity price – an important consideration when a surplus of variable renewable energy

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[18] Information on support measures draws heavily on the following sources: Finon (2012), NREL (2010), IEA (2008, 2012.e), Bahar et al. (2013), and on the IEA/IRENA Joint Policies and Measures Database (IEA/IRENA, 2013).

[19] IEA (2011) surveys policy support for renewables according to instrument types. The following IEA countries are listed as relying mainly on feed-in tariffs or premiums as of 2011: Austria, Canada, Czech Republic, Denmark, France, Germany, Greece, Hungary, Ireland, Korea, Luxembourg, Netherlands, Portugal, Slovak Republic, Spain, Switzerland and Turkey. Argentina, China, Egypt, Kenya, Malaysia, South Africa and Uganda are among countries that have also implemented FIT policies (see IEA/Irena 2013).

can drive electricity prices down. FIT premium systems have been used in several European countries, including Spain, and Denmark for onshore wind.

48. A fixed-price system can be adjusted annually for inflation, include a predetermined decrease, or be based on time of delivery (NREL, 2010).[20] Mechanisms have been introduced to better manage overall cost, including premiums that evolve between a set cap and floor. Some systems also control for the total payment (electricity price plus premium), again with a cap and a floor. A third variation adjusts the premium, computed as the difference between the spot price and a pre-determined level – this is essentially a fixed-price FIT with the difference that generators must put their electricity on the market.[21]

3.1.3 Quantity-based systems

49. Quotas for renewables can take several forms. In general, the obligated party (power producer, supplier or consumer) has to meet part of its supply/demand from specified renewable energy sources.[22] This can be facilitated by the existence of a market for tradeable green certificates (TGCs). Each certificate corresponds to a MWh of electricity generated by an eligible 'green' source. In some cases, a less commercially viable technology is entitled to more than one certificate per unit of generated electricity (*e.g.* off-shore wind in some systems). The obligated parties must surrender a number of certificates that matches their obligation under the system or face paying a penalty or buy-out price.[23] In principle, it is in the obligated parties' best interest to pursue RE options at least cost, which should in turn ensure that policy costs are kept to a minimum.

50. Tradeable green certificates (TGCs) were conceived as technology-neutral so as to encourage the cheapest solutions and minimise cost (the main justification for a market-based, tradable certificate system). These systems are nonetheless sometimes banded by technology, with shares of the overall goal to be met by specific technologies. To ensure compliance with the goals, penalties (or a buy-out price) apply to obligated parties that do not meet their quota (*i.e.* surrender enough certificates).

51. An alternative is a general programming approach which can be based on auctioning (Maurer et al. 2011). The auctions propose long-term contracts for power generation from a given set of technologies for which project developers will compete, guaranteeing a least-cost supply for the intended generation capacity. In most recent arrangements, a central buyer is established to settle the awarded contracts – the government is not a direct party.

3.1.4 Other measures: grants, tax preferences, government loan guarantees, etc.

52. Fiscal measures and access to low-interest rate loans are other common tools in the renewable energy deployment policy kit. Fiscal measures include corporate depreciation deductions, investment or production tax credits, and household tax credits. A drawback of some of these policies is that they require annual renewal as part of budget discussions, in contrast with FIT that are fixed and charged to electricity

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[20] Adjustments for inflation are especially attractive for institutional investors who want to hedge against inflation.

[21] The UK Contracts for Difference (CfD) make generators pay if the electricity market price is above the pre-agreed tariff (Department of Energy and Climate Change, 2012).

[22] IEA (2011) surveys policy support for renewables according to instrument types. The following IEA countries are listed as relying mainly on tradeable green certificates as of 2011: Australia, Belgium, Italy, Japan, Poland, Sweden and the United Kingdom. The UK's contract for differences can be considered a mix of a price and quantity-based system.

[23] In the United States, these quantity-based systems are known as Renewable Portfolio Standards and may or may not involve tradeable certificates.

rate-payers.[24] Grants (capital subsidies) and low-interest rate loans are also common in both developed and emerging economies.[25]

3.1.5 What has worked best?

53. New renewable energy technologies have been deployed very rapidly in the last few years thanks to the range of policies and measures to support their economic viability, and guaranteed grid access. Countries have sometimes shifted from one policy type (price-based feed-in tariffs) to the other (quota-based systems) on grounds of market-driven cost-effectiveness and as technologies gained market maturity. In many cases today several instruments are combined, either in support of different technologies or to support the same technologies. For some countries, multiple layers of governments and corresponding RE support policies make the picture quite complex.

54. There is no clear-cut answer to the question ‘which renewable-energy deployment measures work best?’[26] Some countries have clearly achieved very fast growth in the deployment and integration of RE in their electricity systems, on the basis of generous feed-in tariffs that considerably de-risked project development from the investors’ perspective. The risk, however, is not eliminated: it is simply shifted to rate-payers or to tax-payers who still pay a fixed amount when the actual cost of RE goes down. Furthermore, as recent history shows, investors have suffered rapid policy adjustments once governments have realised the overly-generous nature of the agreed tariffs.

55. It is also difficult to assess cost-effectiveness when a stated objective of these measures is to deploy a portfolio of individual technologies rather than just any single technology. In theory, a quota-based system should mobilise the best resource and technology at least cost, but in most cases these systems have established quotas by technology type (so-called ‘banding’).[27] One last consideration relates to the price signal to the end-consumer. From this perspective, a rate-based system ought to be more cost-effective than a tax-based one: at the very least, the additional cost related to the RE deployment measures charged to the end-user encourages lower electricity consumption.

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[24] France allows industrial companies investing in renewables to depreciate these investments in a single year. In the US, renewable projects are eligible for an Investment Tax Credit (ITC) or a Production Tax Credit (PTC). The latter allows taxpayers to claim a tax credit worth USD 0.023/kWh for any eligible facility. The ITC allows investors in specific energy projects to claim a credit worth 30% of their project costs. In addition, the American Recovery and Reinvestment Act (ARRA) temporarily allowed recipients to choose a cash grant instead of a tax credit. China provides preferential tax treatments to foreign investments in wind power and bio-energy projects (15% as opposed to 33%), accompanied by reduced import taxes for wind and solar technology components.

[25] Austria provides investment grants for small-scale hydro. In Germany, KfW, a public bank, proposes long-term low-interest loans for up to 100% of investment in renewables. A specific loan programme targets offshore wind in Germany’s Exclusive Economic Zone, capped at EUR 700 million. In Sweden, grid-connected PV installations are eligible for grants. The Brazilian Development Bank (BNDES) also offers low-interest rate loans to renewable projects. Since 2009, China’s Golden Sun programme subsidises PV (70% of the project cost for off-grid), although FIT are also in place. Botswana offers a four-year loan to PV installations for rural electrification.

[26] IEA (2011, 2009) conducted an extensive comparative review looking at three criteria: policy impact, measuring the distance to a target based on a low-carbon scenario; remuneration adequacy, assessing if the support level is enough to encourage capacity development, but not too generous; and total cost, on a per MWh basis. Fagiani et al. (2011) compared price- and quota-based systems looking at Spain’s renewable development out to 2050, taking investors’ risk-aversion into account.

[27] For instance, the UK Renewable Obligation Certificate system allocates two ROC per MWh of off-shore wind, while on-shore wind power receives one ROC per MWh.

56. The cost-effectiveness of policies supporting renewable technologies must also be considered beyond national borders. Not all countries are blessed with constant wind patterns and great insolation. The same PV panel could be much more productive if installed in a sunny region, provided that its electricity can be used locally or cost-effectively transported to consumption centres. This argues in favour of opening support mechanisms beyond national borders and homogenising them for a more cost-effective deployment of the supported technologies (Bahar et al., 2013; GEW, 2013). Unfortunately such possibilities are not exploited, as countries want to support RE 'in their backyard'. Another sign of such national preference is trade tensions in the renewable energy sector, as some countries or sub-national units seek to support their industry through measures to deploy renewables. This may eventually hamper access to the cheapest technologies and slow the rate at which renewables become commercially viable.

3.2 Are renewables entering a financing crisis?

3.2.1 From rapid deployment to stalling global investment

57. The range of support measures for renewables has led to a rapid deployment of capacity, with wind turbines and solar PV installations leading the way, thereby avoiding the lock-in of more polluting energy sources. The learning curve delivered impressive cost reductions. However, the global picture for these technologies is uncertain. Misguided market expectations and fierce competition in the PV panel and wind turbine manufacturing industries have led to significant overcapacity. The manufacturing capacity of PV panels reached 55 GW, twice the annual demand of 27 GW in 2012. The manufacturing capacity of wind turbines was 73 GW in 2011, when 'only' 40 GW of capacity was installed (IEA, 2012.e). Consolidation, including bankruptcy of sector leaders, is underway in both wind and solar manufacturing.[28]

58. Governments had to adjust FIT systems to reflect mounting policy costs as more projects than anticipated were developed in response to rapidly declining equipment costs. Policy changes have also been driven by countries' macroeconomic and budgetary stresses. FITs are being redesigned to automatically adjust to cost reductions, and measures have been taken to cap the total cost of programmes – *e.g.* closing the door once annual budgets have been spent (see examples in Annex 4). In all, these changes have damaged investors' confidence in this sector, especially as some changes were retroactive. After a ten-fold increase since 2004, 2012 may be remembered as the year when clean energy investment fell to USD 269 billion, down 11% from 2011 levels (Figure 8), while 2013 recorded a 22% drop in the first quarter (Bloomberg New Energy Finance, 2013). The impact has not been felt – yet – in the addition of capacities of wind turbines and solar PV panels (*e.g.* capacity additions for both technologies hit record levels in the US in 2012).

59. Regional differences are striking, however. Overall, investment in Asia/Oceania remained strong, with a 14% increase in 2011-2012. However, early 2013 numbers indicate that investment stalled in China, however. Renewable energy investments in both Europe and the Americas recorded a drop; the former was hit by the credit crisis and retroactive policy changes that drove financiers away from the sector. In the US, the cash grant in lieu of the tax credit expired at the end of 2011; the production tax credit itself was due to expire at the end of 2012, triggering a rush of projects in the previous year and a visible funding drop in 2012. The scheme was eventually renewed for two years.

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[28] The following are examples of the ongoing consolidation: Suntech of China, the global leader in PV manufacturing, entered bankruptcy proceedings in March 2013; Germany's Q-Cells filed for bankruptcy in 2012; in the US, Solyndra also went bankrupt. Bosch abandoned its PV activities after a EUR 1 billion loss in 2012 (Reuters News, 2013.c). In the wind industry, Suzlon, India's turbine maker, reported a USD 212 million loss in the first quarter of 2012; Vestas and Gamesa also undertook major cost-cutting (Kaminker et al., 2013).

3.2.2 Will new financial rules hamper clean investment?

60. Governments are also introducing new rules to enhance the stability of the financial sector. These rules may discourage financiers from supporting investment in 'green' infrastructure, including renewable electricity. They matter all the more as they may deter institutional investors who have so far shown limited interest but whose support will be vital if the world is to mobilise sufficient finance to deliver a low-carbon energy future. Rules likely to hamper the development of the renewable energy sector include: (BNEF, 2013.b and Kaminker et al. *forthcoming*):

- Basel III rules, including on liquid assets requirements, which restrict banks' engagement in project finance, especially for projects with high upfront capital expenditures. This is typically the case for wind and solar projects (but also for nuclear, hydro, and carbon capture and storage installations).[29]

- In the EU from 2014, the Solvency II regulations will require insurance companies to hold higher amounts of capital. As shorter-term credits will minimise capital requirements, RE investments with longer-term credits will become less attractive.

- Rules applying to pension funds (including in the measurement of their liabilities and assets-liabilities matching) similarly discourage illiquid investments in green infrastructure projects (Kaminker et al. *forthcoming*).[30]

61. Electric utilities in the OECD are under financial pressure to restore their balance sheets, especially in Europe. European banks, who were leading project finance in this sector, are also facing difficulties, with a disproportionate impact on RE project finance globally. The utilities may turn to other sources of funding for new projects, including national and multi-lateral development banks (which contributed USD 15 billion of investment in renewables in 2011), or power companies that do not face such pressure, *e.g.* from China. Initiatives like the UK Green Investment Bank and Australia's Clean Energy Finance Corporation are also positive developments, but cannot and are not meant to replace banks or utilities in financing RE projects (IEA, 2012.e).

62. Overall, the future of RE finance looks mixed. On the one hand, almost all regions have lowered their levels of support to RE deployment. While this is a following reduction in technology prices, there is a concern among investors about the stability of support measures. On the other hand, reductions in technology costs could counterbalance this risk. This is clearly the stance taken by Bloomberg New Energy Finance in their latest *Global Renewable Energy Market Outlook*, where wind- and PV-based generation become competitive, sometimes with the legitimate help of a price on CO_2 emissions (BNEF, 2013.c).[31]

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[29] Bank debt for such projects is considered asset-backed security. RE project assets are not sufficiently liquid to contribute to meeting the Basel III Liquidity Coverage Ratio, to be implemented by 2019, with an interim requirement to be met in 2015. The Net Stable Funding Rule in discussion could also increase debt prices, as banks would need to seek longer-term funding for themselves or choose shorter-term loans with the need to refinance more frequently. Another cost increase may come from the proposed treatment of interest rate swaps, which project finance must contract to protect against changes in interest rates.

[30] Other practices in the financial sector tend to underestimate the exposure of investments to future climate change, or to neglect the environmental, social and governance dimensions of investments (BNEF, 2013.b)

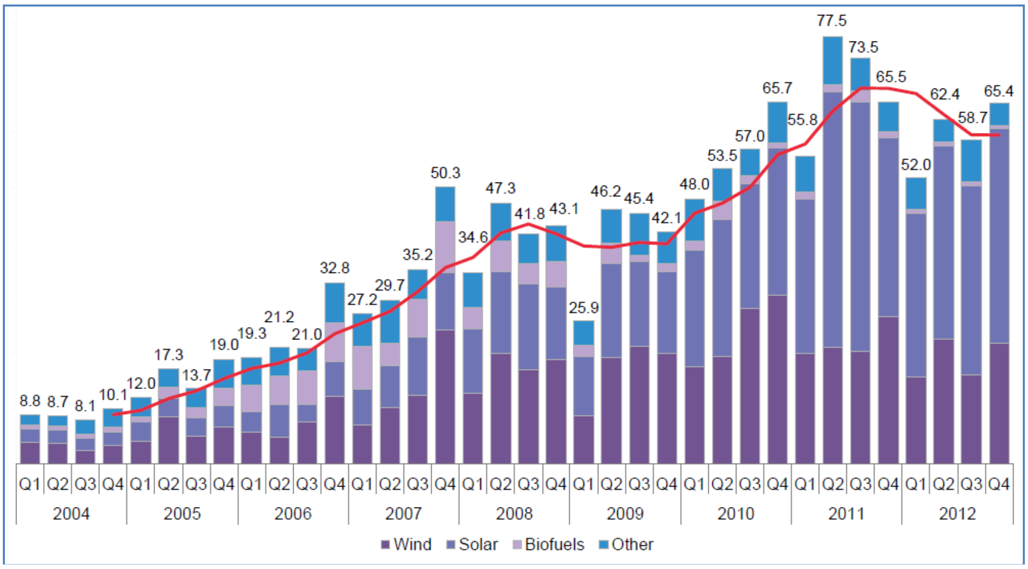
[31] In BNEF's three scenarios (Traditional Territory, New Normal, and Barrier Busting), the EU sees a rising CO_2 price, albeit at different paces. It is only in the most ambitious Barrier Busting case that the US and China put a price on CO_2.

3.3 Summary: progress on competitiveness, incentives need re-thinking

63. The rapid deployment of renewables has been achieved against a number of market failures: the lack of an adequate price on CO_2 and other fossil-fuel externalities, the public good nature of cost reductions through learning effects; and economies of scale. The existing competitiveness gap – which is becoming narrower as equipment costs continue to drop – has been closed by various incentives systems, feed-in tariffs, tradeable green certificates systems, fiscal measures and access to cheap capital. The most effective instruments have been those that provide a predictable return to investors but shift the risk to rate-payers or government budgets.

64. In many countries, support programmes went over-budget or led to visible increases in end-user electricity prices – always a sensitive political issue. Governments reacted with sometimes retroactive changes that have unsettled investors in this sector. New efforts are underway to design support systems that strike a balance between stability and flexibility on cost. It is not clear yet whether the drop in global investment marks a new trend or is temporary, reflecting the rapidly changing conditions. How new financial rules will affect lending for renewable projects is another uncertainty going forward.

Figure 8. New investment in clean energy by sector (2004-2012)



Source: Bloomberg New Energy Finance, 2013.a.

Note: Total values include estimates for undisclosed deals. Excludes corporate and government R&D. Includes small distributed capacity & adjustment for re-invested equity.

4. INTEGRATING VARIABLE RENEWABLE ENERGY INTO ELECTRICITY SYSTEMS

65. The cost–competitiveness of renewables is not the only barrier to their deployment. The integration of variable renewable electricity plants into electricity systems designed for another age poses as big a challenge. Electricity system operators have had to adjust to guarantee the stability of their systems with more variable electricity, and countries are increasingly thinking about market design changes to accommodate a growing share of variable sources. This section describes the system adjustments required to accommodate VRE and the different market solutions under discussion. Decisions in this area will greatly influence how competitive VRE will be in the race to decarbonisation.

4.1 Variable energy requires a more flexible electricity system

4.1.1 The basics of electricity systems[32]

66. Electricity systems are composed of generators that produce electricity, a transmission system that brings this electricity to a nodal point through high-voltage lines, and a distribution system that connects the electricity's various end-uses. The sum of these end-uses at any point in time is known as the load. Electricity systems are managed by System Operators (SOs).

67. Several types of plants are mobilised to meet the evolution of the load during the day: baseload, mid-merit and peaking plants. Electricity systems include reserve capacity margins to be able to face extreme demand situations – *i.e.* peaking plants that may run only few hours per year.[33]

68. To keep the lights on, SOs must watch over a number of parameters (frequency, phase, etc.) A key feature of electricity systems is their flexibility: the unexpected interruption of a plant's supply or the loss of a transmission trunk must be compensated by the immediate dispatch of other plants (referred to as dispatchable plants); similarly, any additional load must be met by matching supply. SOs have procedures for communicating with generation plants in real time: some can be mobilised within seconds, others need more time to start up and are best suited to adjusting supply to demand in periods of minutes to days.

69. To best manage the system, SOs rely on load and supply plans provided by plant operators and energy distributors. The planning for balancing is generally done a day ahead or, in some cases, on the same day for the next hour, or even shorter periods (as little as 15 minutes). These benefit variable energy plants, which have much better predictable output levels minutes rather than a day ahead.

70. A critical element of electricity system management is generation adequacy: the system's ability to match future levels of electricity demand -- *i.e.* to trigger the investments necessary to ensure the flexibility of the system in the future.

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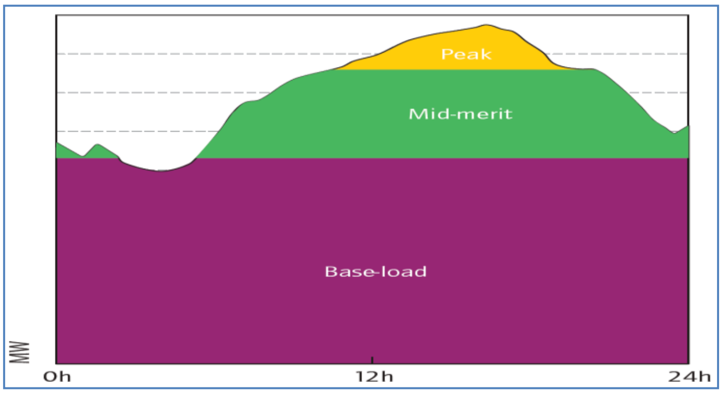
[32] This section is based on Baritaud, 2012.

[33] More precisely, every system operator sets a ***reliability threshold***, an amount of time during which power may not be supplied (*e.g.* 30 hours in ten years in France), or as a quantity of energy that would not be served (*e.g.* 0.002% of energy per year in Eastern Australia). This threshold determines what reserve of peaking plants will be necessary. Ensuring that power will be supplied under *any and all* circumstances would require investment in generation capacity that may never run, an investment that society may not be ready to incur.

Figure 9. A generic daily load curve



Source: IEA, 2011.b.

4.1.2 VRE: introducing variability and uncertainty

71. Some renewable energy technologies are dispatchable: geothermal installations, hydroelectric dams, bioenergy plants and concentrating solar power plants with integrated thermal storage. Unlike VRE, these can be 'counted on' when the system needs more power. Special attention is required if VRE accounts for a large share of total installed capacity and energy supply (IEA, 2011.c):

- ***Variability***: fluctuating output from wind and solar PV plants requires other parts of the power system to follow supply up and down more rapidly than usual. Technically speaking, the system needs to increase its ***flexibility*** to face these rapid fluctuations.

- ***Uncertainty***: the timing of output from wind and solar PV in particular is more uncertain and the variations in amplitude greater than traditional demand variations, forcing SOs to make up the deficit or manage the surplus at short notice.

72. From a system reliability standpoint, a high instantaneous proportion of variable electricity is particularly challenging (Figure 10).While wind and solar account for 35% of electricity on an annual basis, the installed capacities of wind turbines and PV panels sometimes generate 100% or more of the instantaneous load (see 10-11 April and 15 April). The system operator then needs to 'curtail' output from VRE plants to keep the system stable. In these circumstances, part of the generated renewable electricity is simply wasted.

73. This also occurs at lower penetration rates: in Ireland, renewables, mostly wind, supply 17% of national demand annually. For a significant number of hours every year, wind turbines produce more than half the total demand; overall, 1% of wind output has been curtailed, going as high as 7.5% for some wind farms, in order to maintain the reliability of the system.[34] Bulgaria decided to stop the operation of 40% of its wind and solar installations, as the absence of real time production data threatened the stability of the grid.[35]

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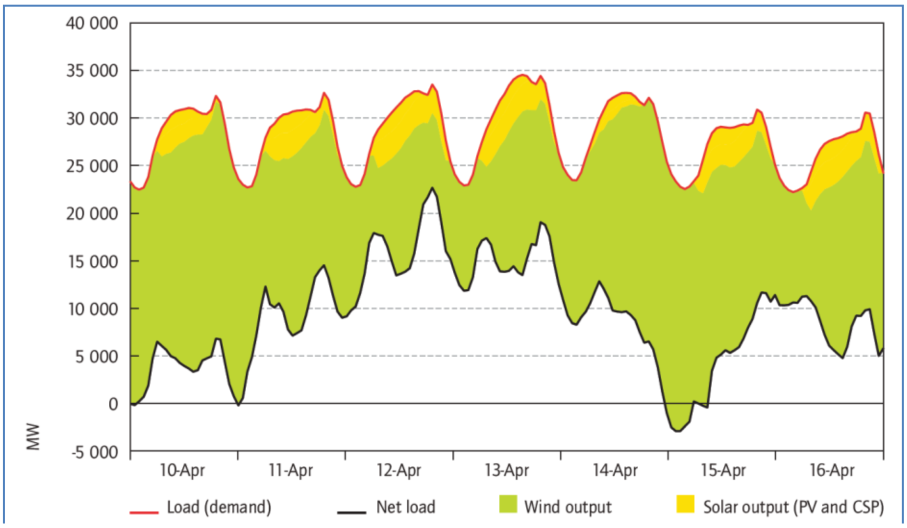
[34] A 2010 study simulated that when wind would account for 38% of all electricity delivered to the grid annually (assuming instantaneous penetration as high as 80%), 5 to 10% of the wind energy would have to be curtailed (EirGrid, 2010, in AEMO, 2011).

[35] Bulgaria features 1.6 GW of wind capacity out of a total system capacity of 12 GW (Reuters News, 2013.b)

Figure 10. **Variability in demand, supply from variable resources and from traditional plants**



Source: GE Energy, 2010, in IEA 2011.c.

Note: This figure shows the modelling of electricity supply and demand for the WestConnect area of the United States assuming a large share of wind (30%) and solar (5%) electricity annually.

4.1.3 Present and future solutions for the integration of variable renewable energy

74. There are several solutions to enhance system flexibility to cope with variable sources of electricity. They sometimes deal with more than one of the challenges listed above. Some have been used routinely and will require scaling up when more VRE capacity is in operation; others have yet to be deployed.

Improving forecasts for variable resources

75. Meteorological services can provide more recent updates of weather conditions that improve VRE predictability (MIT, 2011). Figure 11 describes how the predictive capacity of wind forecasts has improved in Spain for those provided a day ahead and beyond. Such improved predictive capability lowers the cost of VRE integration.

Controlling VRE

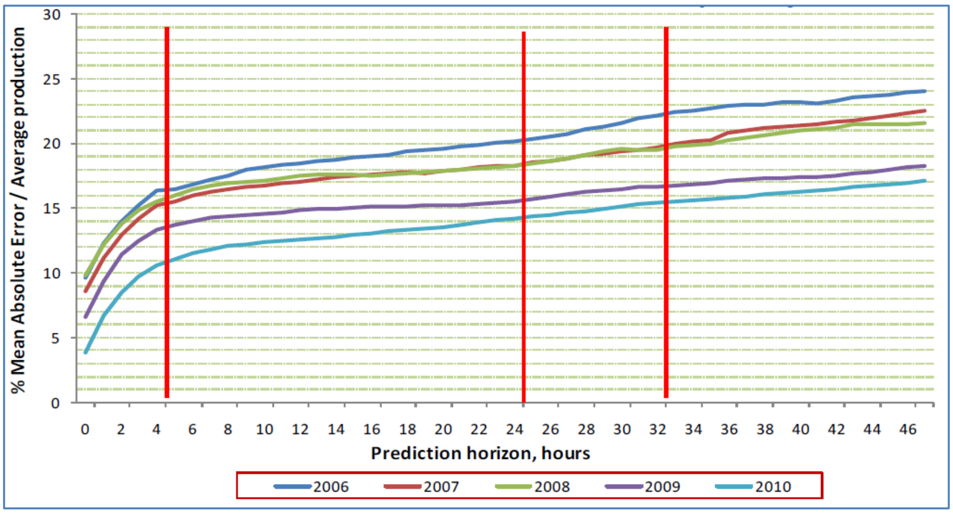
76. While they are variable, wind turbines and PV panels can play a role in their own integration into the grid. Some countries, *e.g.* Spain, can control the speed of wind turbines that are ramping up, which facilitates the management of flexible plants that accompany these variations. Solar PV installations have been fitted with devices to shut them down when too much electricity comes to the distribution network. The growing quantity of solar PV panels connected to the grid has created the opposite risk of system instability if all disconnect at the same time. Germany is currently installing devices to avoid such abrupt disconnection.

Plants suited for flexible dispatch

77. The ability to ramp plants down and up as VRE output comes and goes is a traditional component of an electricity system’s flexibility, but does strain the equipment of dispatchable plants. To avoid

premature ageing of these plants, equipment manufacturers are now marketing combined-cycle gas turbines that are better equipped to deal with this new function.

Figure 11. Wind forecast evolution in Spain (2006-2010)



Source: Red Eléctrica España (2011).

Transmission

78. Increased transmission allows transporting any excess VRE to other consumption centres. The ECF's *Roadmap 2050* describes a scenario with 60% of electricity supplied from renewables in Europe (ECF, 2010). This would require 102 GW of additional cross-border capacity, to be compared with a mere 2 GW in the high-carbon reference scenario. This new capacity would bring the Southern European solar and Northern European wind VRE to consumption centres. Additional transmission allows aggregating VRE resources, therefore lowering overall variability. In China, the State Grid Corporation is working on additional transmission to connect its large wind resources in the West to the consumption centres in the East.

79. Security of supply may also benefit from cross-border interconnections, as a country can rely on its neighbours to meet extreme peak loads or re-route power if transmission trunks become unavailable. As an example, Germany‘s northern wind plants deliver part of their electricity to southern industrial consumers via neighbouring countries. As this has triggered technical problems, Germany plans to build new North-South transmission.

Demand response, including the use of smart grids

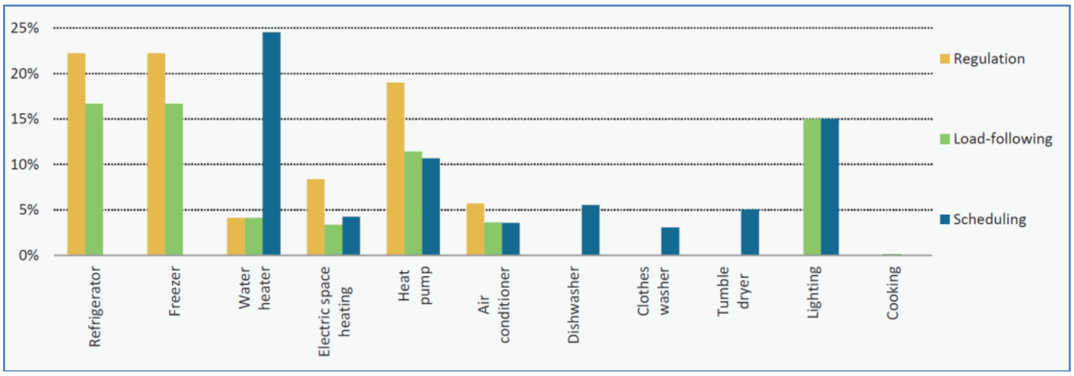
80. In a simplistic approach to electricity system management, the demand side (load) is considered as given, and reserve capacity is available to manage low-probability events of very high demand levels. The demand side can also be managed to enhance system flexibility. Vertically-integrated utilities have long relied on peak-shaving measures, *e.g.* through incentives to consumers to reduce their demand during specific periods. This has avoided investing in peak capacity that may be used very few hours per year, at a very high cost per MWh produced. These demand-side measures were considered a cost-effective way of managing rising peak demand.

81. With available information technologies this logic could be applied to either modulate demand to manage the ramping up and down of variable generation, or to absorb surplus variable electricity that

would otherwise be curtailed. Certain appliances (refrigerators, air-conditioning units, electric water heaters) could be switched on and off for short periods of time without significant loss of service to the consumer. (IEA2012.b)

82. Figure 12 shows the fraction of the energy demand from household appliances that could be commandeered to help manage the system (IEA, 2012.b). Tapping these potentials would require smart grid infrastructure and the willingness of consumers to give the grid some control over when certain appliances could be turned on and off.[36] Broader demand-side response can also be mobilised through market arrangements (see Section 4.2).

Figure 12. Fraction of appliance use that can be used for flexibility in the residential sector



Source: IEA, 2012.b.

Note: 'regulation' relates to supply-demand adjustment in a matter of seconds; 'load-following' refers to such adjustment within minutes or days, and 'scheduling' over longer periods.

Electricity storage technologies

83. The penetration of VRE could be enhanced with the addition of storage capacity to avoid wasting clean electricity when demand levels are low and VRE has to be curtailed. This stored electricity could be used to provide ancillary services beyond serving demand during peak-hours. Storage solutions differ greatly by size, technology, purpose and costs. Storage capacity can be typically described as a power capacity times a number of minutes or hours. The leading technology for electricity storage is currently the pumping of water in reservoirs, generally known as 'pumped-hydro', with some 130 GW of capacity worldwide. Compressed air energy storage is a distant second with around 400 MW. Other technologies are being researched, including batteries and the production of hydrogen for non-electricity usage, which would also avoid wasting unused VRE-based electricity.

84. At present, the main barrier to a broader use of electricity storage technologies is their cost. This cost must be compared with that of the other flexible solutions listed above (transmission, demand-side response, or dispatchable plants).

4.2 Re-thinking electricity markets towards decarbonisation?

85. Signs that current market structures and instruments may not align perfectly with the objective of low-cost generation has led to a discussion about how to effect a transition. What kind of electricity market

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[36] See IEA, 2012.b for a discussion of possible barriers to such 'control'.

organisation is required to ensure that the necessary investments will be made in transmission, flexible capacity, demand response and storage as well as in VRE and other low-carbon technologies, in a least-cost manner?

4.2.1 Today's electricity markets and renewables

86. Electricity market reform, also known as liberalisation, was launched in the late '80s to encourage competition in a sector viewed as overly monopolistic. It was argued that utilities managing all steps of generation, transmission and distribution of power without outside competition resulted in less incentive to control costs and a tendency to over-invest in generation capacity. Unbundling ended this monopolistic structure. Generation, transmission, distribution and provision to end-users became independent businesses, with only transmission and distribution (the grid) remaining as monopolies.

87. Wholesale electricity markets were established at the same time to enhance economic efficiency through enhanced competition. In many parts of the world, generators now bid their plants' output – this this creates a 'merit-order' curve with plants ranked according to the price they ask for their power. The price is set at the level where demand meets the merit-order curve. Except in times of real scarcity, the price will correspond to the marginal cost of the highest bidder, *e.g.* the fuel and operations cost of a fossil-fuel plant.[37, 38] All other plants, with lower marginal costs, receive that price as well. This is typically the case with hydroelectric and nuclear plants that have very low fuel and operations costs. The marginal cost of operating PV and wind plants is even lower, so these installations, if they operate on the wholesale market, bid at prices near zero. They can also operate outside the market, receiving the agreed feed-in tariff, with priority access to the grid.

88. Because VRE can bid at near-zero prices, or are granted priority dispatch, it automatically pushes higher-cost plants out of the market whenever the wind is blowing or the sun is shining. The wholesale market price is driven down as a result.[39] Although there may be valid theoretical justifications for this phenomenon, there is a contradiction in prices going down as more expensive supply is mobilised (VRE, in this case). This is not conducive to stable investment in generation technologies that rely on the market, including the flexible plants needed as more VRE comes into the system.[40]

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[37] Sophisticated markets now take electric grid constraints into account. In the PJM market (Pennsylvania, New Jersey and Maryland), plant dispatch is optimised according to bid prices and transmission constraints. PJM features a myriad of location-related prices; it has become the benchmark for market design (Baritaud, 2013).

[38] The market reform was applied in several industrialised countries, with a view to improving the economic performance of the former monopolies. Even China started unbundling its electricity sector, creating independent generation companies and grid companies but set electricity prices and production plans. Half of the US states have not restructured their electricity sectors. On the other end of the spectrum, Chile conducted a very far-reaching liberalisation of its electricity sector early on.

[39] Negative prices have been observed a few hours per year in markets with high VRE penetration, as some plants with rigid operations are prepared to pay to keep running (Eurelectric, 2010).

[40] This phenomenon is compounded with the 'missing money' problem common to electricity market policy analysts (see Finon, 2013; Baritaud, 2012): 1) marginal cost pricing does not allow the full recovery of capital costs; and 2) prices reach very high levels when capacity is scarce, but these episodes may be too few and uncertain to trigger investment in new capacity. In some cases, regulators have also applied price caps that limit potential revenues from peak times. This missing money problem should hit high-capital cost, low-carbon technologies (renewables, nuclear and carbon capture and storage), currently supported outside the market.

The paradoxes of electricity pricing with a decarbonised power mix

89. Overall, the more VRE is deployed, the lower the wholesale market price. This situation is sometimes portrayed as wind and solar technologies ‘cannibalising’ their own market. Unless scarce capacity drives prices to very high levels often enough, the current pricing mechanism does not allow VRE to recover their capital cost. Will ‘out-of-market’ subsidies be permanently needed to provide adequate returns on capital, or should a growing price of CO_2 be left to do the job, as theory suggests?

90. The paradox is that with more carbon-free electricity sources, generating plants that pay for their CO_2 emissions will have dwindling influence on the price of electricity. The price of CO_2 will not be as helpful toward making low-carbon technologies competitive. Again, only very high electricity prices created by scarce reserves would cover the capital costs of these low-carbon technologies, but their unpredictability and the temptation to control prices are unlikely to create the necessary conditions for low-carbon investment.

91. This price paradox is obviously an issue for future policy-makers, as today’s wholesale electricity markets are far from reaching decarbonisation. It does, however, raise the question of the transition from existing electricity sector organisation and VRE support measures to market-driven approaches that lower cost.

4.2.2 New market designs for the transition towards a low-carbon electricity system?

92. The liberalisation of the electricity sector has been driven by an effort to enhance competition, improve efficiency, and reduce costs. Liberalisation has not been ubiquitous: countries facing rapidly growing demand have focused more on reliability of supply than on market restructuring (Baritaud, 2012). But as more countries consider the deployment of more expensive low-carbon technologies, cost and performance issues are likely to come to the fore. The organisation of the electricity sector will play a major role in how cost-effective decarbonisation efforts will be (Muñoz and Bunn, 2013).

Market arrangements to facilitate VRE integration

93. Because of its uncertain and variable nature, VRE is penalised when it bids supply 24 hours ahead, as any difference between the forecast and power actually delivered to the grid implies a financial penalty for VRE plants. The penalty corresponds to the cost incurred by the system operator acting as single buyer of contracts to increase or decrease the amount of power put on the grid. Several markets have opened intra-day markets, with bidding as little as five minutes before actual power dispatch (Cochran et al., 2012). The system operator is then better prepared to manage the balancing of supply and demand. This reduces overall costs while facilitating the integration of variable electricity (IEA, 2011.c).

Ensuring generation adequacy and flexibility with capacity mechanisms

94. A growing share of VRE lowers wholesale prices and undermines interest in operating and investing in generation needed to meet future demand growth (adequacy), as well as in flexible plants. In a pure market approach, growing scarcity should lead to increasing high prices and unlock capital for investment. When faced with low reserve margins and the risk of disconnecting end-users, some governments have adopted other measures such as capacity mechanisms.

95. Capacity mechanisms can complement electricity markets. They can take the form of a payment per MWh (price instrument) or a capacity market (quantity instrument). Capacity mechanisms can be set several years ahead to allow for construction time and for newcomers. Where they exist, capacity payments represent an important share of peaking plants revenues, in addition to electricity sales (Potomac Economics, 2011). Electricity users can also bid demand response in capacity market auctioning: they

contract to lower their demand, reducing the need to run expensive generation capacity. Failure to deliver the needed capacity is penalised financially.

96. Such capacity mechanisms have not so far been introduced to accommodate the penetration of VRE plants and the resulting ramping up and down of flexible plants (*i.e.* ensuring reliability of the system). More fundamentally, they are in place to guarantee sufficient reserve capacity margins (*i.e.*, adequacy).[41] Capacity mechanisms may be used in the future to deal with both flexibility and adequacy.

97. Capacity mechanisms, for all their effectiveness in stabilising electricity systems, are criticised on several grounds. They are introduced as fixes for the lack of certainty on climate, renewable, or energy efficiency policies and the resulting lack of investment in new capacity, but it may be more efficient to deal with the primary uncertainties in the system, *i.e.* those that are policy-related. They imply a re-regulation of the electricity market whereby a central authority decides how much new capacity is needed. Removing price caps on wholesale electricity markets may be a more powerful tool for attracting peak capacity investment as well as triggering demand side savings. If not used carefully, capacity mechanisms may create unnecessary and costly excess capacity, and discourage otherwise effective demand-side response. When markets are coupled across regions, the introduction of a capacity mechanism in one part of the system will create distortions. Some coordination is then required (Baritaud, 2012).

Tendering for capacity and power

98. Some alternative market approaches to the wholesale electricity markets exist, *e.g.*, in Europe and some US States. In Brazil, for instance, the formerly tariff-subsidised government-run electricity system has moved towards a more competitive environment based on auctions.[42]

99. In Brazil, electricity auctions are run to procure new capacity and to organise competition among existing plants. For new plants, they consist of long-term contracts (*e.g.* 15 years for thermal plants, 30 years for hydro). Depending on the auction, the winners are contracted for a price per MWh (*i.e.* power purchase agreements or PPAs) or for an option on their capacity, with a price per MW, and a 'strike price' that will be paid if the option is exercised. The winner is identified on the basis of which generators will deliver least-cost power to the end consumer.

100. The auctions are a means to ensuring adequate supply in the face of growing electricity demand (roughly 5% per year in Brazil). While the government organises the auction, it does not set the demand growth for which new capacity is sought: this is left to power distributors, who will then assume liability if they have procured too much capacity (adjustment auctions are organised to correct for over or underestimates during the initial auctions). For the marketing of electricity from *existing* plants, auctions lead to contracts of shorter durations (typically five years). The auction mechanism has also been used to procure renewable energy plants other than hydro dams.[43] In some cases, wind plants have won auctions against natural gas plants, as the latter face the risk of gas price volatility in the medium run (IEA, 2012.e).

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[41] There have been several motivations behind capacity mechanisms: in France, rising electricity demand from electrical heating has generated concerns about system adequacy. In the UK, it is the closure of large coal-plants scheduled in 2016, in response to the European Large Combustion Plant Directive. If rolled out, the capacity mechanism would include storage capacity and demand response (DECC, 2012).

[42] This section is based on Tolmasquim, 2012; Maurer et al. 2011; Finon, 2013.

[43] As of 2011, Brazil had successfully conducted a total of 31 auctions for existing and new electricity (Maurer and Barroso, 2011).

4.3 Summary

101. Electricity grids require careful management to ensure the secure supply of power. Variable renewable energy sources are a challenge to electricity systems, but by no means an insuperable one: these systems are intrinsically designed to accommodate unpredictable variations in demand. Larger shares of VRE imply more variability and uncertainty and the need to accommodate them with flexible capacity. Another challenge comes from the need for enough capacity or demand response to face peak demand in periods with low VRE generation, and how to best trigger investment.

102. The issue of VRE integration is very much context-driven. On one side, the EU and some other developed countries have achieved a high level of penetration of renewable electricity with a long history of out-of-market support systems. They will have to introduce new practices to deal with technical challenges related to the variable and uncertain nature of a growing share of their electricity capacities; wholesale electricity markets are also made more volatile as a result. Further, the penetration of VRE drives wholesale prices down due to the low operational cost of these technologies. It is not clear how VRE and other high-capital cost, low-carbon technologies could recover their capital cost under such market arrangements, especially as the electricity system moves towards decarbonisation.

103. On the other side, there are countries that have not restructured their electricity systems as try to meet electricity demand growth; these have lower but still growing VRE penetration rates. Integration issues are less pressing in these countries, but they will require technical and institutional solutions that are being tested in the first group of countries. Much can be gained from international information sharing in this area, including the confidence that variable renewable electricity can play a significant role in climate mitigation.

5. UNCONVENTIONAL GAS REVOLUTION: TRANSITION TO LOW-CARBON OR CARBON LOCK-IN?

5.1 Natural gas: recent history and outlook

104. Natural gas accounts for 21% of total primary energy supply, with 3 307 billion cubic meters consumed in 2010 (IEA, 2012.h). The last decade has been one of spectacular growth in volume for gas use in electricity. Forty per cent of all gas is now used in electricity and co-generation plants, contributing 22% of global electricity supply. Gas-based generation grew 74% between 2000 and 2010, while global electricity output grew 39%. The capacity of gas-burning electricity plants has grown accordingly in the last decade, with some 750 GW installed between 2000 and 2011 (IEA, 2013.a) when new coal capacity totalled 'only' 700 GW in the same period. Growing consumption of natural gas for electricity generation does not in itself run contrary to a decarbonisation agenda in the medium term. It is all a question of whether more carbon-intensive sources (*e.g.* coal) are being displaced and whether the platform is being laid for lower carbon energy to take over from gas.

105. The commercialisation of shale gas has unleashed a new dynamic whose repercussions for the wider energy scene are not yet fully understood. The boom in unconventional gas in North America will soon turn the US from a net importer to a net exporter. It has resulted in decreasing power prices as gas undercuts coal, and therefore contributed to lower CO_2 emissions. At the same time, cheap displaced US coal has been finding a ready market in the EU. Is the US situation an indication of what is to come in other regions? Could this gas boom undermine the needed growth in low-carbon technologies, including renewables?

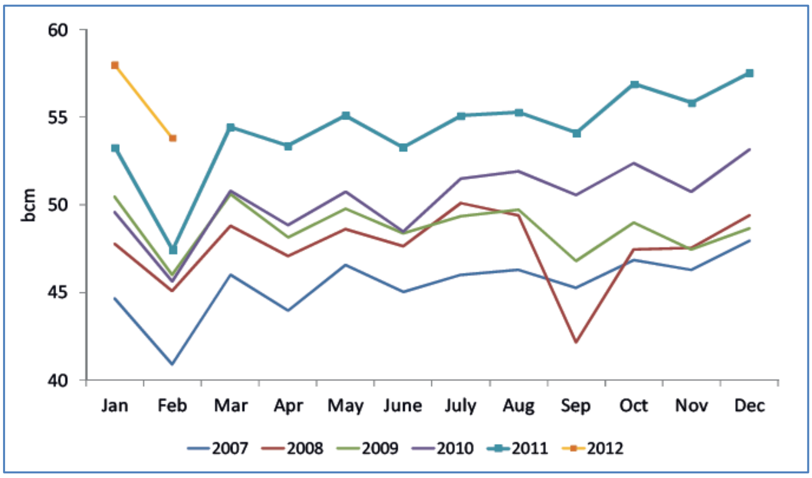
5.1.1. Unconventional gas: in North America alone?

106. Technology developments have turned untapped resources of gas into cheap, accessible reserves. The shale gas boom has relied on the combination of horizontal drilling and hydro-fracturing, or fracking, the injection of a high pressure mix of water and chemicals to create cracks in the shale deposit. In the US, gas is often a by-product of the much more lucrative tight-oil exploration; gas-only fields are not profitable at the low price levels observed in early 2012 (USD 2 per million BTU), but may become attractive above USD 4.5 MBtu.

107. Unconventional gas now more than compensates for the decline in conventional gas production in the US. As of 2011, the US produced 653 bcm, or 54% of all OECD production. Figure 13 shows the remarkable growth in US gas output since 2008. Unconventional gas production will continue to boom in the US in the medium-term, driven by high oil prices which encourage gas extraction as a by-product of tight oil (IEA, 2012.d). Beyond this, the Energy Information Administration projects a 40% growth in US gas production between 2011 and 2040, driven mostly by shale gas (EIA, 2012).

108. Beyond geological and technological breakthroughs, the US benefits from favourable market conditions for the exploitation of unconventional gas: a vibrant domestic oil and gas industry with competitive service providers, as well as an active gas market; the availability of capital (cheap credits, joint ventures); easy access by drilling companies to large portions of land for development; a tax subsidy dating back to 1980; and lease regulations requiring the leaseholder to start operation within a given period or lose the leased gas (Bazilian et al. 2013).

Figure 13. Monthly US gas production, 2008-12



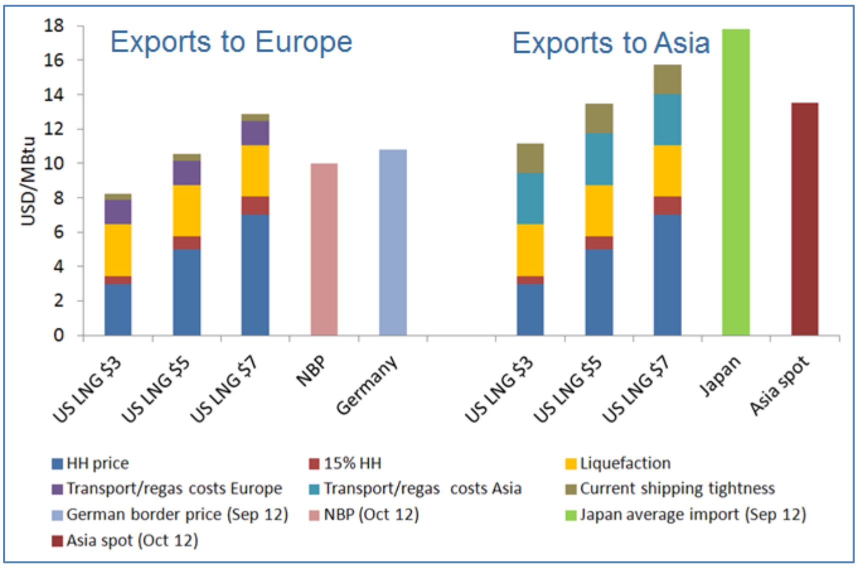
Source: IEA, 2012.d.

5.1.2 Exporting cheap US shale gas to the rest of the world

109. US gas prices have hit record lows, but it is not clear that these price levels can be exported to the rest of the world. Several factors stand in the way of this prospect. First, the US still lacks the liquefaction facilities for liquefied natural gas tankers, though it had invested in LNG-importing facilities which could be retrofitted for liquefaction. Second, liquefaction itself is a costly and energy-intensive operation. Third, transport costs to Europe and Asia are high and facing tight supply. Also, export restrictions apply to natural gas in the US and approval has to be granted by the United States Department of Energy (US DOE). There is pressure on the side of the manufacturing sector for US gas to be reserved to meet domestic demand, on competiveness grounds.

110. In the meantime, 26 export projects have been submitted for approval, and the general view is that some gas export projects will move forward (Financial Times, 2013.b). How many, and with what impact on global gas supply and price beyond North America, remains unclear. As of 2012, regional prices continued to drift apart, with US gas prices hitting USD 2/MBtu, European spot and contract prices in the USD 8-10 range, and average Japan import prices reaching USD 17. Even if US gas exports are competitive under current market circumstances, they will probably not bring European and Asian prices down to the extremely levels witnessed recently in the US (Figure 14).

Figure 14. Illustration of US LNG export prices for different spot prices, and comparison with European and Asian gas prices



Source: IEA (2013.c). Note: HH stands for Henry Hub, the main natural gas hub in the Southern US. NBP stands for National Balancing Point, the UK sport market for gas.

5.1.3 *Prospects for a global shale gas boom: not in the near term*

111. The technology underlying the development of shale gas in the US could of course be deployed in other regions of the world, albeit under different market and geological conditions. This possibility has led to a significant revision in the estimates of technically recoverable resources of conventional and unconventional natural gas. Estimated at 790 trillion cubic meters, these resources amount to 230 years-worth of gas demand at the current level of demand (IEA, 2012.h).[44,45] Although these resources are present in all regions, in the medium term China and Poland[46] offer the most favourable conditions, though shale gas extraction in these countries is not likely to develop at the speed seen in the US. China plans for 100 bcm of shale gas production by 2020, which alone may not cover its growing needs.

112. In Poland, where resource estimates range between 346 bcm and 5 tcm (IEA, 2012.d), only 42 test wells have been drilled so far, against more than 20 000 in the US, where 1 769 individual drills are available (Baker Hughes, 2013).[47] As *The Economist* remarked of shale gas prospects in Europe, “it may take five years to assess whether shale gas exists in commercial quantities, another five before production

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[44] If extracted and combusted, these resources would emit some 1 600 billion tons of CO_2, much above the CO_2 budget allowed to keep temperatures at less than 2°C above pre-industrial levels.

[45] Remaining resources comprise proven reserves, reserves growth and undiscovered resources.

[46] Although in Europe, France appears to sit on the largest resource, estimated at 5 000 bcm (EIA, 2011).

[47] “Exxon Mobil withdrew from Poland in 2012, saying its wells had failed to demonstrate "sustained commercial hydrocarbon flow rates," while ConocoPhillips relinquished its 70 percent option in three concessions in northern Poland, although it retains three more. It has been reported that Canada-based Talisman Energy also has started talks to sell off its Polish exploration licenses.” (Herald-Standard, 2013).

starts and then a few more before shale could provide a significant addition to supplies: in short, a fracking long time."[48]

113. The slow development of shale gas exploration in Europe is in part due to the potential environmental impacts of shale gas and coal-bed methane extraction in a much more densely populated continent. These include (IEA, 2012.c):

- Shale gas extraction requires more wells than conventional gas. Well preparation requires 100 to 200 truck movements per well and local diesel generators are used 24 hours a day during drilling, generating local pollution.
- Fracking involves injecting anywhere from a few thousand to 20 000 cubic meters of water per well, as well as 1 000 to 4 000 tonnes of chemical additives and sand. The water comes from rivers, lakes or the sea, or is brought by trucks (500 truckloads for a typical 15 000 cubic meter use per well).
- Waste water containing chemicals must be recycled, treated, or injected permanently.
- Abandonment at the end of the production life of a well, at which point care must be taken to avoid leaks to aquifers.
- In the case of coalbed methane extraction, water present in reservoirs must be extracted with the gas. The disposal of the vast amounts of extracted water (180 million cubic meters in the US in 2008) requires treatment, as it contains high levels of sodium, calcium and magnesium.
- The venting or flaring of methane in the early extraction phase automatically adds to the CO_2 intensity of the extracted gas (3.5% for flaring as methane is transformed into CO_2, and 12% when venting is applied).[49]

114. The IEA (2012.c) find that the minimisation of environmental impacts of shale gas would add a 7% fee to the financial cost of a typical shale-gas well, which would not undermine its economic viability and may give shale gas a 'license to operate'. This would equate to USD 0.3/MBtu. A US-focused analysis indicated a potentially higher cost as high as USD 1/MBtu.[50]

5.2 Would a gas boom support or undermine decarbonisation through renewables?

115. Cheap gas has reduced the price of electricity in the United States, which automatically challenges the economic competitiveness of other generation sources, including solar PV and wind. Gas

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[48] *The Economist*, 2013.

[49] GHG emissions from shale gas have been the subject of controversy in the US research community, ignited by first estimates that shale gas would be 20 to 100% more CO_2-intensive than coal as a primary fuel (Howarth et al., 2011). O'Sullivan and Paltsev (2012) studied the practice of 4 000 wells in the US, and found that "[…] the production of shale gas and specifically, the associated hydraulic fracturing operations have not materially altered the total GHG emissions from the natural gas sector" (p.5).[49] The US Environmental Protection Agency announced an expert review to assess the environmental risks related to shale gas (Reuters, 2013.b).

[50] Jeffrey Logan, personal communication. Logan et al. (2012) project that an additional cost of USD 1/MBtu to implement best environmental practice for shale gas recovery would result in a 17% reduction in future gas use in power generation by 2050. Gas-based power generation would still double from 2010 levels.

also replaces coal in power generation, where it lowers CO_2 emissions per kWh at a negative cost to the electricity user. This substitution, made possible by the availability of excess gas plant capacity, has helped reduce US CO_2 emissions. Could cheap gas from unconventional resources provide a valid near- to medium-term transition to decarbonisation, at the expense of further deployment of renewables? The interaction of cheap gas and variable renewables should raise three questions:

- Are there potential synergies between VRE and natural gas in power generation?
- Can unconventional gas, if abundant at low cost, make a significant contribution to decarbonisation? What are the associated risks and opportunities?

5.2.1 Variable renewables and natural gas

116. The US National Renewable Energy Laboratory has considered the possible synergies between gas and renewable energy sources, looking at power generation and transport (Lee et al. 2012). In power generation, an analysis of the different risk profiles of variable renewable and natural gas plants points to the complementarity of natural gas and variable renewable plants in a company's portfolio, due in part to the following:

- Solar and wind technologies carry no fuel supply risk (their risk comes from variability and uncertainty).
- Fuel price variability, present in gas, is not an issue for VRE.
- VRE is available in much smaller capacity increments than gas plants.
- Long-term investment in gas plants does not depend on government incentives.
- Gas plants can be dispatched flexibly, which helps the integration of VRE. More VRE capacity should mean a premium for those plants that can be dispatched most rapidly.

117. Cheap natural gas could also indirectly support renewables: it is easier for electricity users to accept a surcharge for renewables if the overall price of electricity is lowered by cheap gas.[51]

5.2.2 Natural gas and climate objectives

118. The IEA produced a *Golden Rules Case* that assumes appropriate environmental regulations applied to unconventional gas, allowing its extraction to move forward. More and cheaper gas cuts both ways on CO_2 emissions: it decreases emissions when substituted for coal in power generation, but also undercuts nuclear and renewables. These two mechanisms play out differently in different regional settings. Overall, the *Golden Rules Case* shows lower CO_2 emissions in 2035 than in the reference scenario, but global emissions would still be 68% above the level required to be on track with the 2°C constraint (IEA, 2012.h). In other words, with countries' climate pledges as we know them today, more gas from unconventional resources would decrease, not increase, global CO_2 emissions, but only slightly.

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[51] IEA (2012.h) illustrates this in the case of the US electricity system in 2020: at a gas price of USD 5/MBtu, households will pay an average USD 128 per MWh, with USD 6/MWh paid to renewables. This subsidy drops to USD 1/kWh if the gas price is USD 2 higher, but the average electricity price reaches USD 138/MWh. A low gas price in this particular situation would lower the cost of RE penetration perceived by households.

More gas in a 2°C scenario?

119. Could more gas change the picture under an ambitious climate policy scenario? For simplicity's sake, we rely again on the IEA *450 Scenario* to 2035 and ask how that picture might be different with more gas. This requires looking at regions separately. In the OECD, gas-based power generation declines in the *450 Scenario*, but coal use in electricity declines even faster and is likely to be burned in CCS-fitted plants, leaving little room for further CO_2 reductions through coal to gas substitution.[52] Outside OECD, a low-carbon scenario is likely to rely on a mix of enhanced energy efficiency, renewables and nuclear; coal-based power would decline and gas-based power would increase from today's levels. In countries where coal is still used in plants without CCS (non-OECD Asia), other scenarios do not point to much potential to increase gas usage, unless much more favourable gas prices were envisioned.

Cost and risks: policy, technology and lock-in

120. In times of economic crisis, there may be pressure to reconsider support to renewables as unconventional gas developments could offer a cheaper, short term alternative on the road to decarbonisation. A more carbon intensive path could be followed in the medium term, while the development of carbon capture and storage would ensure swift decarbonisation further down the line. A recent analysis by E3G looks at this issue from a risk-management perspective, based on a UK decarbonisation objective, and the possibility of a new "dash for gas" driven by a rising carbon price. Another scenario continues support measures for renewables, together with a growing, but lower carbon price, and aggressive energy efficiency (Zorlu et al., 2012).

121. The first scenario is cheaper from a total electricity system cost perspective if all goes as planned. However, it could end up being much more expensive when the following risks are factored in: non-delivery of CCS at scale, or nuclear, or offshore wind, requiring a very high CO_2 price to bring alternative mitigation options; a higher gas price; and the non-delivery of energy efficiency potential. With continued technology support to renewables, the electricity system would be less vulnerable to some of these delivery and economic risks.

122. This example cannot be generalised globally. It does however point to the importance of taking a broad, long-term risk perspective when making decisions on both energy developments (should unconventional gas be developed domestically, in light of future climate objectives and cost?), and on policy instruments (a single carbon price versus a policy package that also targets low-carbon technology deployment). It also raises the question of fuel lock-in: an energy mix that is dependent on gas and the underlying long-lived pipeline infrastructure does commit an economy to a prolonged reliance on gas. This also narrows the choices of abatement technologies to CCS, without which the gas infrastructure will be stranded.

123. As the unfolding unconventional gas story shows, the energy future is uncertain and fundamental shifts can take place within a few years. A future different from the above scenarios could emerge. The consequences of the gas boom on decarbonisation and renewable electricity remain uncertain, but policy choices can lower this uncertainty and rein in gas developments to encourage decarbonisation.

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[52] Less than 1% of the region's electricity output is produced from coal without CCS (about 100 TWh). As electricity emissions are assumed to be under a cap, increased gas use to substitute coal w/o CCS would be neutral in CO_2 terms, unless the cap were adjusted accordingly. If so, less than 50 $MtCO_2$ could be saved out of a regional total of 6 087 $MtCO_2$.

5.3 Summary

124. The competitiveness of various fuels and technologies has been revamped by the rise of cheap unconventional gas production in North America. More of these resources are estimated to be available in many regions of the world, although the conditions for their exploitation differ. In the near to medium term, the US shale gas revolution is not likely to be replicated in other markets on that scale – though surprises cannot be ruled out.

125. On the one hand, VRE may benefit from the availability of cheaper gas in the near to medium term, as gas-based power plants are well suited to accommodate the integration of variable electricity technologies in the grid. And to the extent that new supplies of gas can back off more intensive sources such as coal, shale gas can play a positive role in the transition to a zero-emissions energy system. Gas is half as CO_2 intensive as coal in power generation, and its broader use has helped reduce CO_2 emissions in the US. On the other hand, opportunities for this fortunate substitution of more with less carbon intensive energy sources are not present in all regions. If new unconventional gas ended up delaying the decarbonisation of an energy market, that would be a step backwards.

126. At the global level it seems clear that without additional climate policies the unconventional gas boom will only slightly reduce global CO_2 emissions below current trends (IEA, 2012.h). While the need to rationalise subsidies for renewable energy cannot be avoided, any changes in support measures should be considered in the light of the overall relative competitiveness of low-carbon sources and the need to ensure a progressive elimination of CO_2 emissions to the atmosphere. The relationship between shale gas and the overall emissions trajectory of a particular electricity generation system will differ from market to market. Policy makers will need to be careful to ensure that the availability of a new source of fossil fuel does not bring progress in renewables to a standstill but rather complements the transition to a zero-emissions world.

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ANNEX 1
RENEWABLE POWER GENERATION TECHNOLOGIES[53]

Bioenergy: the use of solid biomass, biogas, liquid biofuels and renewable municipal waste for power production. Used in co-generation plants, biomass can also be burned in coal-fired plants.

Concentrating solar power (CSP): produces power from concentrating solar radiation to heat, used to run electric turbines (four proven CSP technologies are in use today). Requires cooling systems, with large water needs in the case of wet cooling systems. Heat storage can be coupled with CSP to generate electricity in the absence of sunshine. Although their solar resources can be variable, CSP plants with storage can produce a more predictable amount of electricity than photovoltaic panels. In hybrid plants, solar thermal technology is coupled with fuel-based thermal plants to improve efficiency (IEA, 2011.d)

Geothermal power: exploits energy stored in rock, trapped vapour and liquids. The extracted heat drives a turbine to generate electricity. Can provide baseload power.

Hydropower: generated from water moving through turbines; the water is either stored in dams or exploited in run-of-river installations. Pumped storage uses grid electricity to store electricity and to produce power in times of high demand, or for system stability. It is not strictly renewables, unless it uses renewable electricity to pump water.

Ocean power: includes a wide range of technologies exploiting tides, ocean currents, waves, temperature gradients, and salinity gradients. Tidal energy is the only mature technology. Though variable, most forms of ocean power are highly predictable.

Onshore wind: uses moving airflow to produce electricity via an aerodynamic rotor connected to an electric generator. Winds vary both temporally and spatially.

Offshore wind: wind turbines deployed at sea, where wind resource is usually better. Offshore wind requires support structures that rest on the sea bottom; floating devices are also being developed.

Solar photovoltaics power: converts sunlight, both direct and diffused, directly into electricity through the photovoltaic effect. Two main technologies co-exist: silicon-based (with higher conversion efficiency) and thin-film (with lower cost per capacity).

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[53] Based on IEA, 2012.e.

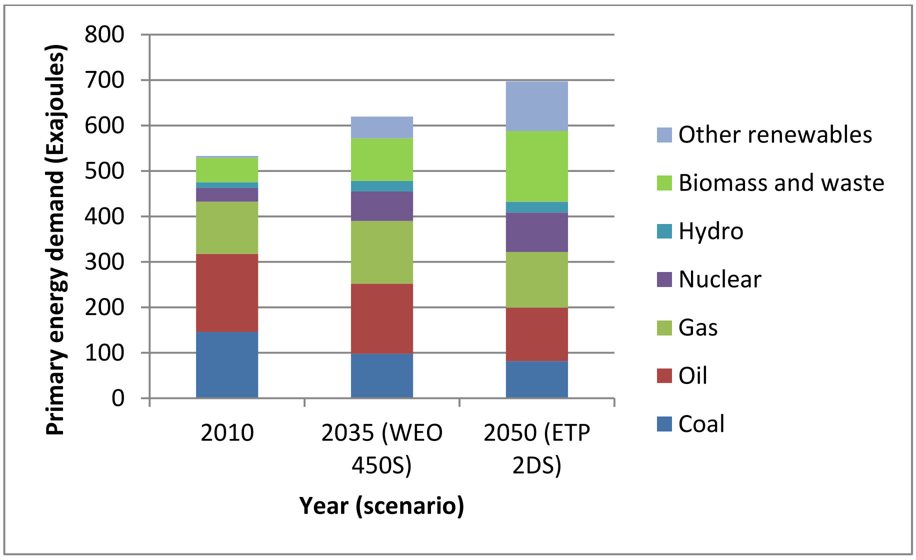
ANNEX 2
CRITICAL ROLE AND LARGE POTENTIAL OF RENEWABLES IN GLOBAL ENERGY SCENARIOS

In addition to the IPCC Representative Concentration Pathways, a wealth of global energy scenarios look at the next 20 years and beyond to identify various paths for the world to remain on track with the 2°C objective. These projections describe what their designers see as the most probable future given current technology and policy efforts, as opposed to a more policy-prescriptive scenario. Both the climate-policy and 'laissez-faire' scenarios provide important insights on the future of renewable energy.

Technological surprises are of course probable over the longer term, but much less so in the coming two to three decades: energy infrastructure is long-lived, capital turns over slowly, and it is those technologies that already exist or in the demonstration stage today that will provide the bulk of our energy supply over that time horizon.

The International Energy Agency's *World Energy Outlook* (IEA 2012.h) and *Energy Technology Perspectives* (IEA 2012.b) consider two policy-driven low-carbon scenarios roughly consistent with the 2°C objective. They combine a price on CO_2 emissions, ambitious energy-efficiency policies across all elements of supply and demand, targeted support for low-carbon technologies and the removal of fossil-fuel subsidies. Over their respective projection timeframes (2035 and 2050), these scenarios show very significant increases in the share of renewable energy in global energy supply.[54]

Figure 15. Global primary energy demand by energy source under IEA low-carbon scenarios



Sources: IEA 2012.h, IEA 2012.b.

Notes: WEO450S: *450 Scenario* of the World Energy Outlook. ETP 2DS: Energy Technology Perspectives, *2 Degree* Scenario. Other renewables include: geothermal, solar PV, concentrated solar plants (CSP), wind (onshore and offshore), and marine power.

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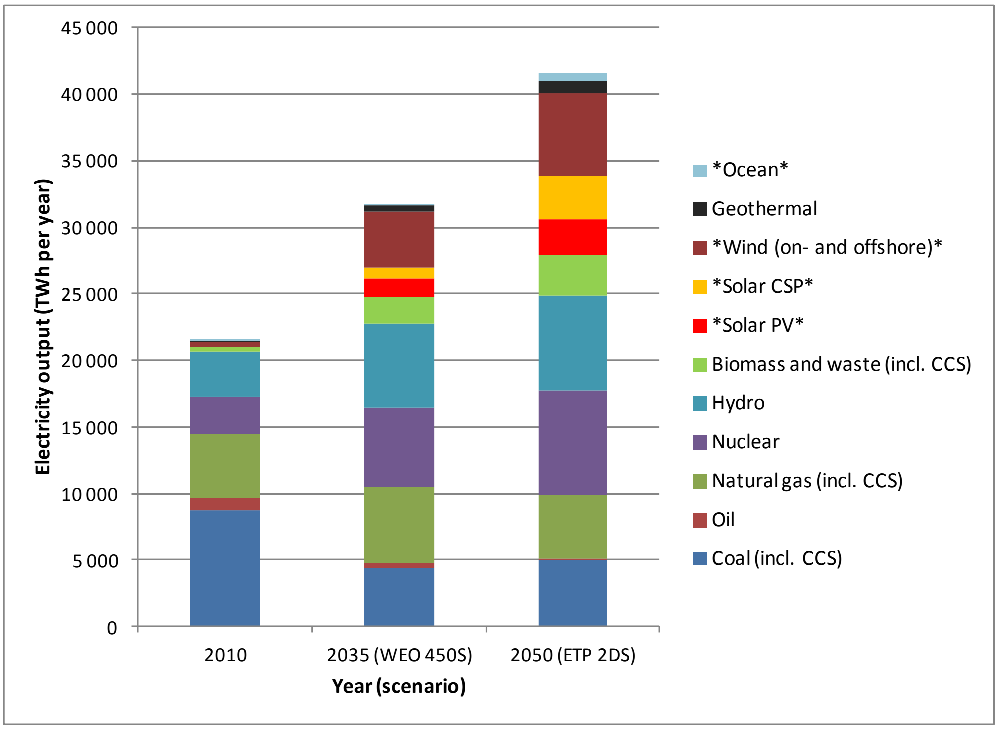
[54] In *Solar Energy Perspectives*, the IEA also explored a scenario that pushes the envelope of solar energy technologies and finds that they could supply half of the global electricity and a third of total energy needs by 2060 (IEA, 2011.d).

The growth is particularly spectacular in electricity generation, where hydro, bio-energy, geothermal, wind, solar, and ocean energy provide 48% and 57% of total electricity supply in 2035 and 2050 respectively, against less than 20% today. The total electricity output from variable resources (wind, solar, and some ocean-based electricity) would be 17 times and 33 times higher than today's by 2035 and 2050. Indeed, the 12 000 TWh generated from these resources in 2050 would be higher than all OECD countries' electricity output today.

Overall, the low-carbon *2DS* scenario of the IEA projects a global average electricity generation cost that evolves from USD_{2010} 65/MWh to USD_{2010} 122/MWh, an 89% increase. Accounting for transmission and distribution costs, including the cost of building smart grids and integrating variable renewable electricity, the retail cost of electricity would be about 60% above its level in 2010. Average global GDP per capita would grow by 160% in the same period.[55] The long-term transition to a decarbonised electricity system appears therefore manageable from the perhaps narrow perspective of electricity prices relative to wealth.

Figure 16. Electricity supply by technology under IEA low-carbon policy scenarios



Sources: IEA 2012.h, IEA 2012.b

Notes: WEO450S: *450 Scenario* of the World Energy Outlook. ETP 2DS: Energy Technology Perspectives, *2 Degree Scenario*. Energy sources with * are variable. CCS: carbon capture and storage.

Cost minimisation requires all low-carbon technologies – but renewables are critical

These climate-mitigation scenarios emphasise the need for a broad range of low-carbon technologies, from nuclear energy to renewables and carbon capture and storage. The logic behind this all-encompassing approach is cost minimisation. The *OECD Environmental Outlook to 2050* (OECD, 2012) evaluates the

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[55] Uwe Remme, IEA, personal communication.

macro-economic cost of various mitigation scenarios compatible with the above IEA energy trends. With all low-carbon technologies available – but deployed reasonably, taking national resources and energy policy choices into account – the net GDP loss would be 5.5% in 2050 from what GDP would be without climate action. The global economy would still be about four times larger than today: climate protection would cost a 0.2% drop in the annual growth rate between now and 2050. The *Outlook* then goes on to describe the impact on real income of removing certain technologies from the available portfolio: carbon capture and storage, nuclear, or energy efficiency combined with renewable energy. A scenario without a push for enhanced end-use efficiency and renewables would be the most costly, with a real income loss ranging between 5.5% and 14.5%. The conclusion here is that if renewables are not, like nuclear or CCS, absolute pre-requisite to meet our climate objectives, they play a crucial role in decreasing the macro-economic cost of our emission reduction efforts.[56]

Overview of other organisations' low-carbon energy scenarios

Several organisations have produced low-carbon scenarios that offer a different view on decarbonisation. The World Wide Fund for Nature drew a path for achieving a nearly 100% renewable energy supply by 2050 (WWF 2011), while stressing a number of challenges along the way. An important difference with IEA scenarios is the extent of end-use energy savings displayed in the WWF scenario: energy demand would be lower 2010 levels by 2050, against a 30% growth over the same timeframe according to the IEA. More interestingly still, the WWF projects a lower absolute amount of energy from renewable technologies than the IEA *2 Degree Scenario* (2DS) (IEA 2012xx).[57]

The Intergovernmental Panel on Climate Change (IPCC), in its Special Report on Renewable Energy, conducted a survey of 164 energy projections covering a wide range of climate-change outcomes (IPCC, 2011a). The survey indicates that for low-greenhouse gas concentration scenarios, the median value of renewable energy supply (biomass and hydro-electricity included) by 2050 is four times the annual supply in 2008; the highest scenario projects an almost seven-fold increase. Hydro-electric output grows only modestly over that time frame, but from a large basis; the bulk of the increase would come from other renewables, which only contribute modestly to our global electricity production today. Table 2. shows the implications for global electricity output for these technologies by 2050.

The representative low-carbon scenarios selected by IPCC and the IEA *2 Degree Scenario* (2DS) confirm the massive increase in renewable electricity supply, with the exception of hydro, a more mature technology. The electricity output of these new technologies is projected to grow 15 to 70-fold between now and 2050. Based on latest cost information, the IEA's 2DS projects an output that is 22 times as high as 2010 levels, accounting for 40% of electricity supply in 2050.

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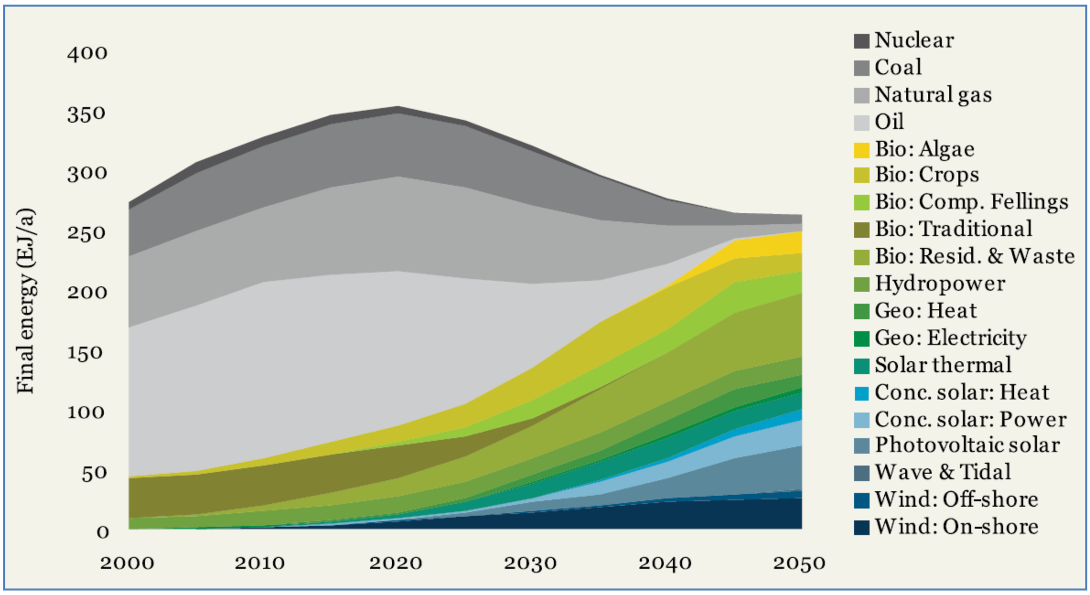
[56] Without CCS and nuclear, the real income losses would be 8% and 9% respectively (OECD, 2012).

[57] By 2050, the IEA *2 Degree Scenario* (2012.b) projects 288 Exajoules of renewable energy supply, against 250 Exajoules for WWF (2012).

Figure 17. Ecofys energy scenario of World Wide Fund for Nature: aiming for 100% renewables



Source: WWF, 2011.

Table 2. Projected growth in renewable electricity supply in IPCC low-carbon scenarios and IEA *2 Degree Scenario* [turn into a range graph]

Technology	**TWh in 2010**	**TWh in 2050 [low; high] *IPCC 2011***	**2050/2010 output ratio *IPCC 2011* [low; high]**	**2050/2010 output ratio IEA, *2DS* [low; high]**
Hydro	3 431	[4 500; 6 500]	[1.3; 1.9]	2
PV	32	[850; 20 800]	[27; 650]	83
Concentrated Solar Power	2	[~0 ; 9 000]	[- ; 4 500]	1 667
Wind (on- and off-shore)	342	[7 800; 14 300]	[23; 42]	18
Geothermal	68	[~0 ; 4 200]	[- ; 62]	14
Bioenergy	331	[3 600; 5 900]	[11; 18]	9
Ocean energy	0.6	[0 ; 2 000]	[0; 3 333]	868
Total excluding hydroelectricity (average)	775	[12 250; 56 200]	**[16; 72]**	**22**

Source: Figure 10.13, p.819, IPCC, 2011a. IEA, 2012.b.

Renewables in less ambitious climate policy scenarios

Scenarios with ambitious climate goals point to the rapid growth in most new renewable energy sources as a means of meeting growing energy demand without increasing CO_2 emissions. Other projections provide an alternative view, with less focus or a less effective response to the climate change challenge in the coming decades. It is interesting to see how these projections envision renewable energy developments, as they may provide a lower bound estimate.

Under BP's *Energy Outlook 2013,* CO_2 emissions continue rising, by 26% between now and 2030. In this outlook, energy supply from renewables, excluding hydroelectricity and biofuels, would grow four-fold, and account for 5% of the world's primary energy demand in 2030 (BP, 2013). In ExxonMobil's *The Outlook for Energy: A View to 2040*, CO_2 emissions would peak around 2030 and reach 36 $GtCO_2$, against 30 $GtCO_2$ in 2010. The contribution of renewables (excluding hydroelectricity and biofuels) to global energy supply would be multiplied by 4 between 2010 and 2040. In spite of this growth, these sources would only account for 4% of total energy supply (ExxonMobil 2013). Under both these outlooks, the new renewable sources would nonetheless be the fastest growing sources over the period.

ANNEX 3
GRID PARITY

Grid parity is not a proper indicator of cost competitiveness. For instance, say that a household with 4000 kWh of consumption pays an average price of 0.2 EUR/kWh, which happens to be the price per kWh of a PV installation that generates 1 000 kWh of electricity per year. In other words, PV has reached 'grid parity'. The household assumes that, once installed, PV panels will meet their electricity needs for the same or lower cost.

In reality, the total electricity cost for this household is equal to: 1) the fixed cost for access to the grid; 2) the variable cost of electricity drawn from the grid; and 3) the kWh cost of its PV-generated power. Under a with-PV scenario, its savings accrue only to the variable cost.

The illustration below shows that total cost is higher in a *With PV* than in a *No PV* case (EUR 1100 against EUR 800). The household would save electricity at a price of EUR 0.1/kWh, with an installation that cost EUR 0.2/kWh. Its total cost, and cost per kWh therefore goes up if it decides to install PV to supply part of its own power. It wouldn't be economical to do so, and should not happen without a subsidy on the cost of the PV installation.

	Without PV	**With PV at 0.2 EUR/kWh**
Electricity consumption	4 000 kWh	4 000 kWh
Supplied from		
- Grid	4 000 kWh	3 000 kWh
- PV installation	--	1 000 kWh
Variable cost		
- Variable, grid-supplied	0.1 EUR/kWh	0.1 EUR/kWh
Fixed costs		
- Grid access	EUR 400	EUR 400
- PV (annualised)	n.a.	EUR 200
Total cost	EUR 800	EUR 900
Grid		
- Variable	EUR 400	EUR 300
- Fixed	EUR 400	EUR 400
PV	--	EUR 200
Average cost to household	0.2 EUR/kWh	0.225 EUR/kWh

ANNEX 4
RECENT CHANGES IN RENEWABLE ELECTRICITY SUPPORT SYSTEMS

The drop in renewable equipment prices and the soaring cost of support measures has led to a number of policy changes (Kaminker et al., 2013; IEA, 2012.e; Winkel et al., 2012):

- Spain reduced tariffs for pre-agreed projects by 30% as a result of an estimated EUR 3 billion deficit in the electricity tariff programme. In early 2012 it temporarily suspended support for new capacity. According to IEA, Spain overshot its 2010 objectives for solar PV and CSP by factors of ten and five, and fully met its 2010 objective for wind.

- The Czech Republic witnessed a solar bubble (with a total capacity of 2 GW and significant impacts on power prices). The country retroactively changed tariffs granted to solar plants, which almost stopped new installations after 2010.

- Germany reformed its FIT for PV, triggering a boom in installations before new tariffs came into effect (1.9 GW in the first quarter of 2012). New FITs are 20-30% below pre-existing levels and are to be adjusted on a monthly basis to keep track with PV prices. At the same time, the renewable energy surcharge had to be increased from 3.6 to 5.3 cents per kWh and is expected to cost EUR 20 billion this year (*Financial Times*, 2013). The surcharge may also be passed on to industrial electricity users, who had so far been exempted. A retroactive cut in the tariff for one year has been under discussion, with no decision taken yet.

- France adjusted its then-generous tariffs for PV in 2011, as the drop in prices led to requests for installations in 2010 that were well beyond the 2020 target. The tariff will now be adjusted every quarter on the basis of new installed capacity. There is also a cap of 500 MW per year on capacity eligible to the adjusted tariff.

- Italy has also adjusted its PV tariffs downward, after a boom in installations in 2011, and a mounting programme cost. Out of a total electricity bill of EUR 42 billion, the official estimate reported a cost of renewable energy at EUR 9 billion, with economic benefits evaluated at less than EUR 3 billion (gas savings and lower wholesale electricity prices).

- The United Kingdom also had to lower its feed-in tariffs to solar PV, due to a surge in activity.

- Japan introduced a set of feed-in tariffs for solar PV, wind, geothermal, small hydroelectric and biomass. As part of the scheduled review, it announced that its previously generous USD 0.50-0.52/kWh tariff for solar PV would be reduced by 10% (Bloomberg, 2013.b). In its Renewable Energy Medium Term Market Report, IEA pointed out that Japan’s world’s-highest tariffs could “pose economic sustainability concerns over the medium-term”. Tariffs would be financed through consumers’ electricity bills, with industry being largely exempted (an approach similar to Germany’s).

- China may stop a capital expenditure subsidy that has been provided to PV projects before installation. The subsidy raises concerns about the performance of the supported plants. The 20-year guaranteed feed-in tariff would become the main subsidy to solar power; this tariff may also be cut significantly to reflect declining PV panel prices (Bloomberg, 2013.a).

ANNEX 5
OVERVIEW OF ELECTRICITY STORAGE TECHNOLOGIES

With 130 GW of installed capacity worldwide, pumped-hydro is the most widely deployed form of electricity storage today; it relies on two water reservoirs, allowing water to be pumped up from the lower to the higher reservoir using cheap electricity from the grid. The water is run through the reservoir's turbines when electricity is needed (and its price is highest). Elzinga et al. (2013) point out that the current price differentials in electricity markets are not large enough to justify new pumped-hydro capacity. Pumped-hydro is currently used mostly to provide ancillary services, or emergency-reserve capacity.

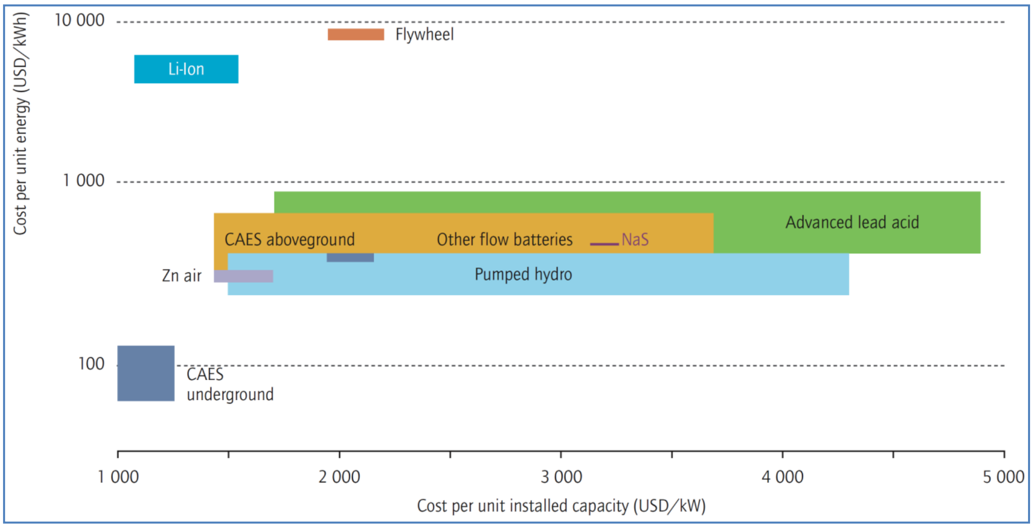
The second most common technology is Compressed Air Energy Storage (CAES), albeit with a much more modest 400 MW in two installations (Germany and the US). In this case, compressed air is stored in geological formations, and combined with gas to run turbines that generate electricity.

A third group of storage technology is batteries, with sodium sulphur (NaS) technology leading in capacity terms (316 MW installed, according to Elzinga et al., 2013). Lead-acid batteries are widely used as well, including with 1 MW capacity installations at wind farms. Batteries are sometimes installed as part of solar PV installations for storage in off-grid uses, or to avoid delivering excess electricity to the grid in times of congestion.

Battery storage could get a boost from the deployment of electric vehicles and the possibility of temporarily tapping their batteries once connected to the grid. This would also require smart grid technologies that allow both grid-to-vehicle and vehicle-to-grid electricity flows. The timing, magnitude, and accessibility of this potential storage are very uncertain at this stage.

Concentrated solar power plants can also include storage capacity: some of the unused heat is stored, *e.g.*, in molten salts, and can then be used to run a steam turbine and generate power. The relative size of the turbine and storage can be dimensioned to best meet the needs of the corresponding electricity grid (IEA, 2011.d).

Figure 18. Life-cycle costs of storage technologies per unit of installed capacity and energy



Source: Elzinga et al., 2013. Note: Vertical axis is in logarithmic scale. The authors of the figure only included technologies for which reliable and recent information was available.