WORLD ENERGY COUNCIL
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For sustainable energy.

World Energy Scenarios

Composing energy futures to 2050

Project Partner
Paul Scherrer Institute (PSI), Switzerland

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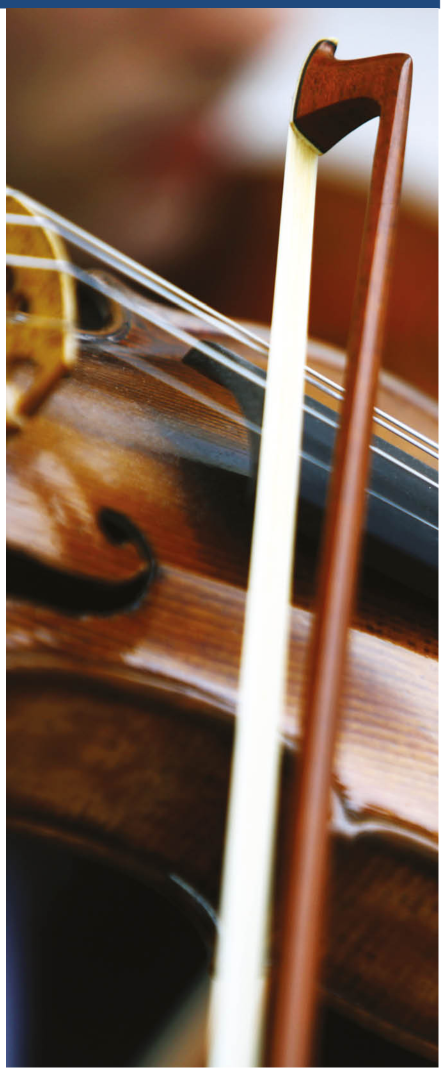

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Preface by Pierre Gadonneix, Chairman of the World Energy Council

Secure, reliable, affordable, clean and equitable energy supply is fundamental to global economic growth and human development and presents huge challenges for us. Future energy supply and demand, future environmental and social contexts are subject to a knot of uncertainties that are difficult to predict, such as the global economic and geopolitical situations and new technical innovations.

In a world becoming more global, where new technologies foster bring faster innovations and demand changes in our behavioural responses, the task of predicting the future becomes harder.

The great economic crisis in 2008 took the whole world by surprise and it took us more than two years to fully understand the magnitude of the shock and draw on the full lessons of its consequences for the energy sector. The current development of new unconventional fossil fuel resources in the world, especially in the US, also boomed almost unexpectedly, creating new opportunities.

Looking back at these events, and at how the world community had to adapt quickly to major disruptive changes, world leaders now do not want prognostics and descriptions of the future that are likely to be proven false. Rather they critically need long-term scenarios, apt at showing a diversity of possible trajectories, at identifying ‘weak signals’ that could become game changers, at considering regional ruptures, and at imagining how they could impact on the global scene. World leaders need to be prepared for a more diverse set of possible futures in order to make their own choices.

Hence, scenario work becomes all the more necessary to become prepared for a range of possible futures. That is the reason why I am so happy to introduce this first edition of our WEC World Energy Scenarios: Composing energy futures to 2050. They will be a valuable contribution to world energy leaders, by outlining uncertainties to open room for future opportunities.

The WEC’s World Energy Scenarios: Composing energy futures to 2050 are based on a unique and original bottom-up approach, building on the extended network of the WEC’s 93 member committees and 3000 member organisations in the world. The WEC Energy Scenarios were built through a number of workshops with key energy stakeholders around the world. They benefit from a truly regional approach which enables them to deliver projections based on region differences. This way, the WEC identified two general scenarios, and a series of eight refined regional scenario breakdowns.

The WEC World Energy Scenarios: Composing energy futures to 2050 also benefits from the WEC’s tradition of neutrality which enables them to open wider the options that are considered viable for the future and to integrate rationally ‘black swans’ (theoretically impossible events) in the two trajectories described. Each of the scenarios has its singular logic that is made explicit and is thus ready for different interpretations and decision making. What is more, neither of the two WEC scenarios is absolutely ‘good’ or ‘bad’ on all of the three dimensions of the WEC’s energy trilemma (energy security, energy equity, environmental sustainability). Neither scenario relies on a ‘magic wand’ to radically change the future. Rather, both scenarios are exploratory and show the multiplicity of possible choices regarding energy sources, technologies, policy instruments and measures, behavioural changes promotion, geopolitical shifts and their impacts on the trilemma’s dimensions.

The two scenarios mainly differ from each other because – among other parameters – they strike a different balance between market initiative and government governance.

These two scenarios put all of us in a position of responsibility towards our global future. Each of our choices, on a type of energy source, on a type of public policy, will shape our global trajectory. These two WEC Energy Scenarios are therefore an instrument of our global responsibility. They provide us, energy leaders, with the long-term vision and information that makes us adept at exerting our leadership and accountability.

I therefore wish you an insightful dive in our two scenarios and encourage you to consider them as a basis for future exchanges and global negotiations on our common future and opportunities, starting at our 22nd WEC World Energy Congress in Daegu, South Korea, this year!

Foreword by Dr Christoph Frei, Secretary General of the World Energy Council

Energy in Transformation – Securing tomorrow's energy today

This is a time of unprecedented uncertainty for the energy sector. Energy demand will continue to increase, driven by non-OECD economic growth. The pressure and challenge to further develop and transform the energy system is immense. To make things more daunting, policymakers and business leaders today have to take critical decisions on our future energy infrastructure in a context of unprecedented uncertainty. Over the last five years we have seen acceleration and increased complexity of various energy policy drivers and investment signals.

The latest **World Energy Issues Monitor** illustrates that uncertainties on future CO_2 prices, recession and energy prices continue to keep energy leaders awake at night. There is indeed great dynamism in investment signals with cheap natural gas prices de-linking from oil prices, collapsing solar prices, uncertain carbon emission prices or increasing nuclear costs affected by enhanced post-Fukushima safety requirements. As a result, there is much greater uncertainty behind the outlook of nuclear or renewables than five years ago; there is much greater optimism regarding energy resources today compared to five years ago (shale gas vs. peak oil); and there is much greater and new awareness of the energy access and affordability issues, driven by the 2012 UN International Year of Sustainable Energy for All on the one hand and by financial hardship on the other. Yet, awareness is one thing, delivering in time is another: we are still very far away from a global deal on these issues.

We are all struggling to take long-term investment decisions that are robust and deliver the resilient energy infrastructure we will need. We will be locked into the energy infrastructure that we build today for the next half-century – for good or for bad. Physical assets with a long lifespan therefore need to be robust to adapt to different possible futures and withstand technology innovation or global policy developments. They also need to be resilient to change driven by greater stress from the accelerating energy-water-food nexus, from extreme weather events or, by new threats from cyber terrorism. In this context, finding the right policies that build on our resources and recognise specific limitations is a struggle for every single country. Only a sound policy framework enables the delivery of a robust and resilient infrastructure whereas an opportunistic policy approach may endanger energy security, hamper environmental viability, decrease social equity and put national competitiveness at risk. It is with the consideration of such outlined complexity and uncertainty that the WEC promotes the **energy trilemma** approach with the objective to deliver balanced, predictable and stable policy frameworks. It is such balance that mitigates political risk, which too often keeps the necessary investments from flowing.

With the urgency to take critical decisions in a context of daunting uncertainty, more than ever we need an impartial, inclusive and fact-based dialogue on our future. We need to improve our common understanding of the implications of today's decisions and actions so we can make them the ones that deliver the future we want. A key foundation for policy and investment decisions is a thorough understanding of critical drivers and uncertainties, which will define our future. Exploratory scenarios – plausible and coherent stories of how our future may unfold, based on a systemic analysis of critical drivers and uncertainties – provide a reference point to challenge and test our own assumptions and thereby strengthen the foundation for our capacity to define balanced policies and take informed investment decisions. This foundation is as strong as it is impartial, capable of capturing signals from very different regional or sectoral dynamics and, transparent to interested stakeholders. I am personally convinced that the WEC, together with our knowledge networks and project partners is uniquely placed to be the world's reference for energy scenarios, with our unparalleled network of 3000 organisations in almost 100 countries, including public, private sector and academia, including Brazil, Russia, India and China (BRICs), developing and industrialised countries, including producing and consuming countries, and covering all technologies. With this in mind, the WEC has committed to develop its scenarios with an open source spirit to ensure that our insights are accessible to all and enable energy leaders to work on our sustainable energy future for the greatest benefit of all. Already today we have organisations, including Saudi Aramco, that have chosen to use (at no cost) the model that we are jointly developing with our project partner Paul Scherrer Institute (PSI) in order to quantify our scenario stories and we are committed to supporting the growing interest from governments and the private sector in this regard.

What can 'Symphony' and 'Jazz' do for us? There are many ways to read the two scenarios, which describe two very different future worlds: one, in which the world attempts to orchestrate mitigation; and one where the world will focus on adaptation. One, in which trust is placed in leadership and cooperation; and one where trust is placed in decentralised decisions and markets. One, in which energy access is a government programme; and one where market-driven growth is the rising tide that lifts all boats. The hard truth is that, in both worlds we seem unable to mitigate the climate challenge in time to the extent our scientists believe is necessary to avoid the risk of dramatic climate effects. In a Symphony world we will take this as a call for greater urgency to adopt a global deal and coordinated action. In a Jazz world we will take this as call to redefine physical, economic and social resilience. I believe that both Jazz and Symphony provide us with valuable guidance and that we must prevent ideological discussions that will only slow down the finding of effective solutions to face the challenges ahead.

The real discussion must be on how can we can do both: enhance greater collaboration with a view to further strengthen institutions in charge of safety, green trade, development finance, the exchange of best practices and technologies, or a focused research and development effort in critical game-changing areas such as energy or storage or carbon capture and storage. And also on how we make our world one that is resilient against the change that we must be prepared for.

Foreword by Rob Whitney, Chair of the World Energy Scenario Study Group

It is an honour to have chaired the WEC Global Energy Scenarios 2050 Flagship programme. These WEC scenarios are special, they are not developed top-down by a small team of experts, they are genuinely bottom-up scenarios encompassing learned inputs from the wider WEC membership, with hands-on experience in the energy sector. The WEC scenarios are exploratory, in that we have not set a predetermined endpoint such as a specific target for atmospheric CO_2 levels. We have taken two pathways forward and worked out where they might lead. They are meant to be credible rather than aspirational: what we think could happen, not what we would like to happen. The WEC scenarios are built on strong foundations, the WEC information resources built up through our work programmes and the global WEC knowledge networks. We have truly tried to formulate WEC views for these scenarios

The Scenarios Study Group have taken accountability to our WEC constituency seriously. We have continually exposed the scenarios to scrutiny and sought additional input. We have had regional workshops in seven of the eight WEC regions: at Delhi, Bangkok, Beijing, Cancun, Johannesburg, Paris and Washington. We presented the information in WEC Energy Leaders summits in Turkey, the United Arab Emirates and India, and at meetings across the world from Brussels to Wellington. At the Executive Assembly in Monaco 2012 we introduced the two scenario names **Jazz** and **Symphony**, describing our consumer-driven scenario, and our voter-led scenario.

Unlike some other scenarios we have not been transfixed by global CO_2 levels. We have developed a metric based on the WEC energy trilemma goals, giving equal consideration to energy equity (access and affordability), and energy security, as we do to environmental sustainability.

The project has involved working closely with PSI who we entrusted with the complex modelling task of putting numbers on our scenarios. We debated long and hard about how the key input parameters, gross domestic product (GDP) growth and the price of carbon, would progress in the two scenarios and across the regions. Part of this discussion was the recognition of the difference between the cost of carbon – the technological avoidance cost of CO_2 emissions – and the price of carbon – what society would be prepared pay to reduce CO_2 emissions.

In the event there is a clear differentiation. In Symphony CO_2 emissions drop from 2020 onwards and we get close to achieving the 450 ppm atmospheric stabilisation levels for CO_2, but there are still over half a billion people without access to electricity. In Jazz there is almost universal access to electricity in all the WEC regions except sub-Saharan Africa, but CO_2 emissions only level out at the end of the period.

The publication of this report and the roll out of the Jazz and Symphony Scenarios at the Daegu Congress is not the end, it is just the beginning. The Scenarios are not forecasts; they are credible explorations of two futures. In one we pass through the Doha Gateway and global governments all make the concessions necessary for global CO_2 governance. In the other we leave it to consumers to choose between consumption and sustainability. In the event we expect the future will lie somewhere between the two. Will we get the best of both worlds with the markets reflecting a citizens' consensus on social equity and energy sustainability, and governments doing what only governments can do to enable the goals? The alternative is the worst of both worlds: government's making economically sub-optimal policy decisions, and consumers focusing on short-term price signals and self-interest, thus increasing both energy poverty and atmospheric CO_2 levels.

I refer you to the other WEC flagship programme and their 2013 report, World Energy Trilemma: Time to Get Real – the case for sustainable energy investment. Our next step should be demonstrating with our scenario tools how this action plan could make substantial progress on achieving all three trilemma goals by 2050.

Finally I would like to thank all WEC members who have participated in this study, and in particular the executive team, Hans-Wilhelm Schiffer (Vice-Chair), Karl Rose (Project Director), and the WEC staff Philip Thomas and Ayed Al'Qahtani who laid the ground work for the project, and Dan Rieser who has contributed greatly through his efforts and done a great job in collating all the material for this report.

1. Executive summary

World Energy Scenarios 10 key messages

1.	Energy system complexity will increase by 2050.
2.	Energy efficiency is crucial in dealing with demand outstripping supply.
3.	The energy mix in 2050 will mainly be fossil based.
4.	Regional priorities differ: there is no 'one-size-fits-all' solution to the energy trilemma.
5.	The global economy will be challenged to meet the 450ppm target without unacceptable carbon prices.
6.	A low-carbon future is not only linked to renewables: CC(U)S is important and consumer behaviour needs changing.
7.	CC(U)S technology, solar energy and energy storage are the key uncertainties up to 2050.
8.	Balancing the energy trilemma means making difficult choices.
9.	Functioning energy markets require investments and regional integration to deliver benefits to all consumers.
10.	Energy policy should ensure that energy and carbon markets deliver.

The WEC's World Energy Scenarios to 2050

The WEC has built two scenarios typified by characteristics, which, each from their own perspective, may comprehensively describe large parts of the world in 2050. In this scenario exercise, the elements of the two scenarios are generalised as being applicable to the (albeit imaginary) whole world: the more consumer-driven Jazz scenario and the more voter-driven Symphony scenario. While scenarios are 'music based', they are completely different in nature.

As an energy scenario, Jazz has a focus on energy equity with priority given to achieving individual access and affordability of energy through economic growth.

- **Jazz** is a style of music, characterised by a strong but flexible rhythmic structure with solo and ensemble improvisations on basic tunes and chord patterns. In Jazz, musicians have freedom to take the lead and improvise; others in the band will often follow.

As an energy scenario, Symphony has a focus on achieving environmental sustainability through internationally coordinated policies and practices.

- A **Symphony** is a complex piece of music with a fixed structure composed to be played by a symphony orchestra. The orchestra will have a conductor and 80 or so orchestra members will each have a specific role to play and score to follow.

These scenarios are designed to help a range of stakeholders address the 'energy trilemma' of achieving **environmental sustainability**, **energy security**, and **energy equity**.

The WEC's approach is distinctively different from the scenario building approach that others have undertaken. It is open, inclusive and transparent:

- Open – as every move has been meticulously documented, the assumptions and the quantification results, including 'the model' are publicly available.
- Transparent – as the WEC has set out clearly how its scenario stories have been translated into assumptions and from there into quantification results,
- Inclusive – as a wide range of stakeholders have been consulted, from producers and governments to consumer representatives and energy supply enterprises.

This approach can only be done successfully by a network like the WEC's with its impartial and inclusive membership structure. Over 60 experts from more than 28 countries have contributed to the WEC's scenario building process over a period of three years.

The WEC's scenarios are not a roadmap, instead, the organisation has put together credible and pragmatic assessments of the reality of what is actually happening and not what WEC would like to happen in an ideal or politically directed world. The WEC's World Energy Scenarios to 2050 are therefore exploratory, rather than normative.

Table 1– The WEC's scenarios at a glance: Jazz and Symphony

Source: World Energy Council (2013)

Jazz	Symphony
• World where there is a consumer focus on achieving energy access, affordability, and quality of supply with the use of best available energy sources.	• World where there is a voter consensus on driving environmental sustainability and energy security through corresponding practices and policies.
• Main players are multi-national companies, banks, venture capitalists, and price-conscious consumers.	• Main players are governments, public sector and private companies, NGOs, and environmentally minded voters.
• Technologies are chosen in competitive markets.	• Governments pick technology winners.
• Energy sources compete on basis of price and availability.	• Selected energy sources are subsidised and incentivised by governments.
• Higher GDP growth due to faster convergence across countries, higher international competition, and low environmental constraints.	• Lower GDP growth due to less convergence, more environmental constraints and a more capital-intensive growth pathway
• Free-trade strategies lead to increased exports.	• Nationalistic strategies result in reduced exports/imports.
• Renewable and low-carbon energy grows in line with market selection.	• Certain types of renewable and low-carbon energy actively promoted by governments.
• In the absence of international agreed commitments carbon market grows more slowly from bottom up based on regional, national and local initiatives.	• Carbon market is top down based on an international agreement, with commitments and allocations.

The world and its energy landscape in 2050

Table 2 – The world in 2050

Source: World Energy Council (2013)

	JAZZ 2050	SYMPHONY 2050
GDP growth (CAGR, PPP)	3.54%	3.06%
Population (billion)	8.7	9.3
Technology support	Limited; energy choice based on free markets – only limited nuclear, CC(U)S, large hydro	Government support for nuclear, large hydro, CC(U)S and renewables
Climate policy	Limited (and more diverse)	Stronger (with global convergance)
Resources	Better access to unconventional resources (esp. gas)	More expensive unconventionals (less competition, regulation, water)
Technology innovation	Further development of CCGT, decentralised power (SPV), wind, gas vehicles, EVs	Focused R&D programmes, esp. CC(U)S demonstration, nuclear, solar photo voltaic (SPV)
Efficiency	Increasing	Increasing more strongly

Source: World Energy Council (2013)

Table 3 – Population without access to electricity (in millions)

Source: World Energy Council (2013); IEA 2000–2012 (historical data)

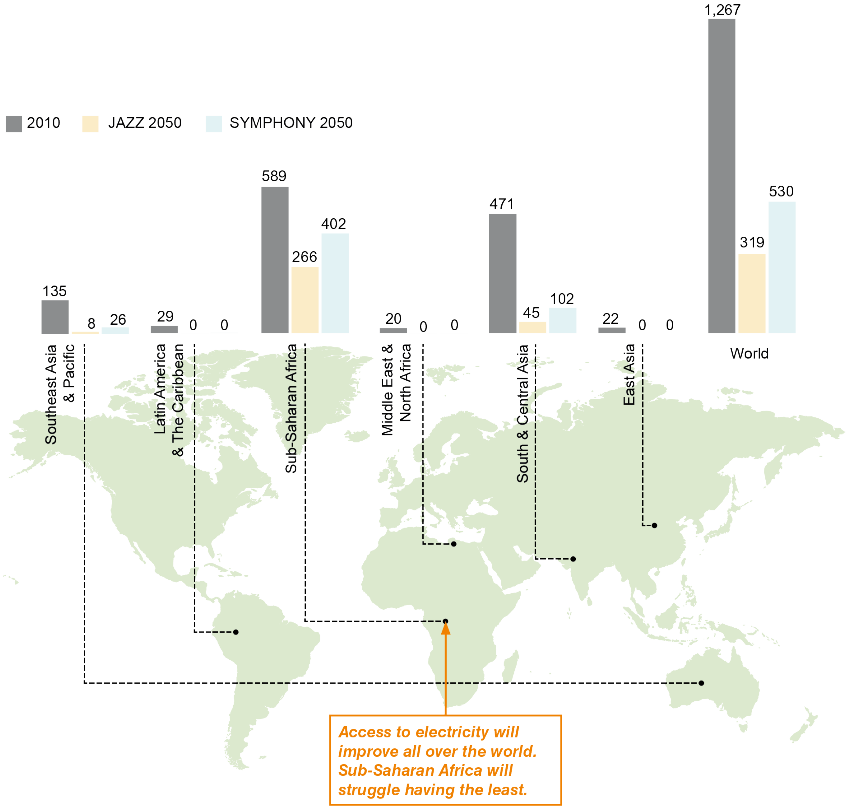

Table 4 – The WEC's view on global economic growth up to 2050

Source: World Energy Council (2013)

GDP growth, compound annual growth rate (CAGR) % market exchange rate (MER) %purchasing power parity (PPP)

	1990–2000	2000–2010	2010–2020	2020–2030	2030–2040	2040–2050
Jazz	2.9	2.8	3.2 (3.9)	3.1 (3.8)	2.9 (3.5)	2.6 (3.1)
Symphony	(3.2)	(3.5)	2.8 (3.3)	2.6 (3.2)	2.5 (3.0)	2.2 (2.7)

'For decarbonisation to be more effective, citizens play a crucial role, as consumers in Jazz, and voters in Symphony.'

Managing the change: energy system transition to 2050

The energy landscape we expect to see in 2050 will be quite different from how it looks today. Meeting future energy demand will be a key challenge. The world's population will increase from approximately 7 billion in 2013 to approximately 8.7 billion in the Jazz scenario and approximately 9.4 billion in the Symphony scenario in 2050, which is equal to a 26% increase (36% respectively). The GDP per capita will also increase from slightly more than 9,000 US$2010 on average globally (US$2010 MER) in 2010 to approximately 23,000 US$2010 in Jazz and roughly 18,000 US$2010 in Symphony in 2050. This represents an increase by 153% and 100%, respectively. Mobility will also increase, with car ownership in terms of cars per 1000 people increasing from 124 in 2010 to 244 in 2050 in Jazz and 193 in Symphony. This equates to an increase by 98% and 57% respectively.

The WEC estimates that **total primary energy supply** (equal to consumption) will increase globally from 546 EJ (152 PWh) in 2010 to 879 EJ (144 PWh) in the Jazz scenario and 696 EJ (193 PWh) in the Symphony scenario in 2050. This corresponds to an increase of 61% in Jazz and 27% in Symphony. Just to compare: from 1990 to 2010 – which is roughly half the time span covered in this scenario study – total global primary energy consumption rose by approximately 45%. It is expected that global primary energy consumption will continue to rise, but at a much lower rate than in previous decades. Meeting both global and regional energy demand will be a challenge. There is no one global solution to the energy supply issue. Instead, each of the individual parts of the challenge must be worked out to reach the global goal of sustainable, affordable and secure energy supply for all.

Energy efficiency will increase significantly in both scenarios: primary energy intensity as measured in energy use per unit of GDP created will decrease by 50% and 53% in Jazz and Symphony respectively in 2050 for primary energy intensity. Hence when comparing primary energy consumption to GDP produced, only half the amount of energy is needed until 2050 to produce the same output. This is true for both scenarios although primary energy consumption is higher in 2050 in the Jazz scenario than it is in the Symphony scenario. The WEC's World Energy Scenarios to 2050 show that energy efficiency and energy conservation are absolutely crucial in dealing with demand outstripping supply – both require a change in consumer priorities and have cost implications across industries – and hence capital is required to finance energy-efficiency measures in terms of an initial investment before it can pay off.

The **future primary energy mix** in 2050 shows that growth rates will be highest for renewable energy sources. In absolute terms, fossil fuels (coal, oil, gas) will remain dominant, up to and including 2050. The share of fossil fuels will be 77% in the Jazz scenario and 59% in the Symphony scenario – compared to 79% in 2010. The share of renewable energy sources will increase from around 15% in 2010 to almost 20% in Jazz in 2050 and almost 30% in Symphony in 2050. Nuclear energy will contribute approximately 4% of total primary energy supply in Jazz in 2050 and 11% in Symphony globally – compared to 6% in 2010.

Regional developments – Future economic growth shifts from developed countries to developing and transition economies, in particular in Asia. Of all the **eight regions** considered in this scenario study, Asia will be characterised by highest economic growth, both in relative and absolute terms. By 2050, nearly half of all economic growth (measured in terms of production of GDP) will happen in Asia and its three sub-regions: Central and South Asia, East Asia and Southeast Asia and Pacific both for Jazz and Symphony. This means that the share of Asia on total primary energy consumption will increase from 40% in 2010 to 48% in Jazz and 45% in Symphony. To compare: by 2050, Europe and North America (including Mexico) will make up about 30% of total global primary energy consumption in Jazz and 31% in Symphony (2010: 44%). Africa, including the Middle East will account for 15% (Jazz) and 16% in Symphony (2010: 11%) and Latin America and The Caribbean (LAC) 8% in Jazz and 7% in Symphony (2010: 5%).

Global electricity generation will increase between now and 2050: in 2010, global electricity production was 21.5 billion MWh globally. In Jazz, this is expected to increase by 150% to 53.6 billion MWh by 2050. In Symphony, the increase is about 123% to 47.9 billion MWh by 2050. Simply due to the sheer increase in electricity production that is needed to meet future demand, the **future electricity generation mix** will be subject to tremendous changes up to 2050.

Electricity generation from renewable sources (RES-E) will increase around four to five times by 2050 in comparison to 2010. This is strongest in the Symphony scenario. In Symphony, electricity generation from hydro doubles, for biomass, the increase is eight-fold and for wind eleven-fold when comparing figures for 2010 with 2050. Solar photovoltaic (PV) has the highest increase of approximately 230 times between 2010 and 2050. By 2050, globally, almost as much electricity is produced from solar PV as from coal – coal, and coal with carbon capture (utilisation) and storage (CC(U)S).

The share of RES-E will increase from approximately 20% in 2010 to more than 30% in 2050 in Jazz and nearly 50% in Symphony. The degree to which RES-E will be used and investment in CC(U)S technologies for coal and gas (and also biomass) will be decisive in mitigating climate change.

CC(U)S technologies are widely employed in Symphony and hence subject to higher growth rates in the Symphony scenario than in the Jazz scenario. Half of the total electricity generated based on fossil fuels will be in conjunction with CC(U)S in 2050 in Symphony. Combining nuclear and CC(U)S for gas, coal and biomass, more than **80%** of all electricity generated in 2050 will be **from low-carbon sources in the Symphony scenario**, compared to **40%** in the Jazz scenario. To compare: In 2010, only one-third of global electricity generation was from low-carbon sources.

The overall **degree of electrification** measured in terms of the share of electric energy on the final energy mix, increases up to 2050 significantly. In Jazz, the degree of electrification will be almost 30% in 2050, in Symphony this will even be slightly more than 30% in 2050 – as compared to 17% in 2010.

Electricity access, measured as the share of population connected to the electricity grid will increase in both scenarios: energy access will hence improve. While in 2010,

1.267 billion people were without access to electricity globally, this reduces to 319 million in Jazz and 530 million in the Symphony scenario in 2050.

As a result, electricity consumption per capita increases globally by 111% in Jazz and 78% in Symphony in 2050.[1]

Huge **investment in electricity generation is** needed to meet future electricity demand. The WEC estimates that total investment needed will range from US$19 trillion in Jazz to US$26 trillion in Symphony in 2050 (in 2010 terms) – and this is for electricity generation only measured in terms of cumulative investment in electricity generation in both scenarios (2010–-2050, trillion US$2010, undiscounted). Depending on each scenario, a total of between 46% in Jazz and 70% in Symphony of this is to be invested in renewable electricity generation. Major investment requirements are in solar PV, hydro and wind electricity generation capacity. The WEC's work clearly highlights that the availability of funds for investment is one of the key clusters in scenario building terms that will shape the energy landscape until 2050.

'This is a time of unprecedented uncertainty for the energy sector. Energy demand will continue to increase. The pressure and challenge to develop and transform the energy system is immense.'

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1 The estimate of 1.267 billion people without access to electricity for 2010 differs from that of the World Bank of 1.2 billion people due to differences in a relatively small number of countries, including Pakistan, Indonesia, South Africa, Thailand, and Gabon, where the International Energy Agency (IEA) uses government data (which typically report more people without access) while the World Bank uses estimates derived from various types of surveys.

World Energy Scenarios to 2050: Key scenario messages for policymakers and energy leaders from Jazz and Symphony

1. Energy system complexity will increase by 2050

The energy landscape we expect to see in 2050 will be quite different from how it looks today. Meeting energy supply and demand will gain complexity. Energy systems will remain complex – there are substantial system integration costs especially when a large proportion of renewables are involved due to increased network expansion costs in both transmission and distribution systems (especially in the Symphony scenario). To better understand and ultimately cope better with this increasing complexity, integrated system modelling will deserve more attention in the future to provide a more holistic view and lead to a better understanding of complex energy systems.

2. Energy efficiency is crucial in dealing with demand outstripping supply.

The WEC's World Energy Scenarios to 2050 show that energy efficiency and energy conservation are absolutely crucial in dealing with demand outstripping supply – both require a change in consumer priorities and have cost implications across industries – and hence capital is required to finance energy-efficiency measures in terms of an initial investment before it can pay off. Both in the Jazz and Symphony scenarios, electric mobility comes later than originally expected – at the earliest after 2030. Policymakers and industry need to undertake even greater effort to promote the share of renewables in electricity production which is not increasing enough to ensure environmental sustainability in the long run up to 2050 and beyond.

3. The energy mix in 2050 will mainly be fossil based.

The WEC's World Energy Scenarios to 2050 show that, in 2050, fossil fuels will still play a crucial role for both power generation and transport, this is particularly so in Jazz. Coal is going to play an important role in the long run, especially for power generation in China and India, the two most rapidly growing demand centres up to 2050. Natural gas, especially from unconventional sources, will play an increasing role and gain more importance in the energy share. An example is the transport sector where heavy transport will depend on fossil fuels for decades to come.

Oil will continue to remain dominant for transport, an increase in importance of unconventional sources – in particular oil sands, and oil shale – is expected. No renaissance of nuclear energy is anticipated in the next decade. In the Symphony scenario, the WEC anticipates a large increase of non-CO_2 technologies globally, including hydro, other renewables such as solar PV and wind, nuclear and carbon capture and storage (CCS).

4. Regional priorities differ: there is no 'one-size-fits-all' solution to the energy trilemma.

There is no global solution to the energy supply issue. Instead, reaching a solution is relies on solving each of the individual parts to reach the global goal of sustainable, affordable and secure energy supply for all. Critical uncertainties remain, especially with regard to CC(U)S and the future development of energy storage technologies that are scalable in economic terms

In this complex world, governments play a crucial role in determining and establishing frameworks for markets to function in both scenarios. Industries and markets need to provide efficient solutions. Up to 2050, the reality will lie somewhere between the Jazz and Symphony scenarios in terms of energy supply, energy demand increases, and GDP growth – or it might even go beyond the levels indicated here.

5. The global economy will be challenged to meet the 450ppm target without unacceptable carbon prices.

The WEC's World Energy Scenarios to 2050 underline that a reduction of greenhouse gas (GHG) emissions is possible in the second half of the scenario period if it comes to global agreements and the implementation of cost-efficient market instruments like emissions trading within a cap and trade system (assumed in Symphony). Hydro, other renewables, nuclear and CCS as a cost-efficient CO_2 mitigation option can play an important role after 2030 – dependent on the assumed CO_2 price. Such a price for CO_2 has to be high enough to create the right signals to provide an adequate incentive for CO_2 reduction.

The WEC's World Energy Scenarios to 2050 indicate that these large reductions in CO_2 are possible when governments are acting and industry players and markets are given right incentives to provide suitable technological solutions to achieve this. However, current signals indicate that the global economy is not on track to meet the 450ppm target (in terms of the emission pathway) without unacceptable carbon prices. In the Symphony scenario, CO_2 emissions begin to drop from 2020, but fall short of the 450ppm target. In the Jazz Scenario, lower carbon prices emissions do not plateau until around 2040.

6. A low-carbon future is not only linked to renewables: CC(U)S is important and consumer behaviour needs changing.

Carbon capture, use and storage (CC(U)S) is a suitable technology (in addition to renewable electricity generation) to reduce CO_2 emissions. Given a CO_2 price signal CC(U)S can play an important role after 2030 as a cost efficient CO_2 mitigation option.

Such a price for CO_2 has to be high enough to create right signals to provide an adequate incentive for CO_2 reduction. Issues remain such as technical feasibility at a large scale, public resistance and the upfront infrastructure cost. These are addressed more in Symphony where CC(U)S and solar contribute equally to the decarbonisation of energy systems by 2050.

For the decarbonisation to be more effective, citizens play a crucial role, as consumers in Jazz, and voters in Symphony. Changes in consumption habits can be an effective way to decarbonise the energy system. Voters need to balance local and global issues.

7. CC(U)S technology, solar energy and energy storage are the key uncertainties up to 2050.

The WEC believes that CC(U)S technology, solar energy and energy storage are the key uncertainties moving forward up to 2050. CC(U)S technology is already available and is potentially one of the lower-cost, deep decarbonisation options, but it will always be an added cost and will require major pipeline and other infrastructures. For CC(U)S to work, clear legislative frameworks are needed – combined with infrastructure investment and the right incentives.

A low-carbon future is not only linked to renewables: CC(U)S is important and consumer behaviour needs changing. Changes in consumption habits can be an effective way to decarbonise the energy system. Voters need to balance local and global issues.

The WEC assumes that solar technologies, in particular solar PV, will take off promoted by feed-in electricity tariffs, subsidies and net pricing in Europe, and solar technology prices tumbling. The technologies then make major inroads, and used in India, Africa and other countries to bring power to rural and off-grid communities. Subsidies are needed for solar to be economic and to create an incentive for investment to happen. Subsidies for solar are higher in Symphony than they are in Jazz, which leads to a higher trajectory of uptake of solar PV in Symphony.

As far as energy-storage technologies are concerned, pump storage is a well-developed and widely applied technology, its use is limited. Other new and emerging energy storage technologies, batteries, hydrogen, power to gas (hydrogen or methane), still need more research and development (R&D) before they become commercially viable. Investment in R&D is therefore needed to promote these technologies which could play a key role up to 2050 especially to overcome the problem of intermittency of high levels of renewables in Symphony.

8. Balancing the energy trilemma means making difficult choices.

Citizens face a choice between affordable energy with higher economic growth in Jazz, or more expensive energy prices and less impact on the environment in Symphony. This underlines that a holistic long-term view on the energy sector is required to address these energy trilemma issues up to 2050 and beyond.

For politicians, the time of short-termism is over: clear and stable legislative frameworks are needed to ensure financial predictability, for markets to develop and for industry to provide solutions to rising global energy needs.

9. Functioning energy markets require investments and regional integration to deliver benefits to all consumers.

The availability of funds for investment is one of the key clusters in scenario building terms that will shape the energy landscape until 2050. The WEC has assessed the investment implications both for the Jazz and the Symphony scenarios at the global and regional level. Long-term investment decisions are needed to meet future energy demand.

The investment costs associated with each scenario are in the region of approximately US$265 trillion (US$2010) in the Jazz scenario and approximately US$19 trillion (US$2010) in the Symphony scenario for electricity-generating capacity only.

For an investment in this region to be taken, clear signals are needed, together with high financial predictability, stable regulatory frameworks with low regulatory risk and functioning markets to ensure that energy can be delivered to all consumers who need it and to the greater benefit all.

10. Energy policy should ensure that energy and carbon markets deliver.

The WEC firmly believes that energy policy should ensure that energy and carbon markets deliver investments, promote regional integration and hence provide benefits to consumers. In Symphony, an agreed 2030 decarbonisation target could provide the right signals to investors of incentivising investment in different technologies.

In Symphony, governments should be aware that promoting new technologies through subsidies such as feed-in tariffs can also lead to ‘energy market bubbles’. In the Jazz scenario, governments can facilitate the growth of national and regional markets by cutting the red tape, and the promotion of regional integration and greater cooperation. This will lead to better market integration and the creation of regional markets with greater benefits for all consumers.

Assessment of Jazz vs. Symphony

Energy security

There is not a lot of difference in energy security in the two scenarios. Symphony makes use of a wider diversity of energy resource types, and has government-promoted investment in infrastructure. In Jazz there is higher energy production and a greater trading and diversity of international fossil energy suppliers.

Energy equity

On average, energy equity progresses better in Jazz. More people are able to afford more energy because the global market leads to higher GDP growth. Energy equity is less in Symphony because there are inevitably interventions restricting GDP growth: in the Symphony scenario, funds directed into low-carbon initiatives would actually start diverting funds from other government priorities such as healthcare and other programmes: Financial resources are not limitless, and governments have to set spending priorities. Wise policy choices, as identified in the WEC World Energy Trilemma 2013 report, could avoid this drop, as countries strive to score well on the trilemma index.

Environmental impact mitigation/sustainability

Symphony scores well on environmental impact mitigation, particularly CO_2 emission reduction, with emissions dropping after 2020. In Symphony externalities are more effectively internalised: this is primarily because countries adopt a range of mechanisms to meet treaty obligations on CO_2. Higher carbon prices would achieve higher emission reduction. In Symphony the market instrument emission trading is assumed to be the leading mechanism for meeting CO_2 emission obligations in the second part of the scenario period.

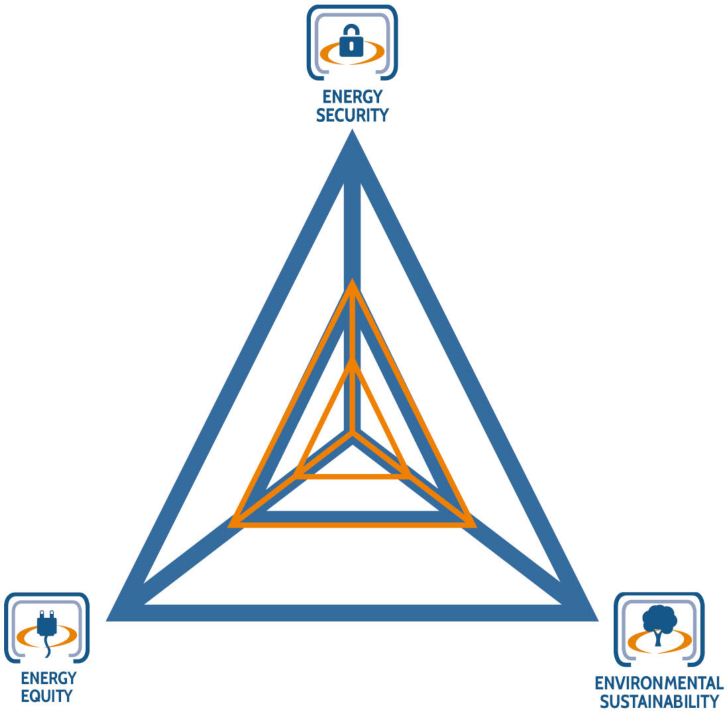
Jazz does not do so well, with emissions not dropping until after 2040. A lot of the difference relates to a slower development of a global price for carbon. Jazz performance improves markedly if a bottom-up carbon market develops early in the scenario, but the higher GDP growth still means higher emissions. Jazz therefore puts more emphasis on adaptation, rather than mitigation (as in Symphony), as markets can adapt quicker than state governments.

Jazz

- Higher energy production
- Greater trading and diversity of international fossil energy suppliers

Symphony

- Wider diversity of energy resource types
- Has government-promoted investment in infrastructure



Jazz

- On average, energy equity progresses better
- More people are able to afford more energy because the global market leads to higher GDP growth

Symphony

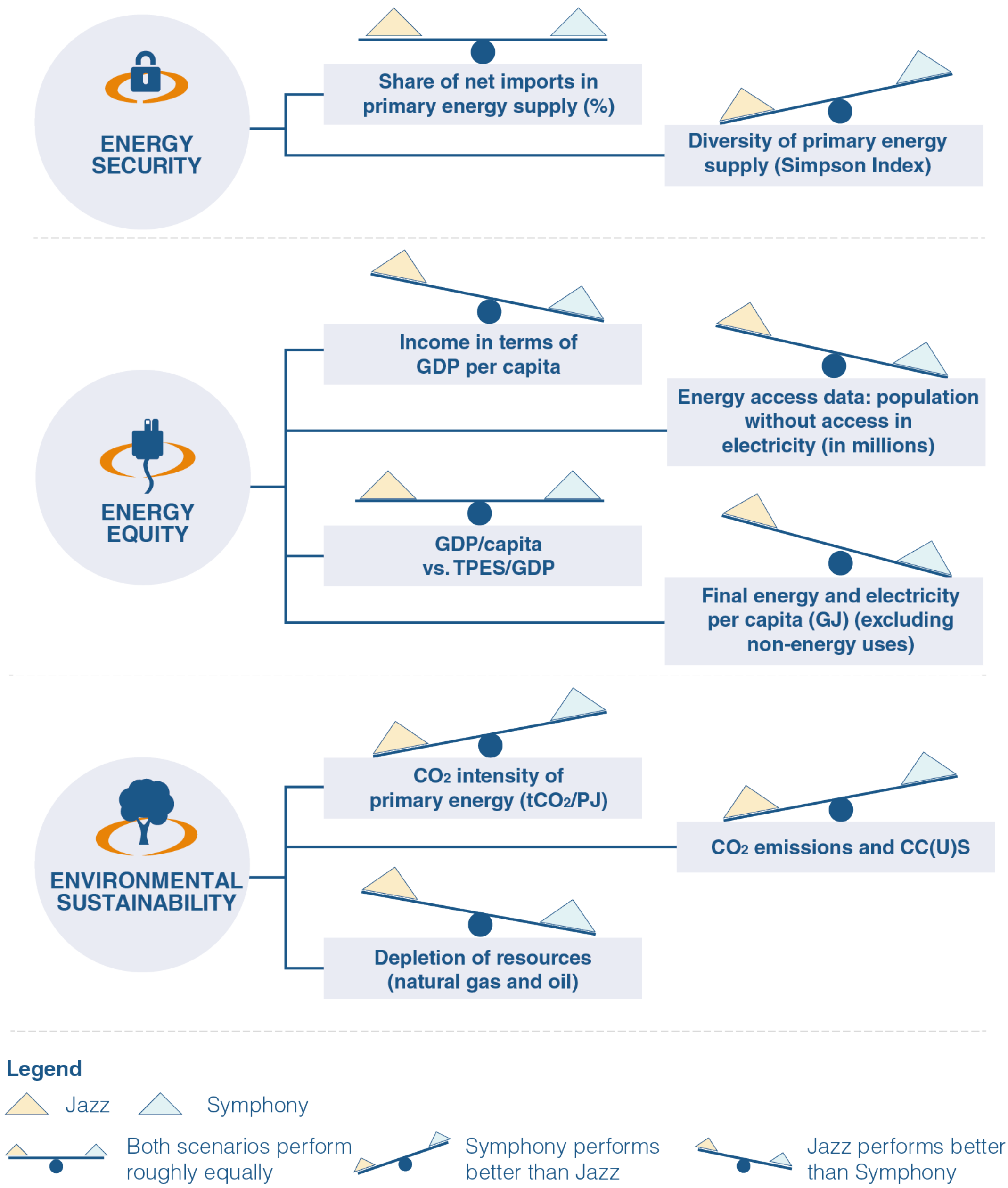
- Energy equity is less because there are inevitably interventions restricting GDP growth
- Funds directed into low-carbon initiatives would actually start diverting funds from other government priorities such as health care and other programmes
- Financial resources are not limitless
- Governments have to set spending priorities
- Wise choice of policies as identified in the WEC World Energy Trilemma Report could avoid this drop, as countries strive to score well on the WEC's trilemma index

Jazz

- Emissions don't drop until after 2040
- Performance improves markedly if a bottom-up carbon market develops early in the scenario, but the higher GDP growth still means higher emissions
- Puts more emphasis on adaptation

Symphony

- Scores well on environmental impact mitigation particularly CO_2 emission reduction, with emissions dropping after 2020
- Externalities are more effectively internalised: this is primarily because countries adopt a range of mechanisms to meet treaty obligations on CO_2
- Higher carbon prices would achieve higher emission reduction
- The market instrument emission trading is assumed as the leading mechanism for meeting CO_2 emission obligations in the second part of the scenario period


ENERGY SECURITY
Share of net imports in primary energy supply (%)
Diversity of primary energy supply (Simpson Index)
ENERGY EQUITY
Income in terms of GDP per capita
Energy access data: population without access in electricity (in millions)
GDP/capita vs. TPES/GDP
Final energy and electricity per capita (GJ) (excluding non-energy uses)
ENVIRONMENTAL SUSTAINABILITY
CO_2 intensity of primary energy (tCO_2/PJ)
CO_2 emissions and CC(U)S
Depletion of resources (natural gas and oil)
Legend
Jazz
Symphony
Both scenarios perform roughly equally
Symphony performs better than Jazz
Jazz performs better than Symphony

2. World Energy Scenarios to 2050

The starting point for the scenario building process

Since the release of the WEC white paper on scenarios in 2010 following the Montreal World Energy Congress, the WEC has continuously worked on developing its scenarios project.

To obtain the best possible input from energy experts worldwide, the WEC has adopted an open, inclusive and transparent process with input from constituents into the scenario stories a scenarios study group, expert participation and interviews, and a series of regional workshops in Delhi, Johannesburg, London, Beijing, Cancun, and Washington.

This bottom-up process is also reflected in the WEC scenarios themselves, with worldwide representatives across eight study regions:

- Asia, subdivided into three separate regions:
  - South and Central Asia
  - East Asia
  - Southeast Asia and Pacific.
- Europe
- Latin America and The Caribbean
- Middle East and North Africa
- North America, including Canada, the USA and Mexico
- Sub-Saharan Africa.[2]

The WEC's scenario findings have been disaggregated and are reported both for the global level and the regional level:

- Global results summarise top-level findings for the whole world, including cost for the investment in power-generating infrastructure.

- Regional results – based on the regional disaggregations, including regional investment need breakdowns for power generation.

At a later stage, the WEC intends to carry out further in-depth work, including regional assessments, industry specific assessments or technology 'deep dives'.

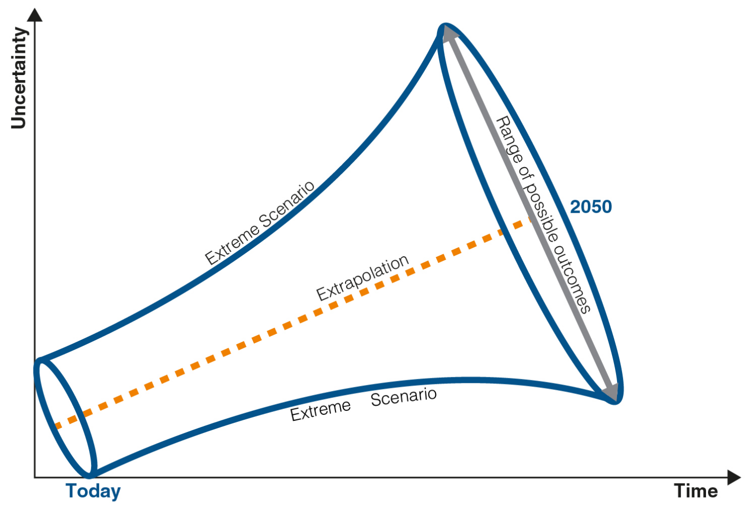
2 These regions have been defined for the purpose of this study and do not correspond to the official WEC regions. Further regional breakdowns for specific WEC regions will be carried out at a later stage.

The WEC's open, transparent and inclusive approach to scenario building

The WEC has built two scenarios which may comprehensively describe large parts of the world in 2050. In this exercise, the elements of the two scenarios are generalised as being applicable to the (albeit imaginary) whole world.

Although it is impossible to predict the future, one can see signals of what is to come in the present day environment. The result is a scenarios funnel – a range of different options within a probability space acting as upper and lower bounds; the reality is likely to be somewhere in between. Scenarios are therefore neither predictions, nor forecasts. Predicting the future is not possible. As we move on, the range of possible future outcomes becomes greater – especially since uncertainty increases. As trends and innovations pick up speed and gain momentum, their impact increases.

Figure 1 – The scenario funnel: As uncertainty increases, the funnel widens
Source: World Energy Council (2013)



The signals we observe today can be distilled into drivers, critical uncertainties, and pre-determined elements that form the future. It is of strategic importance that governments and companies who seek to make investments and take decisions in the energy sector undertake some sort of long-term planning exercise. In order to aid senior decision makers and policymakers in this endeavour, the WEC began its newest scenario building exercise in 2010.

These scenarios are designed to help a range of stakeholders address the 'energy trilemma' of achieving **environmental sustainability**, **energy security**, and **energy equity**. The scenarios are meant to challenge us, but still remain achievable.

We do not intend one scenario to be better than the other. There will be things that succeed in both scenarios, and there will be failures as well. As a result, there will certainly be winners and losers in each scenario. The findings will allow us to make progress on all three aspects of the energy trilemma.

To develop a view of how the energy landscape might look in 2050, the WEC started by looking at the critical drivers of the energy system from the broadest possible viewpoint by adopting a systemic approach. The WEC structured its analysis by first identifying 116 drivers that will affect the energy landscape globally up to 2050, by then by narrowing these 116 drivers down to 29 issues and grouping these 29 issues into five different areas:

1. Economics/finance/trade
    - Super-cycles vs. boom and bust?
    - Population and megacities
    - Investment in infrastructure
    - Prices of energy-commodities and CO_2
    - Rise of China
    - Globalisation and trade
2. Resource availability and access
    - Reserves – coal, oil, gas, rare earth elements (REEs), and so on
    - Security of supply and demand
    - Geopolitics – Middle East and North Africa (MENA) instability
    - Competition for resources
    - Energy–water nexus
    - Equality, energy access and poverty
    - Land use and access
3. Energy systems and technologies
    - Energy efficiency
    - Technology – supply and demand side
    - Technology – environmental issues
    - Smart grids (including interconnectivity)
    - Renewables (true associated costs)
    - Mobility
    - Nuclear
4. Consumer behaviour and acceptance
    - Costs vs. values
    - Leadership – state vs. private groups
    - Acceptance
5. Government policies
    - Climate change and environment
    - Competitiveness, price, affordability
    - Demand management and energy efficiency
    - Energy mix
    - RD&D
    - Security of supply

Output from each of the 29 underlying critical issues was then combined with the messages from regional workshops and further expert input to yield two distinctly separate scenario stories, differentiated in terms of 15 different ‘clusters’, as they are called in scenario modelling terms.

The WEC's key scenario drivers: 116 drivers – 15 key clusters – 5 areas

Based on the comprehensive work that the WEC did to identify the 116 key issues that will have an impact on the energy landscape up to 2050, 15 key clusters were identified and used to derive the two future 'spaces' or scenarios.

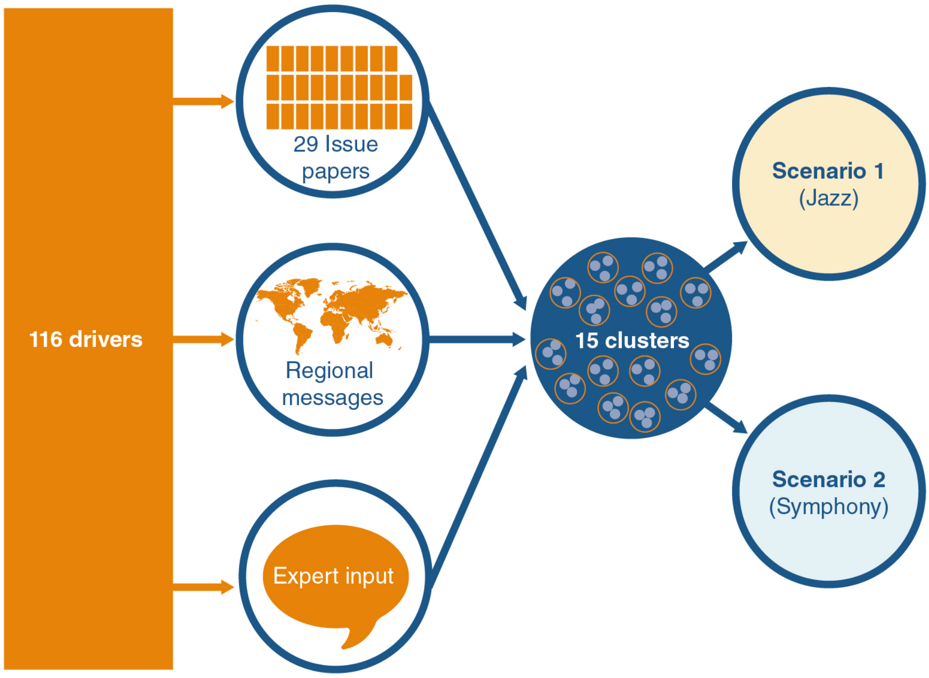
These 15 key clusters are:

1. Government and the role of state
2. Availability of funds: investment
3. Mitigation of CO_2
4. Equality, energy access and poverty
5. Global economics
6. Energy prices
7. Consumer/citizen acceptance
8. Energy efficiency
9. Technology developments
10. Security of supply
11. China and India
12. Energy poverty
13. Energy sources
14. Competition for resources
15. Skills shortages

In the WEC's view, the future development in these 15 key clusters will determine how the energy landscape might look in 2050. All clusters are therefore equally important; none of them is more important than another.

The WEC has used these key clusters and bundled them to form two separate future spaces, depending on the exact assumptions made that ultimately represent two different views of the world, and hence two possible future 'scenarios'. The two scenarios stories that were developed on these methodological bases are therefore exploratory and not normative, equally probable but differentiated – rather than just good and bad. The two scenarios developed on this basis are called 'Jazz' and 'Symphony'.

Figure 2 – The WEC's scenarios: Two future spaces
Source: World Energy Council (2013)



The World Energy Scenarios to 2050 are designed to glimpse of what the future might look like in a plausible and maybe challenging manner – yet they are not meant to be exact or precise forecasts. What follows is a detailed description of the two scenario stories.

The WEC's scenario stories: Jazz and Symphony

Jazz scenario

Jazz has a focus on energy equity with priority given to individual access and affordability of energy.

Jazz is a style of music, characterised by a strong but flexible rhythmic structure with solo and ensemble improvisations on basic tunes and chord patterns. In Jazz musicians have freedom to take the lead and improvise; others in the band will often follow.

Jazz is a world where priority is given to access and affordability of energy. It is a scenario where competitive cost solutions are determined by the free-play of market forces, which allocate capital without altruistic motives. Technology choices and developments are driven by competitiveness based on cost and reliability, within global energy markets. Governments should facilitate achieving economic growth through the use of best available energy sources.

As energy sources will compete on the basis of price, quality and availability, and since there is less government support for low-carbon energy technologies, governments will facilitate the role of the private sector to drive competition and lower prices even further e.g. for factor input and capital cost to boost investments.

Major players in this scenario include:

- Global companies (multi-national corporations) with expanding supply chains
- Banks and venture capitalists who provide funding
- Entrepreneurs who thrive in a competitive environment
- Consumers who are price conscious and want affordable energy and who do not consider climate change an issue until they achieve a minimum level of economic growth.

This state of markets does not imply that governments play a passive role. Rather, the priority of governments, especially in developing countries, is to fuel economic growth with the use of best available energy sources.

This scenario envisions that the world in 2050 will be quite different from what we see today. Market governance and structures will change significantly, and we will see new technologies coming online which will change the manner in which energy is produced and consumed. In this scenario, governments focus on driving economic growth, especially in developing countries, through best available fuels. As governments do not pass regulations supporting low-carbon energy, there is less distortion in energy markets. Due to less government intervention, there is a favourable climate for overall open global competition. Also with the advent of free trade areas (FTA), natural resource trade expands globally within the member countries.

Market movers are:

- Global companies with international supply chains who move products across rapidly shrinking borders.
- Banks with sufficient liquidity who provide much-needed capital for increasing economy activity.
- Venture capitalists who fund breakthrough technological research in order to gain larger shares in successful new market entrants.
- Entrepreneurs who engage in the process of creative destruction by constantly offering new goods and services.
- Consumers who will increasingly demand higher levels of service, and access to more sophisticated goods at affordable prices.

In this scenario, markets slowly link together towards a globally unified and liquid market, with the spread of technology and the establishment of strong trading ties across different regions. The ‘always connected’ consumer who has a great deal of information at his fingertips and is therefore able to make more informed decisions is at the heart of this scenario.

Governments reduce taxes in order to encourage spending and subsidies on fossil fuels are almost eliminated as the private sector begins to provide basic services, displacing government-funded programmes. As a result, levels of service rise in response to the increased level of competition in the marketplace, but the minimum cost also increases.

Symphony scenario

Symphony has a focus on achieving environmental sustainability through corresponding policies and practices.

A Symphony is a complex piece of music with a fixed structure composed to be played by a symphony orchestra. The orchestra will have a conductor and 80 or so orchestra members will each have a specific role to play and score to follow.

Symphony is a world where governments reach a consensus on driving environmental sustainability through corresponding policies and practices. The focus in this scenario is on achieving environmental sustainability through corresponding policies and practices. Governments begin to put nationally suited regulations in place which support the development of low-carbon technologies, like renewable energy and CC(U)S projects. As a result there is a higher degree of consensus between governments, who play a more proactive role in this scenario.

Players include:

- National governments acting as central planners
- Non-governmental organisations (NGOs) and international institutions
- Voters who are more environmentally aware and whose choices ultimately shape policy and rate local and more immediate environmental issues higher than climate change, especially in a developing country context
- Private and public sector companies.

Governments agree to give priority to environmental sustainability and recognising other countries' national development and energy security needs. This common agreement allows them to put in place various measures and mechanisms to drive investment into select areas, e.g. renewable energy subsidies, CO_2 reduction obligations, carbon taxes, CC(U)S mandates, and so on.

At the heart of this scenario is the environmentally aware voter who is willing to reduce their energy consumption and accept a price premium for 'greener' energy.[3] There is a high level of tolerance for top-down, mandated energy-efficiency and conservation policies and directives. The influence of NGOs and activists is strong and they spread their message through social networks and demonstrations. Political engagement is high and this provides governments with the necessary popular support to put strong measures in place for increasing the share of renewable energy in the primary energy mix.

The market mechanism emission trading is introduced globally as the leading instrument to reduce CO_2 emissions and to increase the share of renewable energies. In the early part of the scenario period the energy sector is regulated in more detail through special taxes, feed-in tariffs, subsidies, state-funded projects, and national schemes for limiting CO_2 emissions.

Given the intermittent nature of some renewable energy technologies, governments also look closely at the issue of energy security. Due to the focus on environmental sustainability in this scenario, governments pursue national renewable energy and carbon reduction targets which gradually drive regional consensus.

3 Energy Consumption (EC) is characterised by the product of demand for Energy Services (ES) and the Energy Intensity (EI) being the energy needed to provide those services. Reduction of energy consumption is generally called energy conservation and consists of a reduction of demand for services and/or reduction on energy intensity. Roughly speaking, energy intensity is the inverse of energy efficiency.

Implications for climate

The WEC has analysed where the Jazz and Symphony scenarios might lead in terms of climate change. The WEC has also assessed the potential impact of Jazz and Symphony scenarios on the climate with reference to the work of the Intergovernmental Panel on Climate Change (IPCC).

At the COP 15 (Conference of Parties) meeting, the 15th session of the United Nations (UN) Framework Convention on Climate Change, the 'Copenhagen Agreement' or 'Copenhagen Accord' was ratified by delegates and they endorsed the continuation of the Kyoto Protocol. Specific emissions-reduction targets for 2020 were submitted by individual countries. At subsequent COP meetings, this was reinforced, in particular at the COP18 meeting in Doha when the 'Doha Climate Gateway' was developed – a package of deals that set out a work programme through which both rich and developing countries can deliver a new international climate agreement. The Doha Climate Gateway includes a timetable for a 2015 global climate change agreement and for increasing ambitions before 2020. At Doha, countries agreed a course for negotiating the Durban Platform for Enhanced Action, a new climate deal for all countries to be agreed by 2015 and to take effect in 2020 – the Ad Hoc Working Group on the Durban Platform for Enhanced Action (ADP).

To establish a clear link between energy use and climate change objectives, the WEC has included the Doha Climate Gateway as a key differentiator between its two scenarios. The WEC assumes that in the Symphony scenario, countries pass through the Gateway and successfully negotiate a global treaty. In the Jazz scenario, these negotiations fail, and regions, countries, states and municipalities take their own sustainable development pathways.

Jazz scenario

In Jazz, an assumption is made that that the negotiations on climate change and emissions targets are not finalised. In the absence of international agreed commitments, regions, countries, states and municipalities take their own sustainable development initiatives and pathways. An international carbon market grows slowly from the bottom up based on regional, national and local initiatives, which merge to achieve greater market efficiencies and liquidity.

Commercially viable innovative low-carbon technologies (solar, wind, and city gas/waste to energy) experience growth, major reductions in CO_2 emissions come from growth in natural gas in preference to oil and coal for purely economic reasons.

Symphony scenario

In Symphony, countries pass through the Doha Gateway and successfully negotiate a global treaty because all countries are prepared to accept commitments and concessions. Climate change has more focus along with international initiatives on climate change. Low-carbon technologies are promoted despite lacking commercial viability at initial stages.

The carbon market is top-down based on an international agreement, with commitments and allocations. In the early part of the scenario period, national initiatives to meet treaty obligations to reduce emissions emerge (developed and developing countries). These national initiatives coalesce into regional initiatives with exchange of Clean Development Mechanism (CDM) and other emission units. The final part of the scenario period sees global action on climate change with the market instrument emission trading as the leading mechanism for meeting CO_2 emission obligations.

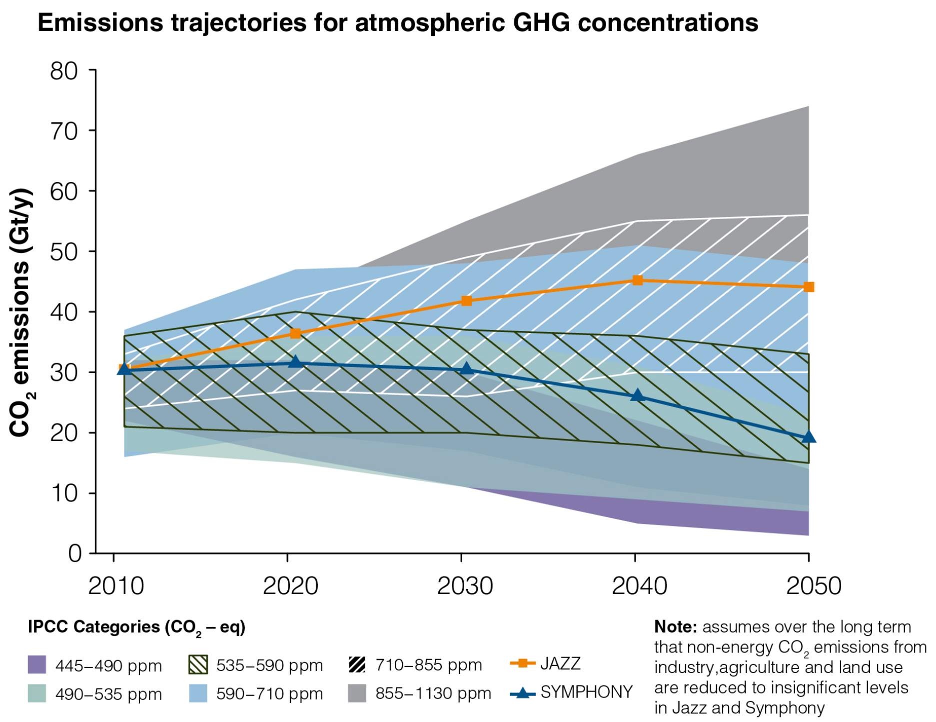
The WEC's scenarios in the wider context

The WEC has analysed where the Jazz and Symphony scenario might lead in terms of climate change. While the global multi-regional MARKAL (GMM) model covers the carbon dioxide (CO_2) emissions from energy use which constitute the major part of all GHG emissions, emissions from other activities (such as agriculture and forestry) and other gases (such as methane and nitrous oxide) are not included in this energy model. WEC has also assessed the potential impact of Jazz and Symphony scenarios on the climate with reference to the work of the Intergovernmental Panel on Climate Change (IPCC).

Figure 3 shows the potential implications of the emissions trajectories for Jazz and Symphony for atmospheric GHG concentrations (and hence climate change) based on the IPCC's 4th Assessment Report:

Figure 3 – Emissions trajectories for atmospheric GHG concentrations

Source: World Energy Council (2013)



Jazz	Symphony
• CO_2 emissions in the Jazz scenario follow a trajectory consistent with a long-term atmospheric concentration of all GHGs of between 590 and 710 parts per million CO_2 equivalent.	• Symphony is on track for 490-535 ppm CO_2 equivalent.

Nonetheless, although Jazz includes a stronger emphasis on adaptation and Symphony on mitigation, in both scenarios additional action is expected over the longer term (beyond 2050), further reducing the impact on climate. The implications of these changes to atmospheric GHG concentrations for surface temperature change, sea-level rise, changes in precipitation, incidence of extreme events and other impacts remain uncertain.

Pressure for climate action will change over the period, the WEC recognises that the climate forcing of CO_2 is considered now to be lower in some of the scientific literature in 2013. There is also increasing awareness of severe weather events that could be linked to climate forcing.

Assessing the robustness of its assumptions: Sensitivity analyses

To develop an even better understanding of the climate change implications of its two scenarios, WEC has carried out a sensitivity analysis on the issue of carbon prices by putting the climate change ambitions by taking the Jazz scenario and implementing the carbon prices that are used in the Symphony scenario. To achieve this, the following definitions were made to differentiate more precisely between a 'carbon price' and 'carbon cost':

- Carbon price is the marginal price that society is prepared to pay to abate CO_2. It doesn't need a market, feed-in tariffs, biofuel obligations and renewable subsidies impose a carbon price.
- Carbon cost is defined as the technology cost of avoiding CO_2.

The result was a 'third way' or intermediate scenario that lies – as one would expect – in between the Jazz and Symphony scenarios as shown in the funnel graph.

In order to analyse the link between policy, energy use and the environment in more detail, WEC will further elaborate on these sensitivity analyses in its future work. An indicative list of future sensitivity analyses could include:

1. GDP sensitivity runs where the GDP assumptions are taken from the Jazz scenario and incorporated into the Symphony scenario
2. Constraints on the development of CC(U)S
3. Constraints on the development of large hydro
4. Constraints on the development of nuclear
5. Constraints on the development of CC(U)S, large hydro, and nuclear (combined)
6. Introduction of GHG caps rather than carbon prices in the model as part of a wider set of policy evaluations (energy intensity vs. absolute values) as part of a normative scenario building exercise.

Carrying out sensitivity analyses would allow WEC to assess the robustness of its modelling work by testing the responsiveness with which the quantifications react to changes in the assumptions. By doing so, the understanding of the scenario quantifications will be deepened. This work, however, is for a later stage.

3. Key scenario clusters and their impact on the global energy landscape up to 2050

Key scenario cluster 1: Government and the role of state

The WEC's view

The role of governments and the state can range from light-handed (only doing the things that governments are able to do) to substantial (with central planning, state ownership and prescriptive legislation).

Government has a range of tools available including market liberalisation, international agreements, energy policy and regulation initiatives, subsidies for both renewable and fossil fuels, tax regulations. These tools can be economically sub-optimal and can often have perverse effects. They can also lead to corruption and inefficient bureaucracies.

Governments play a crucial role in providing frameworks for and designing functioning energy markets, e.g. in the area of energy efficiency where there is a case for governments to provide incentives – either financially or through the provision of information – to consumers because energy efficiency offers a large potential for carbon emissions reduction.

The state has a role as a major purchaser of energy goods and services. This role is particularly important in relation to infrastructure development and research, development, demonstration and deployment of new energy technologies.

Against this background, WEC has formed its view on how governments act in both scenarios, as outlined below.

Jazz scenario

In the Jazz scenario, energy equity in terms of energy access has a high priority. The economy and economic developments are essentially consumer driven with a focus on achieving growth through low-cost energy.

Liberalisation, policy agreements: Liberalised energy markets and high competition for resources on a global basis means. Easy-to-reach international agreements on removing trade barriers. No agreements on international climate policy due to competing and conflicting national interests. The energy market lacks the ability to reach international agreements and common set of basic rules. There is therefore open competition to access energy resources. Countries can also decide on their own policies to exploit energy resources.

Policy initiatives: Policy initiatives aimed at setting framework conditions for market solutions to emerge. Policy is influenced by free market thinking. Energy generation and transmission is unbundled. Foreign investment in the energy sector will be in the form of partnerships with domestic firms to allow technology transfer. Strong determination of the Jazz scenario to achieve market solutions.

Corruption: There is less corruption in many regions but it is still a barrier to growth in Central and East Asia and Africa due to more emphasis on markets and less government involvement.

Bureaucracy: Decreases in many regions, except for Africa, LAC, and Asia.

Tax regulation: Tax rates drop in many regions thereby freeing up money for acquiring goods and services. This implies a reduction in the size of government (lean governments).

International cooperation: No international coordination of energy taxes; varying tax regimes leading to different degrees of economic growth.

Subsidies renewable and fossil fuel: Subsidies are almost all eliminated.

Regulation: Lower government regulation (a minimally regulated environment). Focus of regulation is to create an environment that fosters growth of the private sector and encourage investment. Markets are competitive with absence of monopolies. More transparent monitoring of projects allowing for efficient return on investment.

Privatisation, liberalisation, deregulation: Significant wave of privatisation, liberalisation and deregulation in emerging countries, which attracts foreign direct investment (FDI). This also allows for growth of domestic industry.

Spending: Government has a light burden in financing infrastructure and energy projects, energy consumption, renewables and R&D. The private sector bears most of the financial burden. They will also demand faster payback periods with higher yields. This implies that technologies will have to be cost competitive and fully scalable in economic terms (i.e. in terms of potential synergies, cost savings potential, economies of scale, and so on.). Any investment in infrastructure that is intended to service the poor will focus on creating new markets. In this scenario, investment is focused on making infrastructure available to the poor to turn them into consumers. A comparable example is cell phones where the market has made the networks and the poor have cell phones.

Research and development: Diverse R&D efforts linked to market signals; funded by both private investors and governments. Significant breakthroughs at many fronts – ICT, increasingly fuel-efficient internal combustion engines (ICEs), gas engines, decentralised power-generation technologies.

Health: Quality of privately funded healthcare improves and costs of medicines fall as a result of R&D and competition between insurance and pharmaceutical companies. Life expectancy improves.

Infrastructure: Patchwork of improvements in many regions. Public infrastructure does not develop to the same level as in the government regulated environment. Urban infrastructure improves as the percentage of urban population increases. Infrastructure for trading activities improves vastly.

Symphony scenario

The Symphony scenario portrays a view of the world in which environmental sustainability has the highest priority and hence is voter driven, with an additional focus on energy security. National and regional measures are undertaken by governments to increase the share of renewables in the energy mix. Governments pick technology winners. Governments are also in charge of establishing and developing a carbon market which is top-down, based on an international agreement, with respective commitments and allocations.

Liberalisation, policy agreements: Limited competition and participation of private sector. Domestic interests come first and governments will have to choose between protectionism or liberalisation of their own energy resources. Policy agreements of 'coalitions of the willing' emerge to reduce GHG emissions and set increasingly international standards and targets for carbon abatement, where competing and conflicting national interests can be resolved.

Policy initiatives: Energy policies are set by centralised governments, resulting in increased regulation. Increasing focus on maintaining government subsidies, impacting on future investment, especially in generation capacity. More reactive than proactive policies. Policies are only as good as government capabilities to fund growth and plan strategically. A larger number of supply side measures, especially in biofuels. Feed-in tariffs dominate. The market instrument GHG emission trading is the leading mechanism for the long-term implementation of the transformation of the energy system.

Corruption: Corruption is high in transition economies within South Asia and sub-Saharan Africa.

Bureaucracy: Remains an issue everywhere due to increased government mandates and regulation.

Tax regulation: New taxes are being implemented to finance larger public sector debt in Western economies, along with government-funded energy initiatives.

International cooperation: International coordination of energy taxes. In the second half of the period, the implementation of a worldwide price for CO_2 on the basis of global agreements on GHG emission limitations.

Subsidies: Subsidies remain active in most regions. Subsidies increase for green goods and services.

Regulation: Highly regulated environment. Major national/local energy companies continue to dominate local markets.

Privatisation, liberalisation, deregulation: Level of privatisation remains the same as present levels with no significant increase, particularly in developing countries. Energy increasingly considered a strategic area by governments and the role of state becomes increasingly important. Government processes improve, but they are slower in comparison with private sector efficiency.

Spending: Governments bear a large burden in financing infrastructure and energy projects. Spending increases in renewables and R&D. Government debts increase. There is a lower rate of return and longer payback periods.

Research and development: More focused R&D programmes – driven mainly by public sector funding. International research programmes and technology 'clearing houses' used to facilitate technology transfer. Demonstration programmes for CC(U)S and other carbon abatement technologies.

Health: Population growth in developing countries continues unabated. Increase in private healthcare initiatives. There is an overall improvement in life expectancy.

Infrastructure: New infrastructure projects, mainly in renewable energy and public transport are state funded. Public infrastructure (roads and buildings) improves slowly, but with larger scale. Access to energy and public transport schemes promoted by international institutions, such as the United Nations Industrial Development Organization (UNIDO).

Key scenario cluster 2: Availability of funds: Investment in infrastructure

The WEC's view

In the days after the world wars, countries spent considerable time and money building infrastructure for transportation of people and movement of goods across geographies. This resulted in providing jobs and creating a foundation for economies to flourish. Over time the spending tailed off to just keep up with maintaining these infrastructures. As the world population grew and moved to cities, the available infrastructure has come under increasing strain. In the last 10 years, most of the heavy building of infrastructure has been seen in the developing nations, fuelled by rising incomes and increased GDP in nations such as China, Brazil, Russia and India. Oil incomes have also ensured that a massive infrastructure has been created in the Middle East to convert deserts into oases of activity.

The investments in infrastructure have not been enough to keep pace with urbanisation and industrialisation, resulting in the sheer number of people and vehicles making Asia the home for the worst traffic jams in the world. The proliferation of private car ownership in the largest Asian urban cities has led to major challenges for public policymakers. Tokyo, Shanghai, Jakarta (with more than 100 new cars on the street daily), Bangkok, Manila, and Osaka have extreme road congestion problems. In IBM's Global Commuter Pain Index, which surveyed commuters from around the globe, Beijing commuters ranked as the worst off. In the high-income countries, infrastructure spending on mass transit has happened early and has been upgraded as urbanisation increased. There is a history in these countries of public policy placing a premium on the mobility of their citizens and the government partnering with the private sector to develop transportation innovations and improved efficiencies.

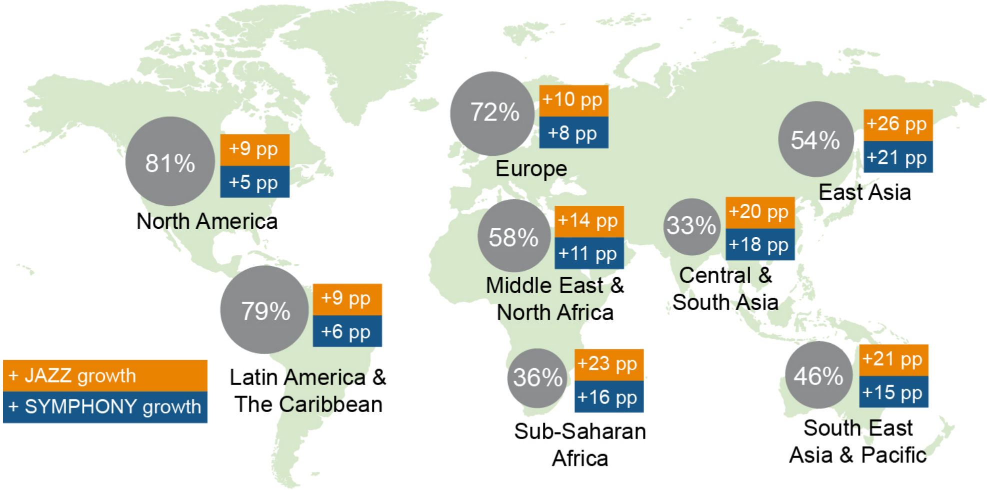
The WEC's assumptions about urbanisation are illustrated in Figure 4.

Some of the highly motorised countries have, in some instances, the highest levels of private car ownership in Asia: New Zealand (82%), South Korea (74%), Australia (70%), and Malaysia (67%). This stands in sharp contrast to China's level of private car ownership (6%), Indonesia (8%), and India (9%). Moreover, these countries have made substantial investments in their infrastructures and mass transit options – for example, Japan has some of the fastest trains in the world. In the days after the impact of the recession of 2008, the world has witnessed considerable commitments by nations to increase their spending on infrastructure. Most of these investments are in the following areas:

- Urban infrastructure and connectivity: roads, bridges, mass transit, housing, sanitation, electricity.
- 'Green energy': improving efficiency of grids, buildings, appliances, reduction of carbon emission.

Figure 4 – Percentage of urbanisation: 2010 percentage and growth to 2050 in percentage points (pp)

Source: World Energy Council (2013)



Jazz: Higher urbanisation rate	Symphony: Lower urbanisation rate
• Good economies increase movement from rural to urban. • Free market and free movement of labour and capital.	• Economies have lower growth rates. • Less urbanisation in Africa and Southeast Asia (compared to Jazz).

Future infrastructure needs: 2010–2050

As part of this scenario building exercise, the WEC has analysed global and regional energy investment needs, primarily in electricity-generating infrastructure (i.e. power generation only). It needs to be taken into account though that the overall total investment needed will be much higher, as it will have to include investment needs in transport, electrification, network/grid infrastructure and other areas, as detailed below.

Transport: The world has traditionally depended on hydrocarbons – namely gasoline and diesel – to meet its transportation needs. With high oil prices and the increased ability and maturing technology allowing, natural gas has, in the recent past, contributed to providing cleaner transportation fuels. In India the impact of using gasoline and diesel had resulted in high particulate matter, especially in Delhi. Smog and dense emission-filled air had caused considerable health problems until the Supreme Court intervened and made the government invest in fast tracking all infrastructure required to set up compressed natural gas (CNG) stations besides mandating all large vehicles and three wheelers (used for public transportation) to convert to CNG. Since then large scale projects have commenced across the country to beef up the liquefied natural gas (LNG) infrastructure. China has become the world's largest importer of LNG and thus ensured that the Australian gas market has a new life. Investments in Australia for capturing, transmitting and shipping gas to the consuming markets of China, India and Europe are expected to cross US$200 billion in the next 5-7 years. Together with the increase of LNG power, large scale CNG projects will be pushed by the growing natural gas supply.

Electric: Infrastructure for the generation, transmission and distribution of power has been inadequate in most countries due to the consistent growth of demand from consumers using the latest gadgets. Use of electric power for transportation – e.g.

electric vehicles (EV) – has also seen a gradual increase as countries support this locally non-polluting transportation fuel. It is estimated that about 100 million electric and plug-in hybrid vehicles will be sold annually in 2050, compared to virtually none today. Substantial investment in terms of 'dollars' has been allocated by countries (especially the developed nations) to upgrade the existing electric power infrastructure.

Most of the investment has been in grid connectivity, network integration, automation of the grid i.e. smart grid. This is expected to lead to generation of considerable data on consumer demand, usage patterns, and thereby ensure utilisation of data to improve demand forecasting, electric power outages, grid monitoring and result in overall energy efficiency and peak power shifts. In the developing nations investment continues to be in creating capacity and availability of electric power in addition to prevention of losses in the system. Large projects have been initiated to increase electric power availability in countries like India by three to four times existing capacity to meet the huge demands from a high growth economy. Electricity generation investments have included nuclear plants, gas supply chains (LNG trains, pipelines), and electric power plants using gas. The world is seized with the need for infrastructure spending and substantial amounts have been allocated by governments, but there still exists a major disconnect between the 'headlines and announcements' and the actual execution of these spending initiatives.

Infrastructure funding and investment instruments, modes

Infrastructure spending is most expected in Europe from the target set of achieving 20% of the energy production from renewable energy. Numerous projects are in the pipeline that range from tidal, solar, wind, bio fuel, bio waste, geothermal, and other resources. The spending in these areas is estimated to cross US$135 billion in 2009. The projects will continue until 2020. Investments are growing at a compounded annual growth rate of 14%. Support for such expenditure is in place and various instruments are available – for example, tax incentives, investment grants, financial incentives, quota obligations, soft or low-interest loans. Each of these is developed to assist investment flow to the sectors as required.

CC(U)S will both require and be facilitated by what will need to be an infrastructure of a similar scale to the current natural gas infrastructure, perhaps even larger than that.

Public or private financing instruments that currently exist within European countries to support renewable energy can be subdivided into different categories. The choice of instruments depends on the stage of development of the technologies or projects. Most renewable energy sources financing instruments fall under three main categories:

- Regulatory instruments in combination with financial support schemes (feed-in tariffs, premium, renewable obligations
- Tenders, fiscal incentives
- Equity finance mechanisms (venture capital, equity, R&D grants, capital/project, grants, contingent grants)
- Debt finance mechanisms (mezzanine debt, senior debt, guarantees).

In addition there presently exist numerous funding programmes in the European market. Some other forms of financing, especially for low carbon technologies are listed below.

Asset finance: Asset finance remains the most important source of funding for low-carbon technologies accounting for US $99 billion (60%) of the total funds invested in

2009. Funding from asset finance can be raised either through project finance, on-balance sheet funding in the form of corporate debt or direct equity investment, or through the bond market.

Project finance: The drop in liquidity caused by the global financial crisis has significantly constrained the ability of project developers to raise funding through project finance. As a result, a much larger share of asset finance has been in the form of on-balance sheet funding. Project finance – the long-term financing of infrastructure and industrial projects based on the projected cash flows of the project rather than the balance sheets of its sponsors – offers an attractive way for companies to fund investments in new generation capacity as the projected cash flow is used to justify the investment rather than the cost being carried on the balance sheet of the project owners.

Private equity and venture capital

A growing share of the funding for low-carbon energy technologies will need to be financed by the private sector. Smaller, more innovative companies backed by venture capital and private equity markets are likely to continue to play an important role in the development of low-carbon technologies. Scaling up and deploying these technologies will require large investment flows which will need to be funded by large corporations. The corporations will finance these investments through a mix of internally generated cash flow and project finance and by issuing debt and equity on international financial markets. In March 2009, US$95.4 billion was deployed in clean energy investment, according to Bloomberg Clean Energy Finance estimates. Of this, US$51.1 billion was managed in core clean energy funds which had more than 50% of their investments in low-carbon energy companies or projects. An additional US$10.3 billion was held by energy and infrastructure funds with at least 10% of assets held in renewable energy. Another US$33.9 billion was managed by environmental and climate change funds in which investments in low-carbon energy represented an important share of the total holdings.

Bilateral and multilateral climate funds

Bilateral and multilateral climate funds offer an important source of finance for low-carbon technologies in developing countries (see Table 5). These funds cover both mitigation and adaptation costs. Much of the multilateral funding is under the management of the World Bank, which has approximately US$9.5 billion of funds to distribute for climate change mitigation and adaptation from 2008 to 2012. A number of countries have also committed funds to support investments in developing countries. Japan has made the largest commitment with US$15 billion being available under the Hatoyama Initiative.

International funds could play a variety of roles as part of a post-2012 agreement. A number of options are under consideration. Future international institutional funding for climate purposes is likely to be significantly larger than it is currently. Existing institutions will need to adapt to handle the larger flow of funds and the different purposes to which they may be put. The extent to which they will continue to deliver international funding in the future, or whether additional bodies will contribute, is the subject of ongoing negotiations.

Derivatives in the energy industry

There has been a significant increase in the derivatives market since the turn of the century. According to recent estimates, the notional value of all financial derivatives in the world has increased from about $100 trillion in 2000 to about $600 trillion in 2010, and a proportion of that is represented by investments in the energy industry. Oil and gas extraction companies as well as refineries around the world use derivatives to hedge their investments. The market risk is usually transferred from the investors to speculators in the financial industry. Volatility in the spot price of crude oil has been associated with derivatives. Price uncertainty increases with the artificial demand created by the speculators who trade physical commodities. When the price is pushed up due to the demand, the speculators sell the oil to make a marginal profit causing more uncertainty in the prices as it tumbles as a result of sudden loss of demand.

A report published by the United Nations Conference on Trade and Development conclusively proves the effects of the commodity derivatives and the price volatility by making the case that, in 2002, commodity prices such as West Texas Intermediate oil had no correlation with the equities such as European equity index Stoxx EU. In 2012, when oil derivatives were worth trillions of dollars and represented a significant portion of the Energy market, Stoxx EU and price of crude oil moved in perfect harmony for many months. However an opposing view is presented by the James A Baker III Institute for Public Policy at Rice University in the publication, The Impact of Energy Derivatives on the Crude Oil Market by Jeff Fleming. Jeff Fleming used statistical analysis techniques such as the Stochastic Volatility Model to try to show that volatility in the oil market cannot be associated with derivatives.

The WEC thinks there should be more debate among the academics, industry leaders and politicians on the role of derivatives in energy markets, and as a result policymakers should decide whether to regulate the derivatives in the energy market in a better way. Currently exchange traded funds, regulated by exchanges, represent about $100 trillion of the total derivatives market worldwide and over-the-counter derivatives, which represent about $500 trillion of the derivatives market, are completely unregulated.

Outlook up to 2050

Investments in infrastructure are high-priority spending for governments of all countries. They have set aside funds to upgrade and build roads, bridges, mass transit systems, housing, electricity grids, CO_2 transport pipelines all needed to manage the rapid urbanisation and growth of population in cities. The funding for these investments, while initiated by governments, is rolled out through multiple models – e.g. public-private partnerships, build-operate – and innovative financial instruments have been created and deployed.

Given the potential challenges of arranging and deploying funding, and execution of projects, it is believed that there will be supply-demand shortages in infrastructure projects and time lags caused by population needs, urbanisation and the creation of the infrastructure required to manage the growth. This will be more evident in the growth markets of Asia, Africa and South America rather than in Europe and the United States. International organisations and population pressures will demand that we be innovative, realistic and persistent in investing in infrastructure.

Jazz scenario

Finance: Private financing and capital is available. Banks lend at acceptable interest rates.

Investments: Most of the aged plants are in developed economies and will require replacements with more efficient plants. Coal plants will move into advanced coal or be replaced by gas. Investment will be mostly private as economics justifies. Regional power-sharing agreements to meet demand and balance countries' transmission systems (driven by industry). The first CC(U)S infrastructures will be developed for enhanced oil recovery (EOR) in North America.

Symphony scenario

Finance: Most renewables-associated infrastructure capital is provided by governments, along with guarantees for energy projects. Private sector financing is limited due to regulatory uncertainty in the early part of the scenario period. Funds directed into low-carbon initiatives would start diverting funds from other government priorities such as healthcare and other programmes. Financial means are not endless, and governments have to set spending priorities. There is less government support for the energy poor.

Investments: Investments are mostly made by governments. Private investment will be limited due to regulatory hurdles. The first CC(U)S infrastructure will be built by North Sea governments and partners, at least partly financed by EU CO_2 credits.

Key scenario cluster 3: Mitigation of CO_2

The WEC's view

Carbon mitigation, adaptation to CO_2 and carbon finance are three key elements that can elevate and offset the negative aspects of energy use and production, as well as heating and transport.

Carbon mitigation

As far as energy supply and efficiency are concerned, mitigation can be achieved through a wide range of measures, such as the provision of tax incentives, wind power production incentive and retrofit schemes for residential buildings. The most important effect of carbon mitigation would be a massive switch from coal to gas in the electricity generation sector (as it happens in the US due to the 'shale gas revolution'). Furthermore, renewable energy certificates and subsidies for certain renewable energy sources and the promotion of domestic resources can be used as mechanisms to mitigate CO_2.

In terms of GHG emission reduction, the impact is extensive. In transport, lower-carbon alternative fuels (ethanol, hydrogen, hydroelectricity and biodiesel) and federal tax credits for purchasing hybrid-electric vehicles can be used to mitigate CO_2 emission, as well as CNG for transport. Also, tax credits to small producers of agro-biodiesel and promotion of biofuels in transport can be applied. In terms of GHG emission reduction, the impact can be significant.

As far as industrial processes are concerned, the planned regulatory framework for industrial GHG emissions can be implemented to promote the reduction of emissions. Financial incentives (soft loans, with below-market interest rate) can be implemented.

In the agriculture sector, CO_2 sequestration and environmental programmes can be implemented to mitigate CO_2 emission. Fertiliser application can be used to reduce methane (CH_4) emissions. The introduction of nitrification inhibitors can also be used to mitigate CO_2.

Waste management can be a tool to mitigate CO_2, for example through the reduction of waste volume by introducing standards of sewage combustion and by introducing landfill and recycling methods. In terms of GHG emission reduction, the impact can be considerable.

In the forestry sector, CO_2 emissions can be mitigated through reforestation, pastureland afforestation, degraded land restoration and reduced slash-and-burn agriculture conversion. In terms of GHG emission reduction, the impact is considered to be minor.

CO_2 mitigation measures are applied globally, regionally and nationally. At the global level, the United Nations Framework Convention on Climate Change (UNFCCC) encourages the intergovernmental convention on climate change. The Kyoto Protocol commits an international agreement linked to de UNFCCC and the Intergovernmental Panel on Climate Change supports the creation of a scientific body for tackling climate change.

At the regional level, despite the diversity and complexity of climate change strategies and policies and measures, most parties now treat climate change mitigation as a core top-level issue in the national policy agenda. Parties are looking for climate change policies and measures to align the goals of emission reductions, energy security, job creation and economic competitiveness, as well as air and water quality. Some parties have progressed through one or more policy cycles and are likely to be more effective in reducing emissions than previous efforts. Many parties have established or are planning multi-sector (cross-cutting) Emission Trading Schemes (ETS) and are supplanting voluntary programmes with mandatory regulations, in sectors of electricity generation, emissions-intensive industry, transport energy supply and road vehicle transportation. Furthermore, parties are continuing to make great use of the relatively low-cost options of mitigating non-CO_2 (i.e. CH_4, N_2O, PFCs, HFCs and SF_6) emissions in industrial processes and waste, but there is little remaining room for further emission reductions in these areas and some parties are developing long-term strategies (e.g. to 2050), with corresponding R&D programmes.

Adaptation (to increasing CO_2 emissions and climate change effects)

Adaptation to increasing CO_2 emissions and climate change include ways of relating to information, insurance, water, urban measures and others.

The possible impact on the energy sector can be considerable:

- In terms of information, measures include national adaptation plans, and the modelling of climate change implications.
- Insurances can help to mitigate the economic risks.
- Infrastructure measures can affect the planning of energy use and electricity supply.
- Restrictions on water resources can help with adapting to water shortages.

Less impact occurs in these cases:

- In cities and urban areas, climate change poses significant risks particularly to coastal, flood prone and fire prone areas. However, the possible impact on energy sector is minor.
- Other areas that can be affected through increasing CO_2 emission levels and climate change relate to land use, changes in land use and forestry, agriculture and food security. This also includes impacts on human health, biodiversity, natural ecosystems, transport, tourism, air quality, geological structures and permafrost. While the effects are still subject to scientific analysis, it is assumed that the possible impact on energy sector – but not the environment – can be minor.

Adaptation (to increasing CO_2 emissions and climate change effects) can be addressed globally in terms of information through the establishment of an Adaptation Committee to promote the implementation of enhanced action on adaptation in a coherent manner under the UNFCCC.

Approaches to address loss and damage associated with climate change impacts can be insurance measures that can help with the adaptation process. More resilient infrastructure is also a pre-requisite for better adaptation. Elimination of counterproductive incentives such as a lack of water meters and leakages in water infrastructures can help with water usage and reduce water wastage. Improving integrated river-basin and ecosystems-based planning can help to address risks in urban areas that arise due to climate change and can help to deal with land use issues.

At the regional level, strengthening and, where necessary, establishing regional centres and networks, in particular in developing countries can help with the provision of better information regarding adaptation. Creating appropriate incentives for private sector action can furthermore help increasing insurance cover. The creation of appropriate incentives for private sector action, including regulation and planning can help addressing water issues. The improvement of the efficiency of the existing irrigation infrastructure and the creation of measures to reduce the risk of insect pests can address issues associated with land use.

Examples of national adaptation plans and strategies being adopted or developed, are in Table 5.

Table 5 – National adaptation plans

Source: World Energy Council (2013)

Country	National adaptation programme/plan	Date	Implementation status
Australia	National Climate Change Adaptation Framework	2007	Establishment of National Climate Change Adaptation Research Facility. The Australian government has invested AUS$4.5 million in “coastal adaptation decision pathways”. The government also funded the “integrated assessment of human settlements” programme which detects localities severely vulnerable to the effects of climate change.
Austria	National Adaptation Strategy	2011	Scientific and economic evaluation of the consequences of climate change study to finish in 2015
Belarus	National system of adaptation to climatic change and development as well as to natural and industrial catastrophes and hazards	Established	Established and functioning effectively in recent years.
Belgium	Belgian National Climate Change Adaptation Strategy	2012	Funding of the research programme Science for a Sustainable Development.
Chile	National Climate Change Strategy	2006	After publishing the national climate change strategy in 2006, the Chilean government published the implementation plan of the strategy in 2008. The action plan is divided in to specific priorities such as: analysis of the climate scenarios at the local level, water resources, biodiversity, energy sector; and others. More concrete actions have also been implemented such as application of calibrated hydrologic balance models to various unregulated watersheds. On the natural preservation front, the Chilean government has begun to implement ecological restoration programmes in degraded systems.

Country	National adaptation programme/plan	Date	Implementation status
Czech Republic	National Programme to Abate the Climate Change Impacts (including adaptation)	2007	Legislation has been added in accordance with the National Programme to Abate the Climate Change Impacts such as the Air Protection Act No. 86/2002 and the Waste Act No. 185/2001.
Denmark	Danish Strategy for Adaptation to a Changing Climate	2013	Established the Information Centre for Climate Change Adaptation under the Ministry of Climate and Energy. Established the co-ordination unit for research on climate change.
Estonia	National Adaptation Strategy	None as of 2013	
Finland	National Strategy for Adaptation to Climate Change	2005	Various research programmes in progress such as Climate Change Adaptation Research Programme, vulnerability assessment of ecosystem services and Finnish Research Programme on Climate Change from the Academy of Finland.
France	National Adaptation Strategy	2006	Developed water saving, began to reduce water abstraction. Began conservation of forest genetic resources.
Germany	German Strategy for Adaptation to Climate Change (DAS)	2008	Developed indicators for the DAS. Enactment of Federal water resources Act 2010.
Greece	National Strategy for Adaptation to Climate Change	Currently under implementation	
Ireland	National Climate Change Strategy 2007–2012	2009	
Lithuania	National Strategy for the Implementation of the UNFCCC until 2012	2008	
Luxembourg	National Adaptation Plan	2011	
Netherlands	National Adaptation Strategy	2007	Began adjustments to water transport systems. Started developing knowledge base and security profile.
Portugal	National Adaptation Strategy	2010	
Slovakia	National Adaptation Strategy	Preparatory works on the strategy have been launched	
Spain	National Plan for Adaptation to Climate Change	2006	
Switzerland	Swiss Strategy for Adaptation to Climate Change	2012	Currently in legislative process.

Country	National adaptation programme/plan	Date	Implementation status
Ukraine	National Plan for Adaptation to Climate Change	None as of August 2013	
United Kingdom	Adapting to Climate Change a Framework for Action	2008	The government has classified the implementation of the adaptation plan into categories: Built Environment, Infrastructure, Health, Agriculture and Forestry, Business and others. More specific objectives within that framework are given a specific deadline. Actions such as: Flood and Coastal Erosion Risk Management strategy for England; Increasing Accuracy of Flood Forecast; Environment Agency Climate Ready Service to provide guidance tools to local Environment Agency Team to promote climate change adaptation; and Defra working with water companies to encourage efficiency campaigns are ongoing actions without a deadline. Adaptation and Resilience to a Changing Climate Coordination Network and Cranfield University has published findings to Community Resilience to Extreme Weather Project in 2011. Department for Communities and Local Government published a review on Overheating in Homes. Other research to be conducted by societies and various universities had mostly concluded by mid-2013. Most of the physical implementation is due by 2015.
United States	Climate Change Adaptation Plan (draft)	2013	Since the final adaptation plan has not been published, no implementation has yet taken place.

Note: Selection only (historic and recent information)

Carbon finance

At the global level, the Kyoto Protocol (since replaced by the Copenhagen Accord) had three market-based mechanisms:

- Emissions trading (the carbon market)
- Clean Development Mechanism (CDM)
- Joint implementation (JI)

Typical policies within countries include: cap-and-trade schemes, baseline and credit mechanism, renewable energy and energy-efficiency certificates, carbon taxes, subsidies, and emission standards.

Global carbon markets have declined, but voluntary markets are expected to grow and fill the gap. Supply and demand is expected to decrease post-2012. Climate investment funds (CIFs) from multilateral development banks have been established in Europe and Asia. There is a trend to expand finance mechanisms beyond Kyoto: CIF, the UN's reducing emissions from deforestation and forest degradation (REDD), national REDD programmes (REDD+), and voluntary schemes.

At the regional level, 90% of trading is based on the EU-ETS (mostly through allowances), with some US-established schemes, and low-carbon initiatives gaining legitimacy in developing countries. As far as carbon taxes are concerned, a carbon tax was introduced in Japan and Australia in 2012 and the UK will introduce a carbon tax in 2013.. South Africa is considering a carbon tax instead of a cap-and-trade approach to meet its targets. The market for carbon offsets is a buyer's market, and post-2012 uncertainty will decrease prices and eliminate incentives to develop projects (except under the JI mechanism).

Tables 6 to 9 include an overview of climate change policies that might affect the energy sectors worldwide going forward to 2050.

Table 6 – Climate change policies affecting the energy sector (I)

Source: World Energy Council (2013)

Mitigation

Subjects	Energy (supply, efficiency)	Transport	Industrial processes	Agriculture	Waste management	Forestry
Focuses	Tax incentives; wind power production incentive; retrofit scheme for residential buildings; renewable energy certificates and subsidies for certain renewable energy sources; promotion of domestic resources.	Lower-carbon alternative fuels (ethanol, hydrogen, hydroelectricity and biodiesel); federal tax credits for purchasing hybrid-electric vehicles; tax credit to small producers of agri-biodiesel; promotion of biofuels in transport.	Planned regulatory framework for industrial GHG emissions; reduction of emissions; financial incentives (soft loans).	CO_2 sequestration; environmental programmes; fertiliser application to reduce CH_4 emissions; introduction of nitrification inhibitors.	Reduction of waste volume; standards of sewage combustion; introduction of landfill and recycling methods.	Reforestation, pastureland afforestation, degraded land restoration; reduced slash and burn agriculture conversion.
GHG emission reduction	Extensive impact	Significant impact	Significant impact	Considerable impact	Considerable impact	Minor impact
Policy						
Global	The intergovernmental convention on climate change (encourages): UNFCCC. The international agreement linked to de UNFCCC (commits): The Kyoto Protocol. The scientific body for the climate change (supports): Intergovernmental Panel on Climate Change.					
Regional	Despite the diversity and complexity of the climate change strategies and policies and measures, some general trends are apparent: Most parties now treat climate change mitigation as a core, top-level issue in the national policy agenda. There is multilevel governance across multiple scales of government on climate change issues. Parties are looking for climate change policies and measures that can align the goals of emission reductions, energy security, job creation and economic competitiveness, as well as air and water quality. Some parties have progressed through one or more policy cycles and are likely to be more effective in reducing emissions than previous efforts. Many parties have established or are planning multi-sector (cross-cutting) ETS. Many parties are supplanting voluntary programmes with mandatory regulations in sectors of electricity generation, emissions-intensive industry, transport energy supply and road vehicle transportation. Parties are continuing to make great use of the relatively low-cost options of mitigating non-CO_2 (i.e. CH_4, N_2O, PFCs, HFCs and SF6) emissions in industrial processes and waste, but there is little remaining room for further emission reductions in these areas. Several parties are developing long-term strategies (e.g. to 2050), with corresponding R&D programmes.					

Table 7 – Climate change policies affecting the energy sector (II)

Source: World Energy Council (2013)

Adaptation						
Subjects	**Information**	**Insurance**	**Infrastructure**	**Water**	**Urban**	**Others**
Focuses	National adaptation plans, modelling	Mitigate the economic risks	Planning	Restrictions and shortage of water resources	Climate change poses significant risks particularly to coastal, flood-prone and fire-prone areas	Land use, land-use change and forestry, agriculture and food security, human health, biodiversity, natural ecosystems, transport, tourism, air quality, geological structures and permafrost
Possible impact on energy sector	Considerable impact	Extensive impact	Considerable impact	Considerable impact	Minor impact	Minor impact
Policy						
Global	Establishment of an Adaptation Committee to promote the implementation of enhanced action on adaptation in a coherent manner under the UNFCCC.	Approaches to address loss and damage associated with climate change impacts.	More resilient infrastructure.	Elimination of counterproductive incentives.	Improving integrated river-basin and ecosystems-based planning.	Improving integrated river-basin and ecosystems-based planning.

Table 8 – Climate change policies affecting the energy sector (carbon finance)

Source: World Energy Council (2013)

Subjects	CDM	Trading	Carbon tax	Off-sets
Focuses	Barriers, additionality		Business reaction	
Possible impact on energy sector	Considerable impact	Extensive impact	Extensive impact	Considerable impact
Policy				
Global	Kyoto Protocol has three market-based mechanisms: emissions trading (the carbon market), CDM (countries) and JI. Typical policies within countries include: cap-and-trade schemes; baseline and credit mechanism; renewable energy and energy efficiency certificates; carbon taxes; subsidies; and emission standards. Global carbon markets have declined, but voluntary markets are expected to grow and fill the gap. Supply and demand is expected to decrease post-2012. CIFs from multilateral development banks have been established in Europe and Asia. There is a trend to expand finance mechanisms beyond Kyoto's: CIF, REDD, REDD+, voluntary schemes, etc.			
Regional	VAT and industrial gas fraud on EU-ETS, banning of industrial gases certified emission reduction credits in the EU-ETS, legislative backlash in USA, Japan & Australia. City and regional schemes may develop. Predictability and low demand will favour AAU and secondary certified emission reduction credits trading.	90% trading EU-ETS (mostly allowances); some voluntary schemes in US; low-carbon initiative gaining legitimacy in developing countries.	The UK will introduce a carbon tax in 2013; the carbon tax in Japan may pass in 2011; South Africa is considering a carbon tax instead of cap-and-trade to meet its targets.	The market for offsets is a buyer's market, and post-2012 uncertainty will decrease prices and eliminate incentives to develop projects (except under the JI mechanism).

Table 9 – Climate change policies affecting the energy sector (research)

Source: World Energy Council (2013)

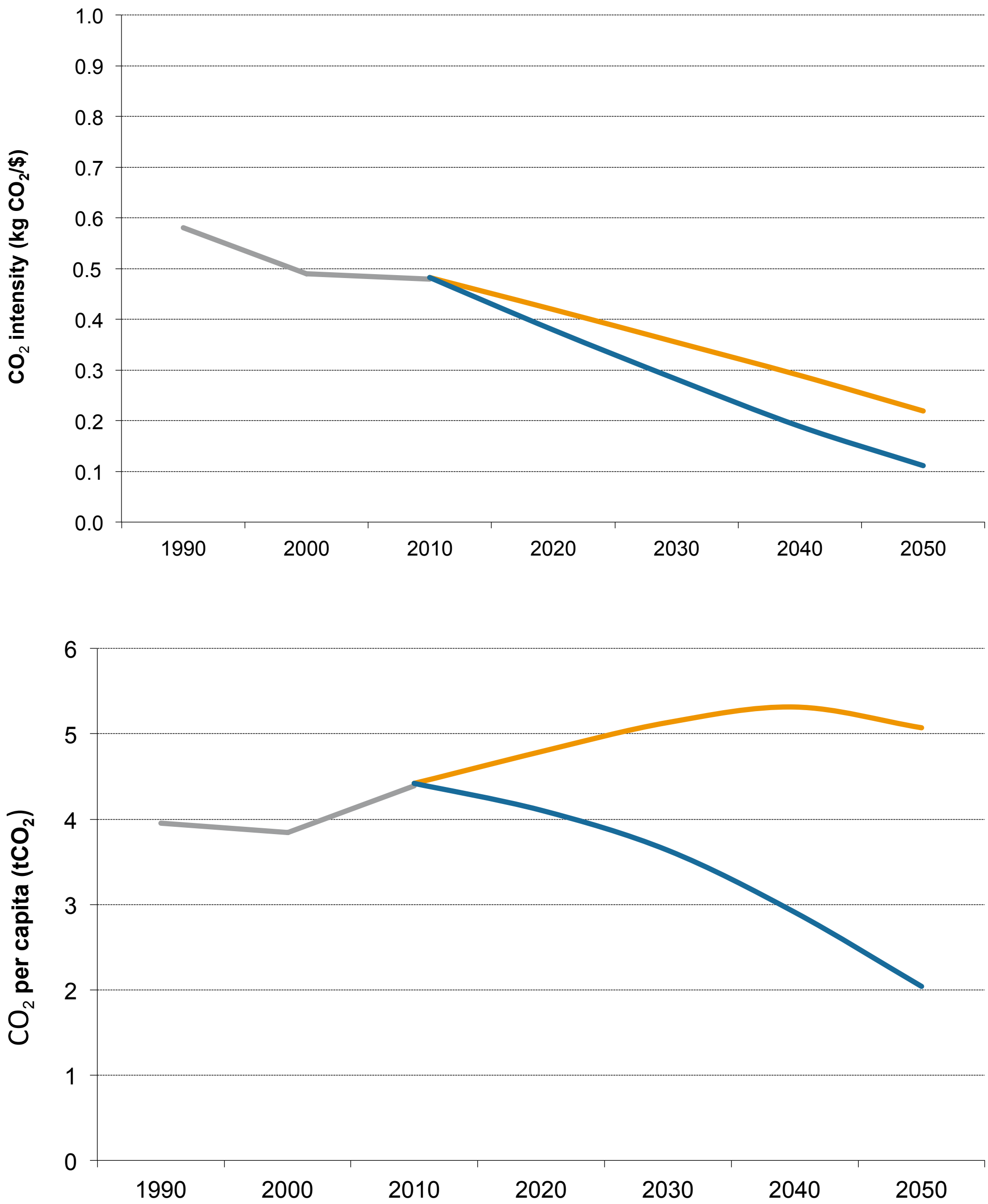
Subjects	Technology needs assessments	Technology information	Capacity building	Mechanisms for technology transfer
Focuses	Identifying and analysing priority technology needs, which can be the basis for a portfolio projects using environmentally sustainable technologies.	Establishing an efficient information system in support of technology transfer.	Application and development of environmentally sound technologies and know-how.	Access to environmentally sound technologies and know-how.
Possible impact on energy sector	Extensive impact	Considerable impact	Extensive impact	Considerable impact
Policy				
Regional	Government-led groups that include academics and business participants, that assess promising technologies.	Databases for current projects that receive government and/or private financial support.	Programmes to help new technologies access to markets.	Incentives such as fiscal and other types, to promote the deployment of new technologies.

The WEC's view on CO_2 intensity and CO_2 per capita until 2050

Figure 5 – Global driver: CO_2 intensity and CO_2 per capita

Source: World Energy Council (2013); WEC/PSI projections; IEA, IMF (historical data)

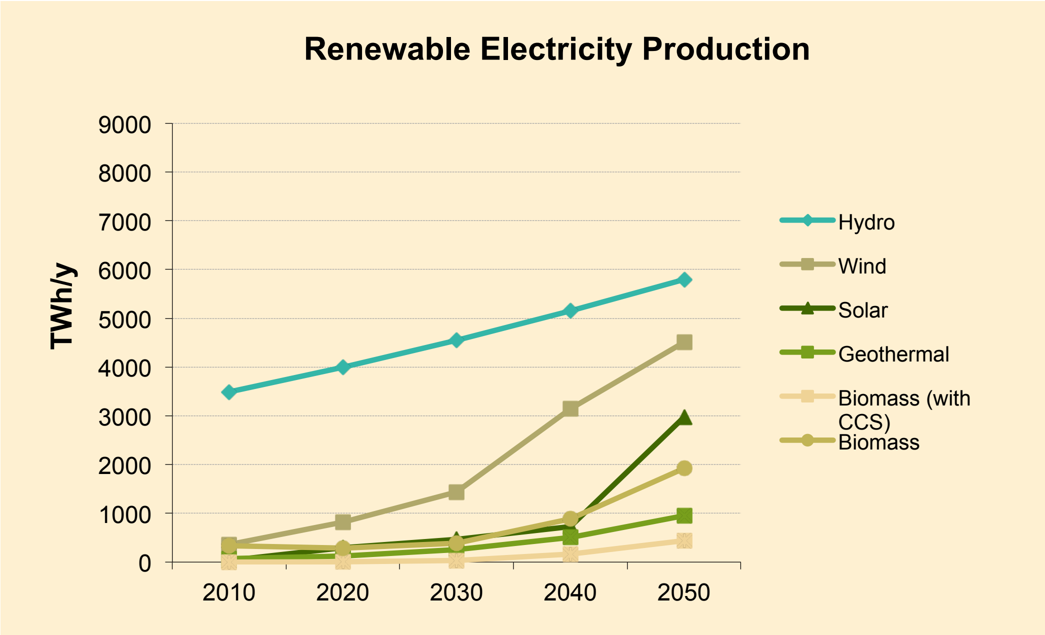
Historical data: IEA CO_2 Emissions from Fuel Combustion Statistics



The WEC's view on the growth in renewables electricity production until 2050

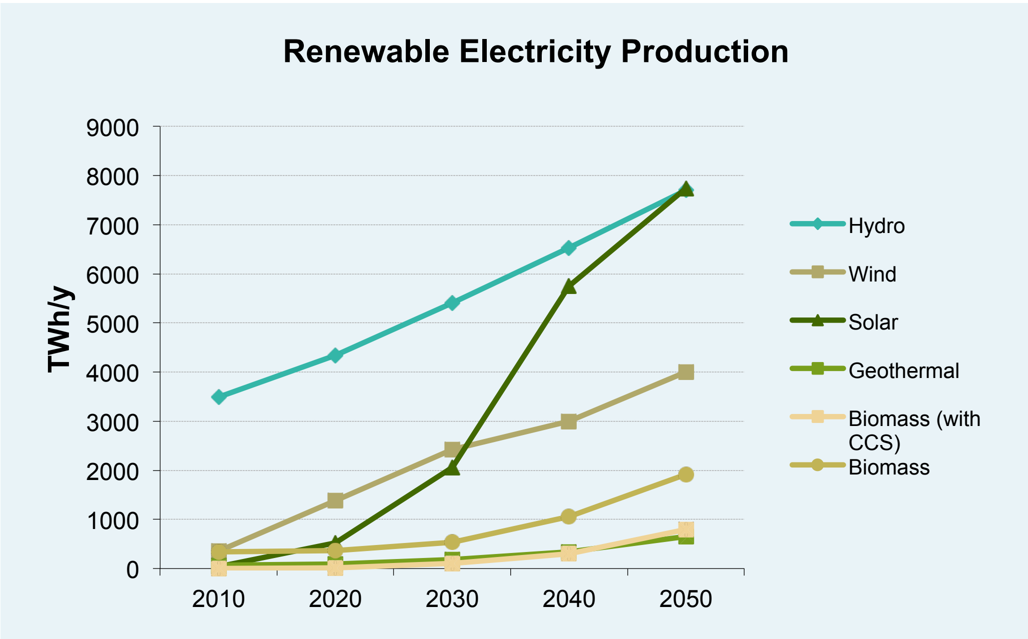
Figure 6 – Growth in renewables electricity production

Source: World Energy Council (2013)



Jazz

Renewable share increases and remains mostly hydro, with growth in solar the highest (in figure 12% p.a. vs. 7% wind/geothermal, 5% biomass, 1% hydro)



Symphony

More stable and quicker transition to renew. More hydro, especially in emerging countries, growth in solar significant (in figure 15% p.a.)

Jazz scenario

In the Jazz scenario there is no global agreement on emission targets and obligations.[4] Carbon pricing in this scenario is determined by the mixture of different emissions targets which governments aspire to reach. Carbon markets will emerge first in Europe and in developed regions where there is a high level of per-capita income. The schemes will be a mix of regional (such as the EU scheme), national (such as New Zealand), state-based (such as California) or even municipal-based, (for example, in China today). They are confined to highly developed nations, but the newly developing nations will adopt them in time. There will be international incentives for least developed nations to join carbon trading markets through investment funding and technology transfer systems.

A bottom-up, global carbon market develops as individual markets combine for better liquidity and to decrease administration costs.

Symphony scenario

In Symphony, countries successfully negotiate a global treaty by 2020 with countries prepared to accept commitments and concessions, based on their present and expected GDP. Individual countries will adopt a range of policies and instruments to reduce emissions meet their commitments. Low-carbon technologies are promoted despite lacking commercial viability at initial stages.

The global carbon market develops from the top down, based around an agreed international framework. In the early part of the scenario period, international trading is based on an extended CDM, with emission credit units having different validly depending on their source. Regional trading schemes will develop but may have different rules. In the later part of the scenario period, trading becomes global through an internationally regulated carbon trading scheme. Emissions trading as a market instrument is seen as the leading way to achieve climate goals in the later part of the scenario period.

Specific carbon prices are provided in Table 10 – CO_2 prices up to 2050.

4 National emission targets that are consistent with the scenarios are implicitly represented via the scenario carbon prices. However, the storylines do not explicitly consider the aspirational/normative targets that some countries have proposed (an example being the EU Roadmap).

The WEC's view on CO_2 prices up to 2050

Table 10 – CO_2 prices up to 2050

Source: World Energy Council (2013)

Carbon price (US\$2010/tCO_2)

	Jazz			
	2020	**2030**	**2040**	**2050**
Sub-Saharan Africa	0	5	10	23
Middle East and North Africa	0	5	10	23
Latin America and The Caribbean	0	5	10	23
North America	8	15	21	28
Europe	0–8	5–15	10–30	23–45
South and Central Asia	0	5	10	23
East Asia	0–6	5–12	10–24	23–38
Southeast Asia and Pacific	0–6	5–12	10–24	23–38
	Symphony			
	2020	**2030**	**2040**	**2050**
Sub-Saharan Africa	10	23	42	70
Middle East and North Africa	10	23	42	70
Latin America and The Caribbean	10	23	42	70
North America	21	28	55	70
Europe	10–30	23–40	50–60	75–80
South and Central Asia	10	23	50	75
East Asia	10–24	23–38	50–60	75
Southeast Asia and Pacific	10–24	23–38	50–60	75

Key scenario cluster 4: Equality, energy access and poverty

The WEC's view

The issue of inequality has many faces. It is, among other things, closely related to population growth and increasing trends of urbanisation and the formation of megacities and secondary cities. The WEC has analysed the economic impacts of global population trends and megacities through 2050 to determine the effect that inequality might have on the future energy landscape. There are essentially three demographic trends that will have profound economic impacts at a global, national, and local level over the next four decades:

1. Human kind has now reached a historic turning point where more people live inside cities than outside of them. There is increasing growth of urbanisation through 2050 and the burgeoning of megacities with populations of more than 10 million inhabitants.
2. Much of the population growth from 2010 through 2050 will result in a shifting to a "'younger' demographic emerging in many developing, lower- and middle-income countries while we witness ageing in the populations in many of the developed nations and China.
3. Most of the population growth rate over the next four decades will be concentrated in the countries and regions that have some of the lowest per capita GDP, which will face the most difficult challenges in dealing with increased demands on infrastructure, energy, basic services, and job creation.

The current world population estimate is 7 billion. In 2020, the global population is expected to be 7.6 billion.[5] By 2050 that number is expected to reach a total of 9.2 billion. This population growth will not be evenly distributed, with most growth occurring in Africa, China, India, and parts of Latin America. The European population is expected to decline over this period. This will have significant implications for global economic growth and trade, which will depend in large part of the public policies implemented at a national level.

Key challenges expected with the anticipated population trends through 2050 will include:

1. Creating employment – especially for the countries with young and growing populations – and maintaining a quality of life for the overall populace, including dealing with poverty and income inequality.
2. Finding affordable, safe, and convenient mobility choices for large population centres.
3. Developing the necessary infrastructure that would support economic growth.
4. Expanding access to housing, energy sources, and clean water, while managing the effects of negative externalities (congestion, traffic, and pollution).

Income inequality is also an important issue at the regional level. Especially in Africa where the WEC expects population growth without economic growth, obstacles to economic development include income inequality, a low life expectancy (52 years), and high illiteracy and poverty rates (one-half of the sub-Saharan African population survive on less than US$1.25 a day). In ASEAN countries, where there is a young

5 The UN population estimates are as follows: by the year 2020 the global population is expected to be 7.6 billion, by 2030 the estimated population will be 8.2 billion, by 2040 the number of inhabitants is expected to be 8.8 billion.

populace with aspirations and significantly different economic development across its member states, each country faces specific challenges. These include: dealing with increased urbanisation levels; job creation; infrastructure expansion; education; poverty; income inequality; and meeting the populace's expectations. While some of the ASEAN countries, such as Malaysia and Singapore, fall into the higher-income category. Many of the other nations, such as Laos, Cambodia, Indonesia, the Philippines, and Vietnam, have young populations, lower GDPs per capita, and higher birth rates. Today, Indonesia, the Philippines, Thailand and Vietnam are all in the top 20 most densely populated countries in the world and (excluding Thailand) they are expected to be in the top 20 in the year 2050. These demographic trends will place even greater demands on the economy and infrastructure in the future.

In South Asia (Afghanistan, Bangladesh, Bhutan, India, Pakistan, and Sri Lanka), where there is a population boom, growth rates are much higher (at 1. 5%) relative to East Asia at (0.7%), the population is younger, and the GDP per capital is lower ($1,085) versus both East Asia ($6,466) and the world average ($8,599). The economic growth of these nations is contingent upon maintaining export-led growth (be it in manufacturing or service) and political stability. Income inequality and reducing poverty levels could prove destabilising over the longer term if not addressed and undermine economic growth prospects for the region. It is expected that by 2100, India will be the most populous country and Pakistan the sixth most populous in the world. South Asia's growth contributes to a number of infrastructure, pollution, and mobility challenges; according to some economists, it also may offer a pathway to accelerated economic growth or a population nightmare. South Asia has a very young population, with between 30% and 40% of their population 14 years of age and under.

The LAC countries of South and Central America are poised for demographic growth with a very large percentage of young people (close to 30%). Brazil has the largest economy in Latin America and one of the largest economies from a global perspective. A principal issue facing LAC is dealing with income inequality and poverty issues, as the region is considered to have the greatest income disparity in the world.

Rising levels of inequality lead to a wide range of consequences, e.g. in the context of urbanisation and the creation of megacities: while the relationship between urbanisation, economic productivity and social development continues to be positive in many regions of the world, slum expansion (which has strongly been associated with poverty) continues to be a sizeable source of urban growth in some areas; young people in slums tend to be more likely to work in the informal economy than their non-slum peers; children in slum areas are less likely to enrol in school and complete primary education; increasing numbers of urban inhabitants are experiencing hunger and with more intensity than those in rural areas; the absolute number of urban poor is increasing; and income inequality in urban areas remains high and is widening in some instances. In comparing the character of contemporary urbanisation across the developing world to the urbanisation experienced in England and some other European countries in the 18th and 19th centuries, UN-HABITAT 2003 observes that "what is different now is that urbanization is not being accompanied by adequate economic growth in many developing countries".

Jazz scenario

In the Jazz scenario it is assumed that the priority is better access to energy and affordability of energy. Global population rises to 8.7 billion by 2050.

Implications for wealth: High and increasing wealth in western world and newly industrialising countries (Southeast Asia, Middle East, and LAC). Increasing 'scissors-effect' – i.e. a widening gap between rich and poor.

Symphony scenario

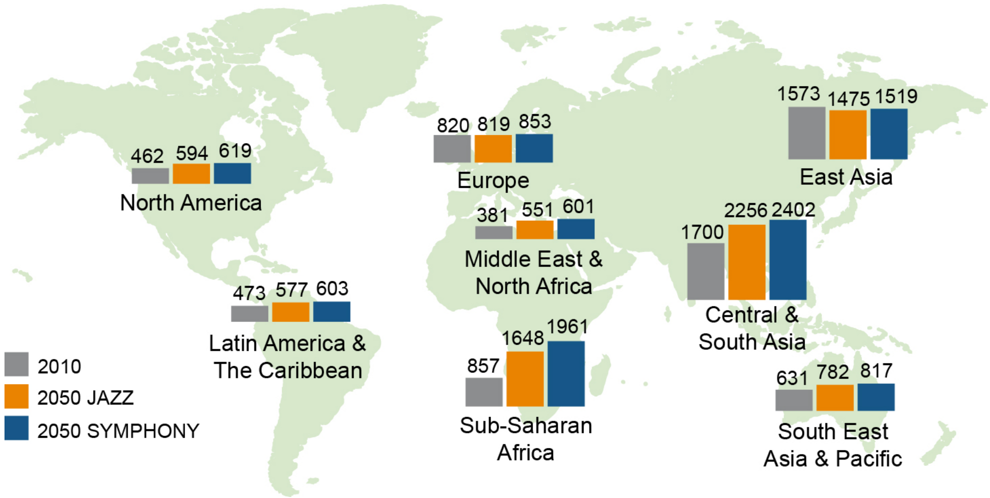
In the Symphony scenario it is assumed that globally, the gap between rich and poor is much smaller. This is also due to more government intervention and policy measures that are designed to narrow the gap between rich and poor. Population rises to 9.4 billion by 2050.

Implications for wealth: Wealth disparity is less obvious in industrialised countries. Wealth in developing nations improves due to technology transfer (e.g. Copenhagen Accord) and multi-lateral programmes (e.g. UNIDO Access to energy programme).

The WEC's assumptions regarding population growth across different regions are stated in the following graph.

Figure 7 – Population in millions

Source: World Energy Council (2013)

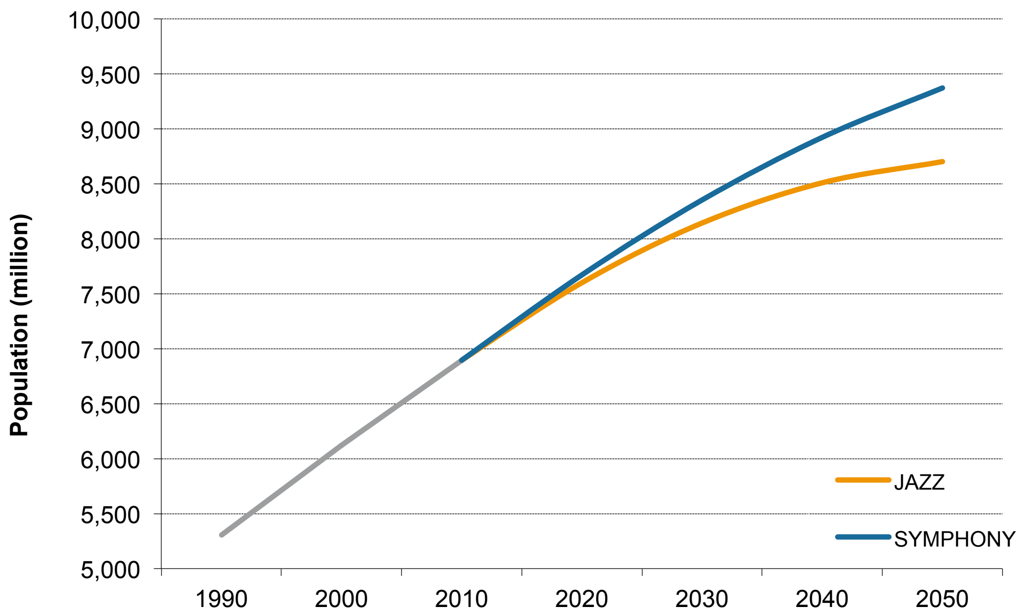


Jazz: **Population growth slows down**	**Symphony:** **Population increases**
• Almost all increase is happening in non-OECD countries. • Population growth in India slows Africa and Middle East still experience high growth.	• Global growth is higher due to lower economic growth rate. • Life expectancy improves in all regions.

The WEC's view on population growth rates until 2050

Figure 8 – Global drivers: Population growth rate

Source: World Energy Council (2013); based on WEC 2011; WEC/PSI projections; UN (historical data); WEC 2011, Global transport scenarios 2050



Key scenario cluster 5: Global economics

The WEC's view

Over the past decades, the world economy has gone through substantial changes. After a period of strong economic growth from the end of the second world war, most western economies followed the way of the social market economy and passed through a period of low-level economic growth in the 1970s and 1980s – dampened only by the outcomes of the first oil crisis in the early 1970s. From the 1990s on, a new recovery began, stimulated by the North-American economy. While, in the 1990s, the US, Europe and other OECD countries were the international driving force of the global economy, the average global economic growth in the 2000s was heavily influenced by economic growth in East Asia (mainly China) and the economic growth in the so-called Tiger states in the 1990s. Since 1978, China has achieved an average annual growth rate above 9%. Overall GDP growth rates have been significantly lower in the US and other developed economies.

The impacts of this accelerated growth on the world economy were different. China flooded the world with low-cost manufacturing, allowing rapid development during the five years before the global financial crisis of 2008. The voracity of the Chinese consumption increased commodity prices in a significant way, causing problems for the importing countries, especially food importers. High commodity prices also had positive effects.

A significant part of the growth of Central and South America and sub-Saharan Africa came from China's commodities boom. The increase in commodity prices was also associated with the 'financialisation' of the world economy. The abundance of liquidity and the absence of more effective controls on the financial market led to the sub-prime crisis and also to pressures on the commodities prices. The increase of world liquidity impacted on the relationship between national currencies. Programmes such as the quantitative easing increased the volume of dollars on the world economy, leading to an appreciation of that currency against others, such as the Euro.

Recent world economy crises

The new period of growth suffered major inflection from September 2008, when a significant systemic crisis occurred. What was originally thought to be restricted to the North-American financial market gradually affected the real side of the economy. The origins of the crisis went back to the collapse of the dollar/gold standard at the beginning of the 1970s, together with the opening of the markets and the free movement of capital. From this time, financial deregulation would be the new order, gradually dictated across the world. Financial innovations and securitisations occurred with full force, bringing general credit expansion and market expansion in the real estate sector, among other consequences. With these new movements, the perception of risk was reduced. The North-American real estate sector became an option for the generation and realisation of profits, incorporating new borrowers. This represented major risks and resulted in the so-called sub-prime market.

In September 2008, the crisis culminated with the world economy slowing down even more sharply, high volatility in the real estate sector and loss of confidence in the financial system. The evident signs of reduction in activity began to appear: reduction in employment, a decrease in investment, reduction in consumption, and retraction in profit and loss of the assets' value. Governments reacted with a series of economic policy measures, implementation of fiscal packages (tax exemptions, fiscal incentive programmes) and monetary and credit packages (reduction of the basic interest rate, monetary stimulus measures). After the 2008–2009 crisis, the world economy started to recover gradually. The first signs of reversal (or at least stability) of the negative rates appeared during the second quarter of 2009. The effectiveness of macroeconomic policy actions initially avoided a deepening crisis. Today, this growth is not yet fully consolidated. Most developing countries have recovered from the post-crisis level of activities. The developed economies still present several problems, such as the persistence of high rates of unemployment, remaining weakness in the financial market, fiscal problems (outcome of the recovery effort), high household debt and difficulties with the real estate market. The developing economies have inflationary pressures due to commodity prices or overheated demand. As a result, uncertainties remain for the future path of the economy.

Role of the state and its impacts on the economic policy

One of the major issues for long-term economic growth until 2050 relates to the perception of the role of the state and its impacts on economic policy. This can be explained by the return of the importance of the state in a context of crisis and recovery, and as an important agent of social change. Alternatively, fiscal problems and public debts in several countries have stimulated discussions about limitations of attributions or about the restrictions of government expenditure. The intervention of the main European governments and the North-American government in attempting to reverse the economic crisis led to a new examination of state intervention. To overcome the crisis, here was a strengthening of the state and national protectionist policies during the global financial crisis, followed by a relaxation of state intervention as the economy recovered. Obviously these measures were adopted in the context of a global financial crisis. It might be too soon to say that these measures violate the liberal economic paradigm. The persistence of factors which hinder the resumption of sustainable economic activities opens up space for a re-evaluation of the participation of the state in the economy, both in crisis and in normal situations.

Direction of the economic policy

Just after the 2008–2009 crisis, many contributions were brought to the economic discussion by economists outside the mainstream searching for clarification of the causes and the role of economic policy in the crisis. Their perception was that the capitalist economy is inherently unstable and that crisis is intrinsic to its own dynamic. How economic policy will develop depends, to a certain extent, on whether the world economy recovers quickly, as well as how governments respond to rebuilding growth and boosting employment and income. This is a crucial point for the decision on economic policy for different scenarios. The environment and changing production structures will also have an impact on the path of economic policy. In general, it is possible to say that the crisis gave a new impetus to the theoretical debate because the monetary policies and the operation of central banks around the world became more interventionist, albeit temporarily.

There are those who believe that the counter-cyclical measures, as well as the reversal of the deregulation process will shift the crisis. There are those who support the return of liberal practices and the minor state coordination in the post-crisis period. The International Monetary Fund (IMF) note, ‘Rethinking Macroeconomics Policy’, is a significant example to stimulate the discussion on changes in economic policy. Primarily, the note was considered a milestone of the IMF’s change of position. More than that, one of its authors, Olivier Blanchard, an economic adviser and the head of the research department, is also one of the more influential mainstream scholars, suggesting that the proposals in the text were part of a deeper debate.

The document reflected the inability of policies and indicators to prevent and control crisis in the current capitalist system. It criticised the model of inflation targeting, the fiscal policies based on Ricardian Equivalence Methods, as well as the deregulation process and financialisation. The note seems to be overvalued by several people.

Emerging critical uncertainties for economic policy for the future to 2050 that will have an impact on the global economy are:

- Inflation control vs. economic growth: are they compatible or conflicting goals?
- Social goals: Will they be incorporated to the economic targets, leading to the implementation of alternative ideas to the conduct of economic policy?
- Will there be more interaction between overall macroeconomic policy and sectoral policies?
- Will there be greater coordination between the economic policies of the various countries of the world in order to find a more lasting solution for the recovery or will we continue in a world where economic policies are managed in a distant way, without any connection?

Macroeconomic policy

The uncertainty placed on the conduct of economic policy raises questions around how macroeconomic policy will be developed. Further questions arising are:

- Will the inflation targeting regime be maintained (with the fiscal surplus, control/reduction of government debt and floating exchange rate), having the Brazilian basic interest rate as the main instrument of economic policy readjustment? (A difficulty of this kind of policy is that it hardly generates a sustained growth.)
- Will there be greater coordination between monetary–credit, fiscal or foreign exchange policies?
- Will there be greater interaction between macroeconomics and sectoral policies or mid- to long-term policies (for example, industrial and technological)?
- Will there be controls on the capital flow? There will be impacts on exchange rates and interest rates. The quantitative easing (an action aimed to increase the liquidity of the financial system) performed by the US Federal Reserve, from mid-2010 strongly affected the devaluation of the dollar against other currencies.

Income distribution and the ‘new middle class’

Another important point that can affect the path of the world economy concerns the changes in distributive profile of income. The growth of emergent economies or those in development – such as China, India and Brazil – and less developed economies has led to improvements in the labour market, with increased legislation and income improvements. Therefore, a new quota of individuals has had the opportunity to participate more actively in the consumer market, which increases the demand for goods and services.

In these same developing economies (and in less developed economies), it is easy to understand why there has been an expansion of a series of social programmes – such as: the Bolsa Família in Brazil; food distribution and employment guarantee programme for the rural population in India; Asignación Universal por Hijo para Protección Social and Programa Famílias para Inclusión Social, from Argentina; and Oportunidades, in Mexico – reducing the number of people in poverty and generating greater social inclusion.

Given the circumstances, the impacts on the future global economy could include:

- The growth of a 'new middle class' putting pressure on prices, as a result of the increased demand, having the chance to lead to a more restrictive macro policy, with less expansive monetary policy (credit reduction; increase of interests).
- More expansionist pressures on macro policy, mainly with fiscal policy.
- The fortification of the role of the state in attending to the demands of the new middle-class. With increased income, the demand of these individuals for other goods and services (as social security, health and education) that may be attended by the state, leading to the need of reviewing its expenses or even its increase.

Fiscal crisis of the European countries and the US

The financial world crisis demanded the wide fiscal interaction of European governments. The direct result was the increase of the fiscal deficits, as well as deterioration of the related debt/GDP, with impacts on economic policy.

The deterioration of the fiscal indicators during the crisis in countries such as Greece, Ireland, Portugal and Spain, generated turbulence in the financial market, including depreciation of debt ratings. To solve the problem and soften market rumours of unpaid debts, many of the countries' elaborate fiscal packages were strongly supported by the reduction of the state's role in the economy and by the systems of social security present in many countries in Europe. Considering that social protection mechanisms were partially responsible for the high level of social coherency, measures that caused the welfare state to deteriorate increased the population's vulnerability. The result was a wave of violent protests in many European countries.

The important question is what impact will this situation have over the economic policy and, more precisely, over the macro policy? Two points seem worth highlighting:

- Increases in state deficits and high tax levels lead to decreases in consumption and hence decreases in economic growth at the national level.
- Expense cuts to oppose these deficit increases, as seen in many tax adjustment programmes in the European countries and the US, strongly affecting growth, complicating greater fiscal stability, and generating social tension.

Relationship between national states and international trade

Another important influence on the world economy is world trade. The continued economic growth has been accompanied by an increase in world trade. One of the most important aspects was the Chinese ascension and symbiosis with the North American economy. The fragile balance generated between these two giants, the US with its huge deficits and China's increased funding, was one of the factors that allowed the unprecedented expansion of global liquidity.

The different strategies adopted by the developed countries and the emerging economies for the recovery of the crisis created economic conflicts, with commercial disputes masked by non-coordinated foreign exchange policies. The great quantitative easing promoted by the US was a strategy to reactivate the economy (because it contributed to the depreciation of the dollar and the artificial increase in the competitiveness of North-American products abroad). Similarly, China maintained an artificially depreciated Yuan as a strategy to stimulate exports.

The fact that the developed countries were at the epicentre of the crisis gave greater opportunity to the developing countries. The developing economies with greater potential (Brazil, Russia, China and India) tried to unite forces and present unique proposals in the international forums. The great diversity of these countries prevented a consensus. As a result, it is difficult to construct a coordinated scenario.

The factors the WEC has considered in the construction of scenarios are:

The predominant form in which commercial relations are verified: bilateral or economic blocks, e.g. when looking at the transatlantic trade relations between the US and the EU or free trade agreements such as NAFTA, Mercosur and others.

The maintenance of the secondary role of international institutions, such as IMF, World Bank and World Trade Organization (WTO), is seen as a direct reaction of the non-coordinated strategies of crisis recovery. In the aftermath of the 2008–2009 crisis, meetings of the G20 became more important than previous G8 meetings, with the developing countries gaining more representativeness in the forums of decision.

Restructuring the world financial system

After one year of discussion, the main remodelling in the North-America financial system was sanctioned in mid-2010 by President Obama, imposing a series of restrictions on financial institutions, and consolidating the supervision of the balance sheets of those companies whose failure presented risks to the financial system. Some of these measures are:

- More stern demands of equity to be maintained by financial institutions and greater control over the operations and speculative funds, mainly in the commercial banks.
- Creation of a consumer financial protection agency to control eventual abuses of the concessions of lending, especially credit cards and mortgages.
- Obligation for companies to seek shareholder approval on policies for bonus payments to executives.
- Performance evaluation for risk classification or rating agency, with penalties including closure of operations for flagrant and repeated mistakes.
- The great question for the world financial system is in the capacity to control capital. The environment of fragile regulation was a key factor in the financialisation of the world economy. The epicentre of the crisis of 2008 was the financial market. Because of the impact that interest rates and exchange rates have on economic policy, greater regulatory coordination may be necessary to maintain greater control.

The problem with prices

Other point that has an impact on the application of economic policy and, consequently, the course of the world economy in the future is inflation.

Before the crisis, most of the world faced more significant inflation rates. Part of this growth was associated with the elevation of commodity prices, although, in some countries (mainly developing ones), it was also due to internal market pressures and improvements of income distribution. With the crisis, the prices significantly dropped, resulting in a deflation in some regions. When the world economy indicates recovery, the prices will elevate again, along with commodities.

The most significant price variation can result in macroeconomic policies even more restrictive, hindering further growth, particularly if the inflation targeting regime remains.

The WEC's assumptions about the overall economic development

Jazz scenario

The following assumptions were made:

Good economic situation: Top of business cycle, with high but unevenly distributed economic growth among regions. High growth in developing and transition economies, gentler growth in developed countries. Sufficient private funding for new investments.

Bad economic situation: Bottom of business cycle, low and unevenly distributed economic growth among regions. Cut-backs reduce new investments and choke energy demand. Pessimism and weaker will to commit investments for long-term as financing is mostly private. Lack of funding sources and capital availability.

Economic volatility: High economic volatility with potential super-cycles.

Capital and labour: Free flow of capital and labour. Flow of foreign capital and workers (all skill levels) from Asian and LAC regions to developed countries and vice versa. Competitive labour market. Domestic worker unemployment increases, especially in skilled sectors.

Institutions: Less prominent role for international institutions as governments sign up to mutually beneficial trade agreements.

Foreign direct investments: Increased level of FDI, especially in Africa.

Policies and competition for natural resources: Higher demand creates more global competition for resources. As a result, the influence of national oil companies (NOCs) grows and there is more exploration and production (E&P). Competition creates cost-effective solutions. New unconventional energy sources kick in when prices are right – oil sands, natural gas liquids (NGLs), shale gas. Competition fosters innovation, and new solutions emerge.

Politics: Stable political environment within countries creates high economic growth, leading to job creation. Domestic politics are determined by the economic performance of the government in charge. Strong support for national governments, influenced by the private sector. Public debts are lower and easier to service due to smaller governments.

Trade: The WTO makes progress on competitive issues. Free and expanding international trade with fewer barriers. Globalised economy. Global competition with few trade disputes. Trade activities increase between countries especially China, India, and Brazil. Trade is made mainly around minerals, oil/gas, and agricultural commodities. Trade ties with developed countries continue and strengthen around tech transfer and services. Latest technologies used and disseminated.

Competitiveness: Influence of market forces. Market seeks competitive cost solutions. Favourable climate for open global competition. BRIC countries outperform developed countries.

Sustainability: Cheaper but less wide-spread solutions due to lack of enforcement by governments. More efficient investments due to transparency, better payback will create sustainable projects.

Manufacturing centres: Manufacturing established in low cost centres and close to major markets resulting in more efficient cost structures and lower prices. Resurgence of industry and manufacturing in US and possibly in EU. Growth of manufacturing and industry in EU depends on EU-level acceptance of common, well-defined, binding carbon policies for all member states.

Urbanisation: Good economies will invite better planning and problem solving. Increasing move from rural to urban areas. Cities grow at a high rate – increasing congestion on roads and land space. 'Ghettoisation' of cities due to income disparity. Rural areas become the target for large-scale, plantation-type farming enterprises.

Megacities: With free market and free movement of labour and capital, the number of megacities is expected to rise significantly. Solutions to congestion, housing availability, and demand for services (water, sewerage, telecom, transport, education, health, energy, etc.) are provided by private companies. Government will step in for more optimal and sustainable urban planning. Increasing number of 'secondary cities'.

Consumer behaviour and lifestyle

- Consumer spending increases.
- Domestic savings level drops.
- Price and highest comfort dominate and differentiate products.
- Increasing levels of consumption, especially in fast moving consumer goods (FMCGs).
- Demand for more sophisticated goods – high-end electronics, cars, etc.
- Entry of foreign retail firms into the market will bring newer technologies faster to developing countries, improving productivity.
- Increasing high-street banking services and lending.
- Equality: gap between rich and poor widens.
- Price is an important factor.
- Luxury goods market increases, driven by higher incomes in developing countries.

Energy consumption: Higher economic growth results in higher energy consumption. Costs and energy consumption rise irrespective of energy-efficiency savings.

Energy consumption/use of electricity in buildings: Growth in energy consumption is expected to remain low in developed, higher in developing countries.

- High demand for air-conditioning.
- More energy efficient buildings in developed countries.
- Higher energy prices motivate more investments in efficient equipment, insulations, and appliances. Also more solar thermal use (heating/cooling).

Energy consumption/usage in industry

- Growth in energy consumption will be closely related to economic growth.
- Expected to be high in manufacturing countries (US and China).
- Energy saving and efficiency expected to increase especially in developing countries which start from lower levels.
- Investments in efficient equipment, insulations and appliances are justified by gains in efficiency and economics.
- Industrial demand for energy reaches all-time peak.

Energy-water-food nexus: For water, larger energy demand will call on more water use in cooling, unconventionals processing, and public consumption. This results in significant food and water stresses.

Symphony scenario

The following assumptions were made:

Good economic situation: Top of business cycle. Sufficient economic performance to fund government initiatives in all sectors, including energy. Overall economic growth is more moderate, but remains unevenly distributed across regions. Clean energy initiatives do well.

Bad economic situation: Bottom of business cycle, sufficient economic performance in developing countries such as China and Brazil continue to fund government initiatives, but at a lower level. Economic performance is much weaker in developed countries as growth rates are low. Large public sector debt develops. Growth is still distributed unevenly. Effect of down-cycle partially mitigated by lower energy demand and energy efficiency gains. Clean energy initiatives suffer.

Economic volatility: More stable economic environment with lower growth levels.

Capital and labour: Restricted flow of capital and labour. Investment is focused into select sectors (e.g. transport, mining and energy - which are of strategic importance) via government intervention. Only highly-skilled foreign workers are permitted into labour markets. Domestic unemployment remains low, as are wages and productivity.

Institutions: Stronger role for international and multilateral institutions as there is a move towards regional energy and climate policies.

Foreign direct investments: FDI into developing countries is not at the same rate as in the Jazz scenario. Fewer sectors experience benefits of FDI in response to regulatory uncertainty in the early part of the scenario period.

Policies and competition for natural resources: Less competition over energy resources as regional interconnection increases. Formation of energy trading blocs to support the trade of renewable electricity. Focus on regional supply and improving energy efficiency. Irrespective of costs certain energy sources are promoted for non-economic reasons, namely energy security (e.g. nuclear, coal w/ CC(U)S).

Politics: Potential political volatility and social unrest from within countries due to series of backlashes against widespread corruption, unemployment and government inefficiencies. In light of the European currency/debt crisis, there is international pressure and a drive towards increased monitoring mechanisms translating into higher regulation.

Trade: The WTO places increasing emphasis on free flow of green goods and services. Increased international cooperation on climate change issues. Individual countries/regions prefer local content and solutions. More fragmented and differentiated global economy. Higher trade restrictions. Trade is focused, with a small set of selected countries.

Competitiveness: Lower market influence as government intervention is increased. Company reputation and ability to work with bureaucratic governments becomes a competitive differentiator. Larger companies with bigger balance sheets take a bigger share of the market.

Sustainability: More expensive to achieve sustainability as efficient prices are not driving actions of participants. Faster implementation of sustainability initiatives at national levels.

Manufacturing centres: Manufacturing centres are established in less-than-optimal locations due to regional development factors. This results in higher costs and prices.

Urbanisation: Governments coordinate urbanisation. There is scope for delays as government budgets tighten and economies have lower growth rates. Move from rural to urban areas continues, albeit at a lower rate. Cities continue to grow in size. Rural areas in developing countries continue to engage in subsistence farming for longer.

Megacities: Restricted movement of labour and capital will reduce the growth of megacities. Solutions to urban problems and services will be determined by government intervention.

Consumer behaviour and lifestyle

- Consumer spending decreases while saving increases.
- High level of domestic savings.
- Government incentives are used to stimulate consumer demand for green goods and services.
- Social activism increases.
- Public perception and corporate social responsibility become competitive differentiators.
- Consumption levels are lower in this scenario due to environmentally conscious citizens.
- Very few market players (mostly local firms).
- Equality: smaller gap between rich and poor.

Energy consumption: Lower consumption in the Symphony scenario. High impact from energy efficiency and saving programmes. Global demand for energy is also lower because of lower growth and changes in lifestyle. Demand continues to migrate east.

Energy consumption/use of electricity in buildings: Growth in energy consumption is expected to remain low in developed countries, higher in developing countries

- Energy saving and efficiency will increase (especially in developing counties as they start from lower levels).
- Building codes enforced in developing countries.
- Fossil fuel consumption expected to peak and then drop.
- Energy efficient equipment, insulation, and heating/cooling appliances are given tax breaks governments.

Energy consumption/usage in industry

- More moderate growth in energy consumption compared to Jazz scenario.
- Energy saving and efficiency measures are mandated and subsidised by governments.
- Fuel switching from fossil fuels occurs to reduce costs and emissions.
- Industrial demand for energy is managed closely.

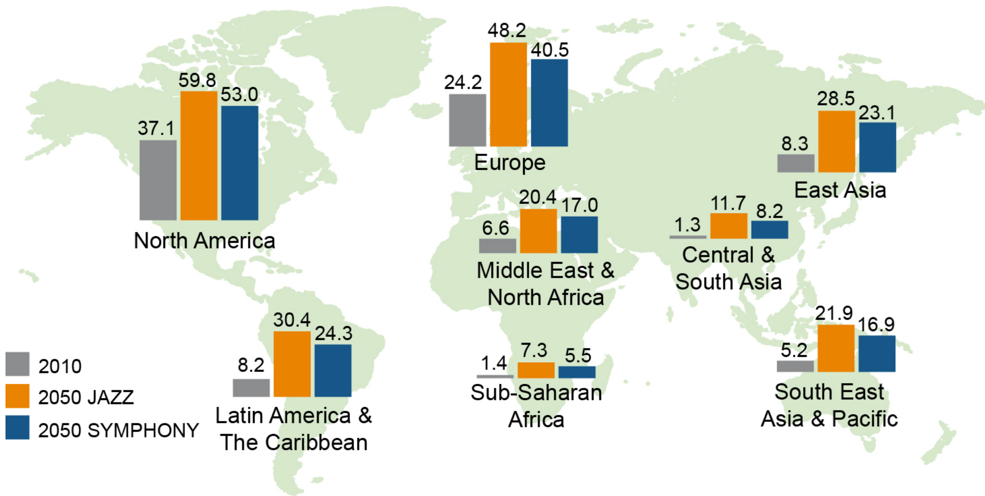
Energy-water-food nexus: Government policies (security of supply concerns) result in increasing contribution of first-generation biofuels to energy mix. Impact of energy system convergence with food system results in food price increases. Genetically modified crops still not accepted in EU. Large contribution of second-generation biofuels in the latter half of the scenario period. Special interest groups (farmers, land owners) lobby for continued government subsidies. Only 2–3% of the world water is fresh. By 2050, the world will require 3090 cubic km of water (509 for developed and 2582 for developing). Use of water in biofuels and shale gas will be a challenging constraint.

The WEC's assumption regarding GDP growth and GDP per capita is shown in Figure 9.

Figure 9 – GDP per capita (thousands of US$2010 per inhabitant in MER)

Source: World Energy Council (2013)

Historical data: IMF, World Economic Outlook Database, October 2012



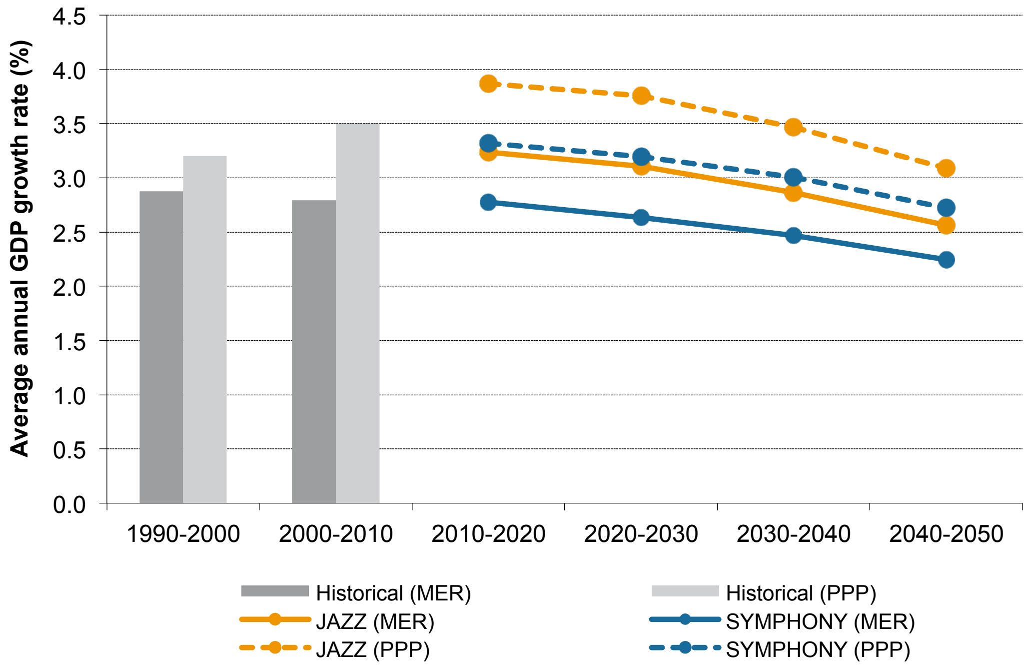
Jazz: Good economic situation/ high volatility	**Symphony: Moderate economic situation/ less inequality**
World : +2.3% p.a. Developed: +1.3% p.a. Developing: +3.9% p.a. Least developed: +4.4% p.a.	World: +1.7% p.a. Developed: +1.0% p.a. Developing: +3.2% p.a. Least developed: +3.6% p.a.

The WEC's view on global economics and the average annual GDP growth rate (in %) is illustrated in Figure 10.

Figure 10 – Global drivers: GDP annual growth rate

Source: World Energy Council (2013); based on WEC 2011; WEC/PSI projections; IMF (historical data), WEC 2011, Global transport scenarios 2050

Historical data: IMF, World Economic Outlook Database, October 2012



Key scenario cluster 6: Energy prices

The WEC's view

As part of its scenarios work, the WEC has extensively examined the issue of energy prices. To form its view on the price and energy commodity scenario from a long-term perspective, the WEC has reviewed the historical energy prices and recent major issues driving these price changes and volatility. The WEC has also examined the historical trend in real terms instead of nominal terms. In particular, the following energy commodity prices have been considered:

- Crude oil price
- Natural gas
- Coal
- $CO_{2.}$

As part of the analysis, WEC has made a distinction between price movements in the short term and the longer term. In the short term, oil prices have been highly volatile. For example, the oil price was US$92/bbl in early 2008. But the Organization of the Petroleum Exporting Countries (OPEC) reference basket (the weighted average of prices for petroleum blends produced by OPEC countries) rose to a record high of US$141/bbl in early July 2008 before falling to US$33/bbl by the end of that year.

There are a variety of factors contributing to the volatility of oil prices: geo-political instability; OPEC and non-OPEC member countries' behaviour; extreme weather conditions and its impact on refineries; and most of all, the imbalance between demand and supply. Short-term volatility is often reflecting the uncertainty in market expectations. The recent price hikes witnessed since 2004 have being explained from a demand side by world economic growth of close to 5% accompanied by a significant increase in Chinese diesel demand to prevent the power shortage at that time. From the supply side, geo-political instability such as the threat from Shia Muslim extremists in Iraq to blow up the Southern export pipeline, civil war threats in Nigeria, political problems surrounding the Yukos oil company in Russia, hurricane damage to oil installations in the Gulf of Mexico, and the psychological impact of the overstated oil and gas reserves of Royal Dutch/Shell, the world's third-largest oil company by 22%.

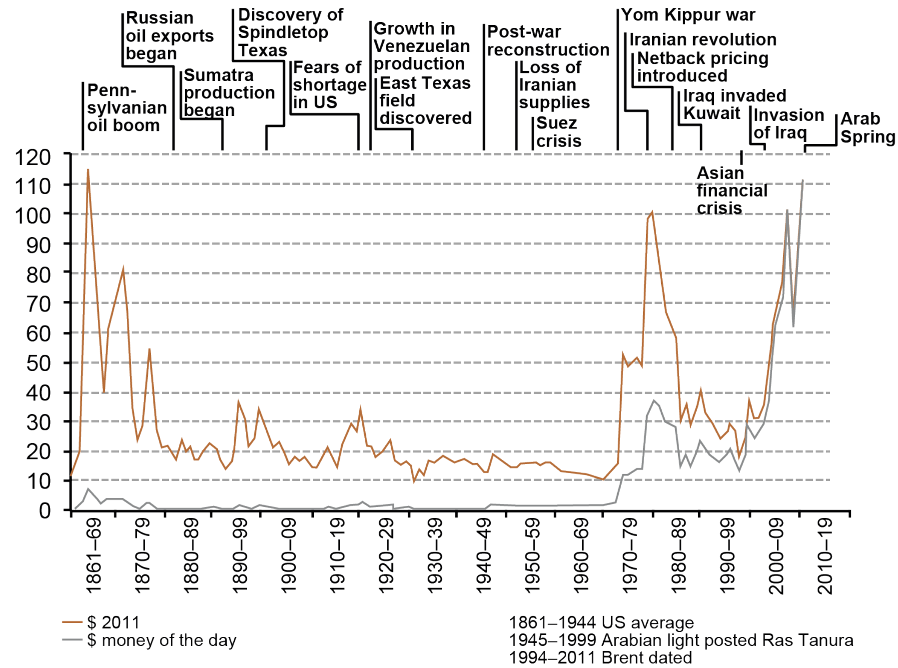
Figure 11 illustrates the oil price volatility.

Figure 11 – Oil price: Real (US$2010) vs. nominal

Source: BP (2012): BP Statistical Review of World Energy, June 2012

Crude oil prices 1861–2011

US dollars per barrel – World events



Another important aspect in energy commodity price movement is its tendency to move together. When evaluating the degree of market integration both within and between crude oil, coal, and natural gas markets, some authors conclude that the world oil market is a single, highly integrated economic market. Prices of raw commodities, including that of crude oil, have also been subject to analysis. It has been found that they have a persistent tendency to move together and this co-movement is well in excess of anything that can be explained by the common effects of inflation or changes in aggregate demand, interest rates and exchange rates. This co-movement is evaluated to be, to some extent, the result of 'herd' behaviour in financial markets where traders are alternatively bullish or bearish on all commodities for no plausible economic reason. Recently, oil price parity has been under question due to the diverging gas price from oil. One explanation could be the ability to substitute gas with coal not oil. Another explanation would be the recent development of unconventional fuels such as shale gas, which is found to be abundant enough to drive down the price of gas. The first explanation could be reversed depending on the carbon price changes through the process of climate convention. But the second explanation would be much more plausible to have a longer-term impact in energy market.

Considering the uncertainties expected to follow in the future, forecast energy prices for the next 40 years remain a challenge. The WEC has therefore formed its own views on how energy commodity prices such as crude oil, natural gas, coal will develop until 2050. The WEC's views for key global economic developments up to 2050 are as follows.

Jazz scenario

Energy prices: In the Jazz scenario, energy prices will be lower with international trade encouraging more E&P facilitate higher GDP growth. Moderate oil prices in the short term. They eventually rise due to demand. High growth of energy demand leads to higher prices at the end of scenario period. Tight oil markets until additional volumes enter from Iraq, Russia, and OPEC NGLs.

Symphony scenario

Energy prices: In the Symphony scenario, energy prices will be higher than in the Jazz scenario. Higher oil and energy prices at the beginning of the scenario period due to tightness in supply markets. Lower and more stable prices are achieved after quicker transition to renewable energy sources. Oil prices are tightly regulated, especially in developing countries. Increase in electricity prices, to pay for infrastructure, leads to a rise in energy poverty. More government subsidies for lower-income groups.

Key scenario cluster 7: Citizen acceptance

The WEC's view

Major industrial projects are increasingly being given a disapproving 'thumbs-down' by the general public. Besides the technical, economic and political framework, public acceptance is now a central criterion for the implementation of major projects, especially infrastructure planning in the energy field. Some project owners, but also politicians, feel helpless when confronted with this problem. National and international arguments in energy and environmental policy no longer seem to clinch matters at local level. On the contrary, they provoke on-the-ground resistance to many projects. At the same time, politicians are more and more reluctant to stand up to broad-based social pressures. This phenomenon is not merely confined to the area of the conventional energy supply, e.g. based on fossil or nuclear energy sources, but has spread to include renewable energy sources. Although renewables are now approved in principle, we find a simultaneous lack of local acceptance, let alone support for, the projects involved. For example, this is just as true of the construction of wind farms or pumped-storage hydro power plants as it is in some regions of the sorely needed extensions to power grids to transport the massively increasing power generated by renewables from the low-consumption production locations to the high-consumption regions.

Citizen acceptance is not a new phenomenon. But, a whole host of reasons have increased the potential to mobilise citizens and their willingness to protest, unfolding a power that can topple even large-scale projects legitimised by the rule of law. Acceptance, in the sense intended here, refers to the willingness of people to tolerate a technology in their own environment. To be distinguished from this is the term 'acceptability', which describes a value-judgement on the acceptance worthiness of a technology, balancing the advantages and the disadvantages. Receptiveness for technical innovations is the prerequisite for a fact-based and enlightened opinion-forming process and a crucial component in cost accounting, when it comes to launching new products, manufacturing plants and services, offering solutions to problems and, ultimately, making a contribution to a country's capacity to modernise and compete.

Until well beyond the middle of the last century, political decision makers and authorities were trusted by the population to plan and approve projects with the general public and their wellbeing in mind. The loss of this trust is evident in many states of the world today. Scandals and misguided developments in politics and industry as well as questionable behaviour and decisions are receiving great media attention. This situation results, for a very large part, from developments in the media in recent decades. All over the country we now find people challenging the decisions of democratically legitimised representatives and their authorities who have issued approvals for infrastructure or major projects in the wake of extensive consultations.

Public acceptance is now growing to be a problem even for renewable energies. The expansion of renewables may be welcomed by a majority of our citizens: 95% believe extensions to and the growing use of renewable energies is important. Nevertheless, the public takes a critical view of extensions to the grid infrastructure and the construction of wind farms, but also pumped-storage power plants, in their own immediate vicinity. People increasingly want to get involved in political and administrative decisions using the available options, or even to question decisions after the event. This can block entire procedures in the longer term and, in extreme cases, cause projects to fail. For grid operators and their investment projects, this has now become part of their everyday life. Hardly any project can be implemented these days without protests and considerable delays. There is a risk that the grid infrastructure urgently needed – mainly to transport the massive renewables-based power from the low-consumption generation sites to the high-consumption regions – will not be in place on time. The politically desired transformation of the energy system toward a system largely based on renewable energies is now seriously imperilled.

Acceptance today is increasingly key for the successful implementation of infrastructure measures and major projects. The ambitious restructuring of the energy-supply system is stalling in many places due to a lack of acceptance. National and international energy-policy targets are threatening to fail. This is true of conventional supply systems, as it is of renewable energies. Especially when it comes to integrating renewables into an existing conventional supply system, the fact is that further infrastructure facilities are essential for politically targeted, future-proof energy-supply structures. Taking those affected seriously and breaking up the simplified pattern of the 'cost-benefit ratio' is a promising approach to a solution. 'Those affected' must become 'those involved': communications should pin-pointedly deal with people's concerns, but also with the advantages of a project, and must adequately integrate the public into the economics of a scheme and into the decision-making process.

Experience of both failed and successful procedures has shown that, for a project to succeed, an acceptance-geared dialogue with all citizens on an equal footing is indispensable. Opponents and advocates must be equally involved. The local and regional benefit of major projects is crucial. If this benefit genuinely does not exist, ways must be found to create it. The benefit must be worked out in a dialogue with members of the public as a joint impetus for town or region, and understood as a joint result. Involving a neutral mediator here can bring further de-escalation and receptiveness. The road to a social consensus in the transformation of the energy system is a stony one – yet all those involved in this process must take that road together.

Jazz scenario

Citizen acceptance: In the Jazz scenario, consumers focus on affordability and energy access. As a result, public acceptance for energy infrastructure projects is high, as long as it is compatible with providing access to cheap energy sources. There is less public acceptance of delays in the consenting process caused by NGOs and individuals.

Symphony scenario

Citizen acceptance: In the Symphony scenario, there is a tension between a voter's consensus on driving environmental sustainability through government decisions, and individuals' and NGOs' opposition to new developments. Voters (NIMBY)[6] and NGOs (BANANA)[7] will oppose energy exploration, generation and infrastructure projects if, in voters' perception, they do not contribute to sustainability or for a variety of other reasons, even if this might lead to higher energy prices, higher emissions and reduced energy security. The cost will be fewer project developments and less infrastructure reinforcement, leading to higher societal cost in the medium to long term.

6 NIMBY – not in my back yard – someone who opposes anything built right by where they live.
7 BANANA – build absolutely nothing anywhere near anyone.

Key scenario cluster 8: Energy efficiency by sector

The WEC's view

Energy efficiency plays a major role in enhancing security of energy supply, competitiveness, net exports, social aspects and, last but not least, as one of the most cost-effective ways of addressing climate change. The WEC found previously that labelling and minimum energy performance standards (MEPS) for refrigerators are the most popular measures implemented to enhance efficiency measures, followed by investment subsidies and MEPS for buildings. Among the most frequent, a variety of measure types can be found (regulations, financial incentives and fiscal measures) showing that there is no preference for a specific policy instrument and that a mix of different measure types is generally preferred. Subsidies for audits are more frequent in developing countries and MEPS for dwellings and tax reduction are more widely used in developed countries. Two-thirds of countries have subsidy schemes. Fiscal measures are mainly used in developed countries where the tax collection system is more developed and revenues from tax are higher. Economic incentives are also used to promote the quality of energy-efficient equipment and services. Tax reductions on energy-efficient equipment or investments have been introduced in many countries and almost equally in all regions: they are in force in about 30% of the surveyed countries. The compact fluorescent lamp is the most common piece of equipment to which this measure applies outside the developed countries. In some European countries, lower VAT is used on labour costs to reduce the investment costs of building renovations.

Improving energy efficiency not only relies on the existence of more and more efficient technologies and equipment; it also calls for a persistent political commitment and, above all, action from everyone at global, regional, national and local levels. The International Partnership for Energy Efficiency Cooperation is an excellent example of the kind of international collaboration that is needed.

There are numerous ways of promoting energy efficiency, and most countries have already defined a strategy towards reaching their targets.

Most energy-efficiency measures are cost effective and help to address issues related to market failures as they help internalising the negative externalities associated with energy use and electricity. Energy-efficiency measures can help poor households to reduce their energy expenses. Energy efficiency is therefore directly related to fuel poverty alleviation. Energy efficiency is not the panacea, not only because of implementation issues, but also because more energy efficiency does not always mean less energy demand. A 'rebound effect' can lead to little energy savings, or even more energy demand, because, as a consequence of their energy savings, households could use more electrical devices or spend the money to buy other products which could cause a higher energy demand in other sectors of the economy. Therefore, energy-efficiency policies have to be carefully designed to avoid such effect.

For energy-efficiency measures to be successful, governments need to combine two complementary approaches: the financial approach – subsidies, loans, fiscal incentives, and so on – and the behavioural approach, to raise awareness among consumers about energy efficiency as an issue itself. They also need to highlight the different policy programmes available in a given country to tackle this issue – although this effect is not certain, as energy-efficient technology is usually more expensive. In the US, demand-side management and integrated resource planning mechanisms have led to the so-called reversed ‘Robin Hood effect’ where poor people were subsidising the higher middle class.

From a market design perspective, the best way to stimulate reduction of energy consumption (both services and energy efficiency) is to pass on correct price signals to consumers. Social tariffs, as used in some countries, are counterproductive for reduction of energy consumption when the best way is to guarantee a decent income to people to avoid poverty, and then the prices should be set correctly without subsidising cheap electricity. In this context, ‘fuel poverty’ is actually a misleading concept, because one could also talk about food poverty, mobility poverty, communications poverty, and so on.. The real issue is poverty in general.

The behavioural approach: getting people involved

Governments need to ensure that consumers are given sufficient access to information as a crucial preliminary step in order to influence their choices. Providing consumers with informative bills and devices to monitor their consumption can increase energy savings by inducing behavioural change.

Labelling is another way of providing information to consumers and encourage them to buy more efficient appliances, cars or houses and therefore incite suppliers to remove the most inefficient ones from the market. Mandatory labelling is more effective than voluntary labelling, as manufacturers cannot then use labelling as a marketing tool by applying it only to the most efficient appliances. Labelling must be designed to be easily understood.

Governments must review labelling regularly so it remains effective: because of recent energy-efficiency improvements in the developed countries, a large proportion of some markets reached the highest category in terms of energy-efficiency labelling (e.g. ‘category A’ for electric appliances in Europe). Therefore, new distinctions between the products have to be made regularly (e.g. in Europe, category A was divided into A, A+, and A++ sub-categories in 2004).

Labelling is often associated with mandatory MEPS, which aim to ban the most inefficient products from the market. MEPS provide a regulatory backstop when the behavioural approach is limited by banning very inefficient products which could otherwise be sold in the market. If governments do not plan to tighten these measures, MEPS could provide incentives for manufacturers to go beyond the minimum standards to reach better efficiency levels. Thus, MEPS appear as a complementary approach, in coordination with informative labelling. Both are non-financial measures and come at a very limited cost for public budgets and studies showed that they come at almost no additional cost for consumers as well.

Financial incentives

Financial incentives represent a major component of public policies in favour of energy efficiency and are well-developed in Europe, in the US and in the more developed countries in Asia. They encompass subsidies, loans and schemes to reduce upfront costs, fiscal incentives, energy-savings options, and other measures, such as energy audits, energy-savings plans, and regulation on quality standards.

Subsidies

Governments can provide investment subsidies which are designed to reduce the cost of investments needed to implement energy-efficiency measures and renovate building or industrial facilities. These subsidies can also reduce the investment needed to buy more efficient equipment, either for domestic, commercial or industrial purposes (e.g. solar water heaters). Subsidies can represent either a fixed amount of money, or a proportion of the investment cost, possibly including a ceiling.

Loans and schemes to reduce upfront costs

Providing loans at lower interest rates compared to the market can help reduce the costs of energy-efficiency measures for consumers. Such loans can be implemented by the banking sector which can offer state-subsidised interest rates. The state can also set up a credit guarantee scheme to incite banks to offer loans more easily to their customers. These measures can help to reduce the barriers to investment and the reluctance to perform energy efficiency measures – which have an immediate cost but also hypothetical savings in the future for both the state and the consumer.

Fiscal incentives

Fiscal incentives comprise schemes which allow consumers to reduce the annual income tax they pay, or schemes which set up specific low taxation levels for energy-efficient products and services (e.g. reduction in VAT rate on labour cost for building improvements, on solar panels, etc.). Fiscal incentives are less costly for public budget than subsidies. They do not reduce the upfront costs and therefore the barriers to investment remain, especially for consumers who pay a very limited amount of tax (i.e. low-income households).

Energy savings obligations

Energy savings obligations (ESO) are a policy instrument employed by governments to encourage energy efficiency. ESOs create legal requirements for energy companies (either generators or suppliers depending of the countries) to achieve certain targets in terms of energy efficiency and reducing demand. Energy companies are rewarded with energy savings certificates, which can be traded in some countries. ESOs are then generally called White Certificates, and the policy tool becomes very similar to the CO_2 emissions certificates trading schemes which are more and more commonly used over the world. In theory, this type of mechanism can achieve a precise energy-efficiency target set by the government at the lowest overall cost to society, by allowing players with the lowest abatement costs to subside more than the others and trade their certificates afterwards.

Additional measures

Some countries also implemented other measures such as mandatory (and/or subsidised) energy audits, mandatory energy-saving plans for large industrial consumers, regulations on quality standards, and so on.

In general, public policies implemented by governments to support energy efficiency tend to rely mainly on investments in building renovation, more efficient appliances, and so on. They are less likely to support behavioural changes (except for some communication campaigns to raise awareness) which are much more uncertain and difficult to monitor and assess accurately. This tendency could be dramatically affected by the development of smart grids and smart meters in the future. Even if these devices remain costly for domestic consumers, they could prove to be very efficient tools for consumers to adapt their behaviour (in particular, they could provide real time and much better price signals to consumers) and for energy companies to plan their production and services.[8]

8 Smart grids will improve the matching of demand and supply. However, critics say that it has not been shown convincingly smart grids will lead to less consumption of electric energy. Similarly, if storage (e.g., through batteries) is part of the balancing issue, then consumption could increase because of the limited efficiency of storage devices per charging/discharging cycle.

Energy-efficiency measures rely mainly on technological changes which occur rapidly; incentives, in particular financial incentives to invest in energy-efficiency measures are closely linked with market conditions (e.g. whether a technology is mature or not, whether the supply chain is sufficiently well-developed, etc.) which also change rapidly. Therefore, policymakers should ensure that the results of policies and economic tools in favour of energy efficiency are assessed regularly to ensure that the consumers who benefit are actually the targets of the mechanism and that the measure in use is the most adapted to the market situation of a given technology or product.

The use of energy-efficiency policies in developed countries is expected to grow, as they can rely on relatively effective institutional and regulatory frameworks, including specific public agencies which are intended to foster, assess and enforce energy-efficiency measures. The tools which are relatively easy to implement and come at almost no cost for public budget are already widely used in developed countries (e.g. MEPS) and these countries are now starting to experiment with more innovative schemes (e.g. ESOs) which could prove to be very efficient, but which require a sophisticated framework to work. One needs to be aware of the 'energy-conservation paradox' where the over-production of zero-marginal cost electricity will often encourage more consumption. This is already the case in some places in Europe and will certainly get worse.

For developing countries, even basic energy efficiency measures are not so common, and a relatively slow development of these measures can be expected in the future (except in BRIC countries), relying mainly on tools with limited cost for public budget such as MEPS in countries where they are not implemented so far. Also, priority is given to promoting GDP growth in developing countries. To implement more innovative tools, more complex and substantial regulatory institutions are needed, and this is unlikely for the near future. Specific situations in developing countries should be addressed adequately, not just by adapting measures from developed countries: specific behaviours and countries' characteristics (e.g. the importance of second-hand goods, use of biomass as a crucial source of energy) should be assessed on a country-by-country basis. In both developed and developing countries there is certainly a large potential for energy-efficiency measures in the future, but the different situations require differentiated solutions.

Households and services

The greatest energy-saving potential in the household and services sectors lies in buildings. From an energy perspective, buildings are complex systems consisting of the building enclosure (shell or envelope) and its insulation, space heating and cooling systems, water heating systems, lighting, appliances and business equipment. Most buildings have long lifespans, meaning that more than half of the current buildings will still exist in 2050. The effectiveness of the building enclosure depends on the insulation levels and thermal properties of walls, ceiling and ground or basement floor. Improvements can reduce heating requirements by a factor of two to four compared to standard practice. Globally, space and water heating are estimated to dominate energy use, accounting for around two-thirds of final use. Energy-efficient technologies include highly efficient heat pumps, solar thermal systems and combined heat and power (CHP) systems with hydrogen fuel cells. Thermal storage can also maximise the energy savings and energy efficiency potential of other technologies and facilitate the use of renewables and waste heat. It includes sensible (hot water, underground storage) and latent ('phase change' ice storage, micro-encapsulated phase-change materials) and thermo-chemical storage. For cooling, active solar thermal and CHP requires thermally driven chillers. Evaporative coolers also work well in hot, dry climates. These units cool the outdoor air by evaporation and blow it inside the building.

Regarding lighting and appliances, the use of deadlines for phasing out inefficient or polluting products is effective (e.g. as seen with incandescent light bulbs). The limitation of consumer choice reduces the moral hazard of transferred goods (e.g. selling a house with a B-rated boiler), reduces the external cost incurred by those who care for the environment, and enables differentiation of top-end environmentally friendly goods by removing the least-efficient (and cheapest) goods.

Setting stricter consumption standards for equipment used in buildings is important for improving its energy efficiency. Energy labels are essential and they are most effective when designed around how consumers choose products. In the residential sector, the main barriers to change are higher initial costs, lack of consumer awareness of technologies, split incentives and the low priority placed on energy efficiency. Overcoming these barriers will require a comprehensive policy package that may include information campaigns, fiscal and financial incentives, and other deployment policies, as well as minimum energy performance standards.

In the service sector, policies to achieve improvements in the enclosure of new buildings, together with highly efficient heating, cooling and ventilation systems will be needed. Given their larger share of total use (compared to the residential sector), significant policy measures will be required to improve the efficiency of energy use in lighting and other electrical end uses such as office equipment, information technology equipment and refrigeration.

Transport

Reducing the energy intensity of transport can be achieved by lowering the growth of car ownership and traffic and improving the energy efficiency of new cars. Technological innovation can, therefore, help the transition to more efficient and sustainable transports systems by acting on vehicle efficiency through new engines, materials and design.

Electrification of the transport sector, including promotion of electric cars and plug-in hybrids, is an important element for making the energy consumption in the transportation sector more efficient. Most governments in developed countries now have strong fuel economy standards and many governments worldwide have announced plans to support wider use of EVs and plug-in hybrid electric vehicles (PHEVs).

Country comparisons show three areas for large reductions in freight energy consumption: better management of the load factors; greater use of trains and ships where possible; and improved fuel economy of trucks. Even though trucks have become somewhat more efficient over time, International Energy Agency (IEA) analysis reveals major opportunities to realise more significant savings through technical and operational measures (such as driver training), and logistical systems to improve efficiency in the handling and routing of goods. According to IEA estimates, better technologies can increase the efficiency of new trucks by 30% to 40%.

To capture the gains of these efficiency measures, greater attention must be directed at encouraging consumers to adopt the technologies and lifestyle choices that underpin the transition away from energy-intensive, fossil-fuel-based transport systems.

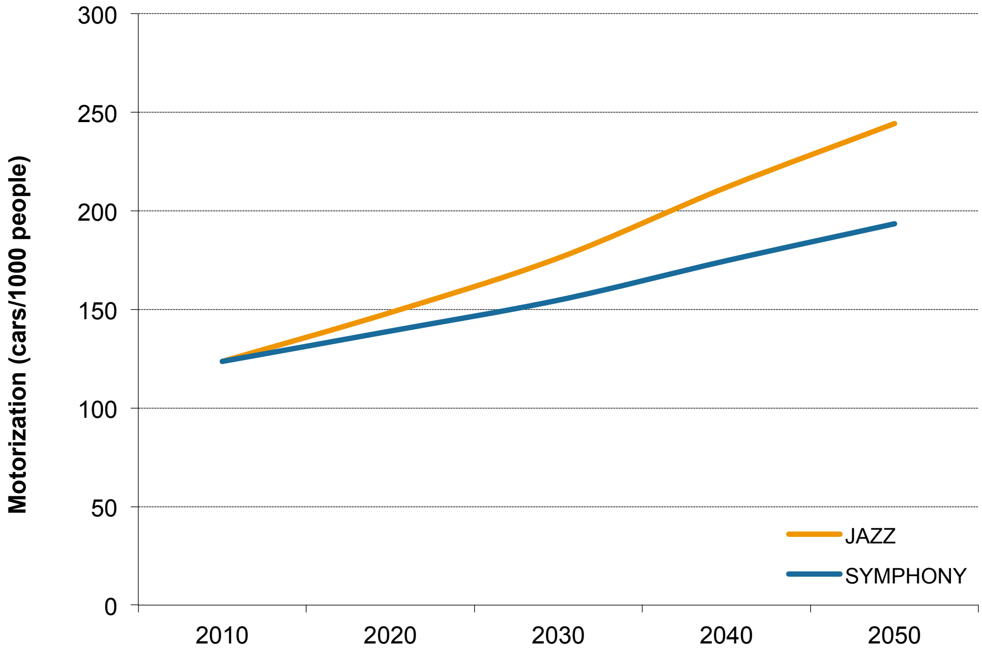
The WEC's view on GDP per capita and car ownership until 2050

Figure 12 – Global drivers: Global GDP per capita and car ownership

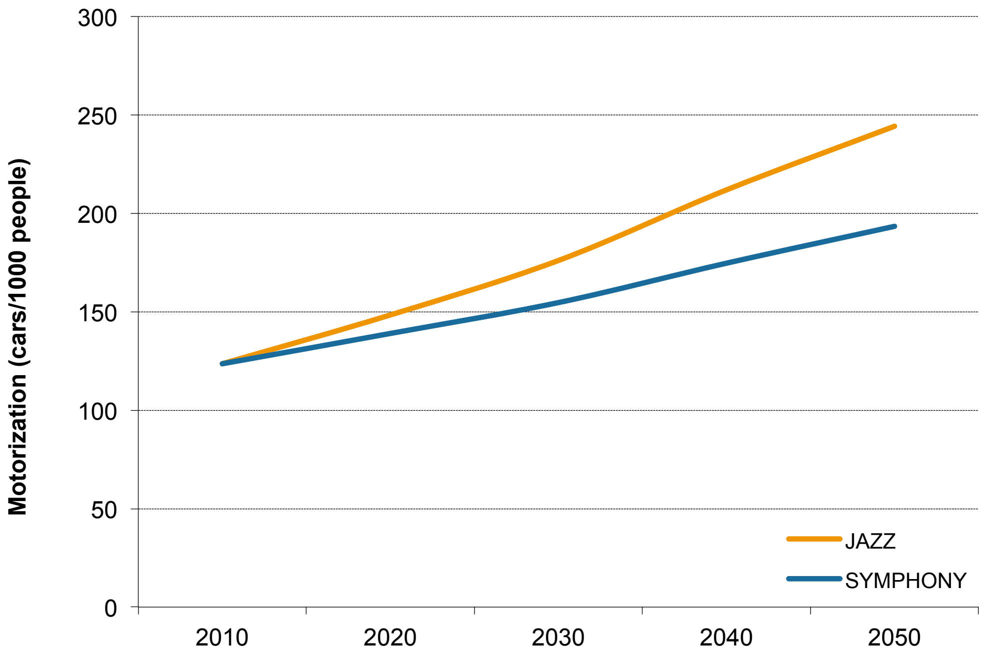
Sources: Global GDP per Capita: World Energy Council (2013); PSI (2013): WEC World Energy Scenarios: Composing energy futures to 2050 (calculated from above) based on: PSI computations

Car ownership: Based on WEC 2011; WEC/PSI projections; WEC 2011, Global transport scenarios 2050

Global GDP per Capita



Car ownership



The WEC has made the following regional assumptions about car ownership and new registrations up to 2050.

Table 11 – WEC car registration assumptions until 2050

Source: World Energy Council (2013)

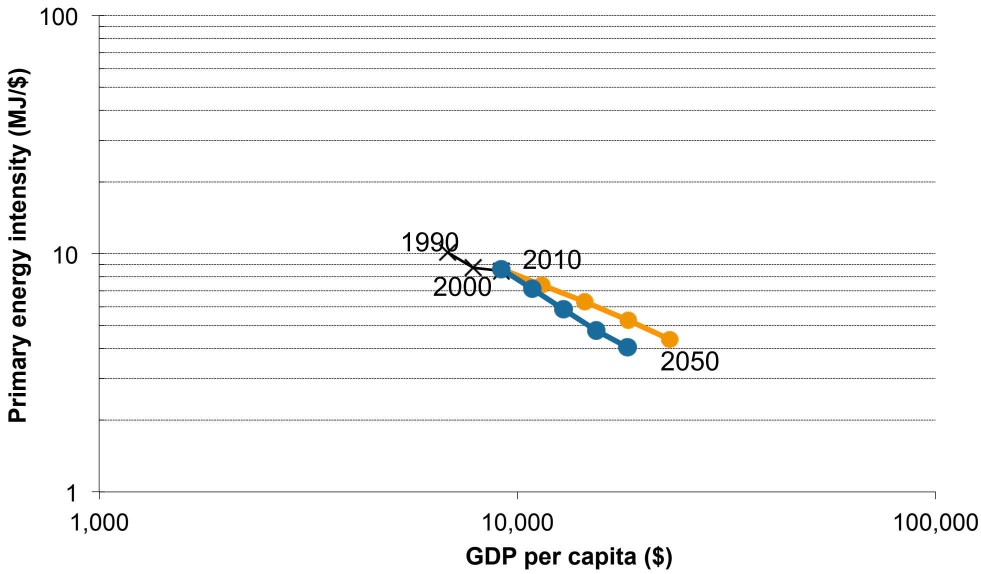
Jazz: +1.27 billion cars in 2050 from today	**Symphony: +0.96 billion cars in 2050 from today**
Stronger demand for sophisticated goods (including cars). **New registrations worldwide:** • 20% in East Asia • 17% in South and Central Asia • 16% in North America • 13% in Southeast Asia and Pacific • 12% in Europe • 9% in Latin America.	More reliance on public transport and car sharing. **New registrations worldwide:** • 17% in East Asia • 15% in South and Central Asia • 19% in North America • 12% in Southeast Asia and Pacific • 12% in Europe • 9% in Latin America.

The WEC's view on primary and final energy intensity until 2050

Figure 13 – Global drivers: Primary and final energy intensity

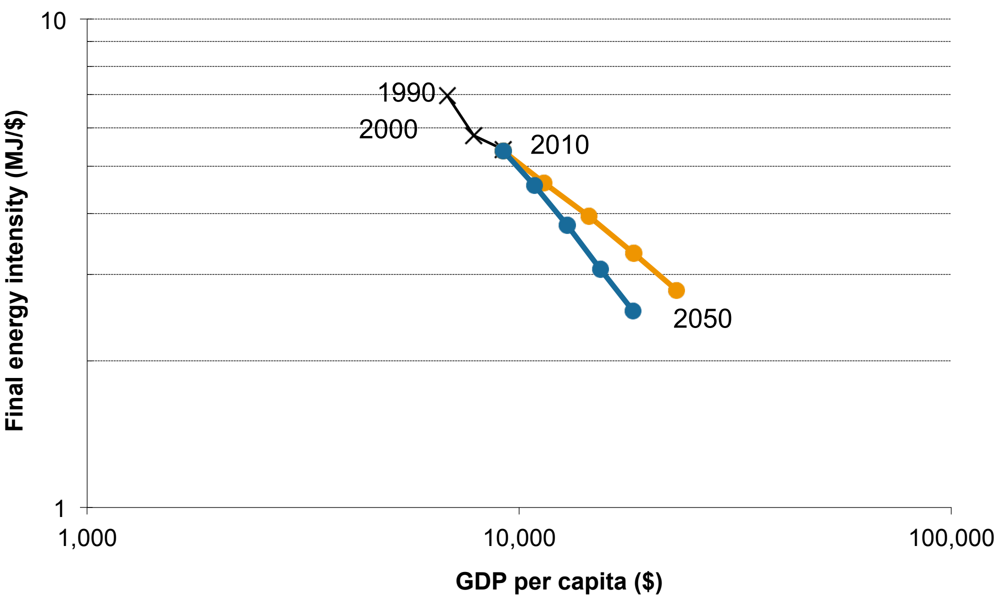
Sources: Primary energy intensity: World Energy Council (2013); WEC/PSI projections; IEA, IMF (historical data); Historical data: IEA World Energy Statistics and Balances, IMF, World Economic Outlook Database, October 2012; Final energy intensity: WEC/PSI projections; IEA, IMF (historical data); Historical data: IEA World Energy Statistics and Balances; IMF, World Economic Outlook Database, October 2012

Primary energy intensity



Notes: The primary energy content of renewable electricity (hydro, wind, solar PV, solar thermal power, geothermal power) is calculated as equal to generation; primary energy amounts for geothermal and solar heating represent thermal energy. Primary energy content of biomass is the energy content (lower heating value) of the biomass. The historical statistics report secondary amounts of biofuel as primary energy, resulting in slightly lower estimates of primary energy intensity.

Final energy intensity



Notes: Final energy includes coal use in coke ovens, blast furnaces and gas works; final energy also includes non-commercial biomass.

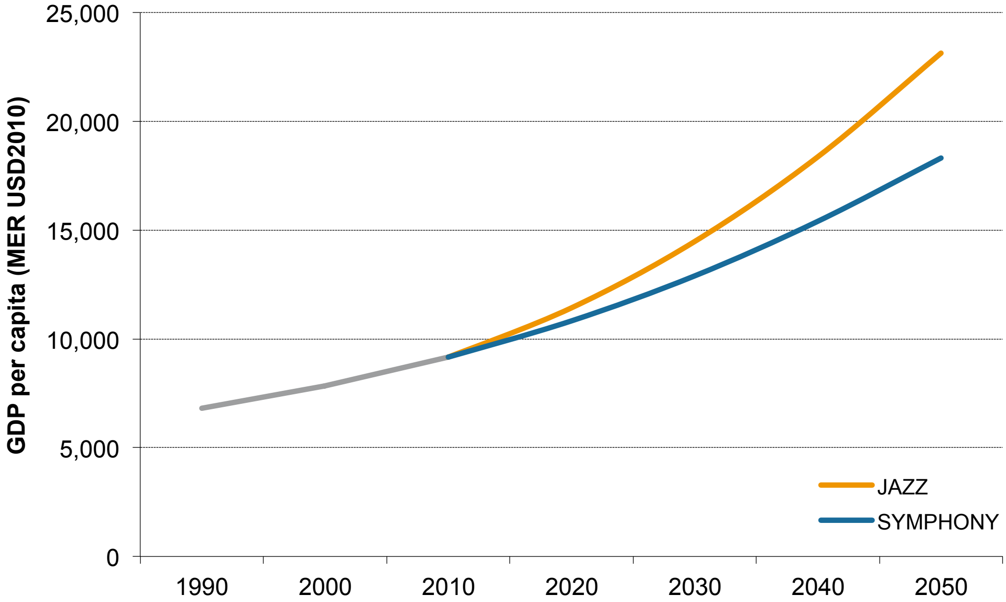
The WEC's view on electrification and the share of electricity in final energy until 2050

Figure 14 – Electrification: Share of electricity in final energy (excluding non-energy uses)

Source: World Energy Council (2013); WEC/PSI projections; IEA (historical data)

Historical data: IEA World Energy Statistics and Balances

Source



Notes: Final energy includes coal use in coke ovens, blast furnaces and gas works; final energy also includes non-commercial biomass.

Industry

Industry is relatively efficient, compared to other sectors. In energy-intensive industries such as chemicals, paper, steel and cement manufacturing, cost-effective efficiency gains in the order of 10% to 20% are already possible using commercially available technologies. Energy efficiency tends to be lower in regions with low energy prices. Cross-cutting technologies for motor and steam systems would yield efficiency improvements in all industries, with typical energy savings in the range of 15% to 30%. Achieving deep cuts in energy consumption will require the widespread adoption of current best available technology, as well as the development and deployment of a range of new technologies, such as smelt reduction, near net shape casting of steel, new separation membranes, black liquor gasification and advanced cogeneration.

Power generation

Energy efficiency in power generation will improve as the ageing equipment is replaced by new generation capacity and infrastructure (such as supercritical coal-fired generators or combined-cycle gas turbine plants). Therefore, it is important to ensure that energy efficiency is taken into account and that new capacity reflects the best available technology. Analysis shows several opportunities to realise significant gains in efficiency in electricity generation from combustible fuels. Finding ways to reduce the heat loss associated with creating steam to move turbines would be a major step forward. The age of a country’s power plants is an important factor, as the current efficiency of most coal-fired power plants is well below state-of-the-art. A gradual replacement of smaller subcritical, coal-fired units should be considered, along with retrofitting larger-scale plants to achieve higher efficiencies (preferably greater than 40%).

Natural gas fuel cells for distributed generation or back-up power are currently used in demonstration projects. Fuel cells and other emerging decentralised power generation technologies are expected to raise overall fuel efficiencies, but require further research development and distribution (RD&D). Commercially available natural gas fuel cell systems are emerging in some areas in developed countries. For example, in Japan more than 50,000 units are already sold from financial years 2009 to 2012 with the support of its government. One of the makers is going to expand its business in Europe.

Use of advanced steam cycle or integrated gasification combined-cycle (IGCC) technologies could raise the average efficiency of coal-fired power plants from 35% today to 50% in 2050.

Greater use of (high-efficiency) cogeneration, including from municipal waste treatment plants, and district heating and cooling can make an important contribution to energy efficiency. Priority access for electricity from CHP is a way to improve the energy-saving performance of CHP systems.

An important aspect in the future of energy efficiency in power generation will be to tackle the effective recovery of heat losses from electricity and industrial production processes, since unused energy-saving potential is far from being exhausted. Reducing transmission and distribution losses is also an important means of improving efficiency in the electricity generation sector. In 2006, such losses represented 10% of final electricity consumption worldwide. The situation improved in IEA member countries: overall losses fell from 9% in 1990 to 7% in 2006. The European electricity industry association, EURELECTRIC, stated in its 2011 report More is Less: The role of electricity in energy efficiency, that there is a clear need to implement innovative solutions in the transmission and, in particular, distribution networks. Although such innovative technology already exists, more effort needs to be made in the implementation phase. The technology is currently mainly implemented in pilot projects. Looking ahead, smart grids will, in the medium term, provide an intelligent platform for a smooth integration of distributed generation, renewable energy sources, electric cars and plug-in (hybrid) cars into the electricity grid. This would result in a reliable infrastructure for demand-side participation by customers and a higher overall system efficiency.

The WEC has proposed in the past a set of 10 main recommendations to improve the implementation and effectiveness of energy-efficiency policies.

1. Incentive prices are needed to make investments in energy efficiency attractive and cost-effective for the consumer.
2. Sustainable institutional support is necessary to give long-term signals to market players.
3. Innovative financing schemes are needed to support consumers at a limited cost to the public budget.
4. The quality of energy-efficient equipment and services should be promoted.
5. Regulations need to be regularly strengthened, enforced and expanded.
6. Measures should be combined in complementary packages rather than implemented as single measures.
7. The situation in developing countries should be addressed adequately.
8. Consumer behaviour should be addressed as much as technologies.
9. The introduction and impacts of measures should be well monitored.
10. International and regional cooperation should be enhanced.

Jazz scenario

Energy saving and efficiency: Significant saving (higher prices/efficient markets) in order to reduce costs. Energy efficiency is driven by consumer demand for cost savings and technology improvements that are facilitated by labelling and efficiency standards. Efficiency brands become dominant in consumer minds (e.g. US Energy Star programme). Market initiatives around smart grids and metres and energy purchasing pools will help energy efficiency. Consumers are reluctant to invest in intangible savings. This will work against efficiency improvements. True costs reflected in market prices, in the absence of energy subsidies, will help encourage energy efficiency.

Symphony scenario

Energy saving and efficiency: In the Symphony scenario, governments focus on energy-efficiency and energy-saving programmes to combat the inability to invest in generation capacity. Efficiency is driven by government mandates, standards, and subsidies for new energy technologies and smart grids, metres and electric vehicles. Subsidised energy costs will work against energy-efficiency improvements.

Key scenario cluster 9: Technology developments

The WEC's view

Technology development and deployment is a key issue in providing a secure supply of accessible, affordable, and environmentally sustainable energy. Reliable and low-carbon energy depends on the development and deployment of one or more technology groups:

- Nuclear power.
- Clean coal power generation technologies, in particular carbon capture, utilisation and storage.
- Solar power and other new renewable technologies such as wind and marine.
- Second -generation biofuels, produced from biomass from marginal land.
- Fuels cells and technologies.
- Energy storage technologies, including batteries and hydrogen, which will facilitate the deployment of electric and fuel cell vehicles, and the introduction of large amounts of renewable electric power which is base load or weather and climate dependent, so cannot be easily matched to variable demand.
- Smart diesel fuel systems and other end-use technology developments.

Table 12 – Comparison of technologies in Jazz and Symphony

Source: World Energy Council (2013)

Technology	Jazz	Symphony
advanced clean coal technologies	driven by China and India ▲	
CO_2 capture and storage		infrastructure ▲
nuclear	▼ safety concerns	business as usual (BAU) response ▼
gasifier	▲ dash to gas	
gas turbines	▲ dash to gas	
wind, marine and solar		▲ with subsidies
large hydro		
bioenergy (second-generation)	subsidies and opportunity fuels are important ▲	
biofuel replacement of diesel/avgas		▲ government strategies
battery	▲ vehicle manufacturers	
electrolysis	sheddable loads	renewable storage
H_2 replacement of diesel/\vgas	▲vehicle manufacturers	
H_2 fuel cell	▲ efficiency programmes	
H_2 heat and electricity	▲developments from vehicle manufacturers	
electric heat pump industry thermal		▲ efficiency programmes
smart grids	▲ functionality	efficiency
other end-use efficiency	lower	higher

Jazz scenario

In the Jazz scenario, secure low-cost energy goes hand-in-hand with global development and energy access. With global development comes a move towards a global price for carbon. This will emerge as part of free trade development and aid negotiations. The global carbon market will be bottom-up from local, national and regional schemes. Technology choices are driven largely by price. Lead times are also important. Coal will remain an important fuel for power generation, especially in China and India. Carbon reduction will be initially by a switch from coal to gas, substitution of coal with wood and opportunity biomass fuels (from agricultural or industrial waste), and renewables (wind, solar, geothermal and hydro) in favourable sites. As the results of decarbonisation begin to register, the cheapest alternatives will increasingly be coal with CC(U)S and nuclear.

Markets will not be perfect and we will see project developers taking advantage of government incentives for many renewable technologies with sub-optimal economics.

In this scenario there will be opportunities for transnational mega projects with international investment, such as Grand Niger, and Sahara solar energy projects.

Prices will drive development of smart grids and other demand-side initiatives.

Entrepreneurs will be quick to pick up on opportunities where there are interventions such as subsidies and feed-in tariffs. They will tend to promote the next available option in renewables rather than evenly advance all technologies.

Technologies: Technological innovation is market driven by companies with significant R&D budgets. Emerging innovation centres attracting and competing for investment capital and human resources. Original equipment manufacturers develop transport solutions most wanted by consumers.

Clean coal technologies: Power-generation efficiency increases (faster in developing countries as they are starting from lower levels, compared to developed countries where efficiency is already high). Subcritical share drops while the shares of supercritical and ultra-supercritical increase. This means higher efficiency and lower emissions. IGCC and coal with CC(U)S increases (more in developed countries) as carbon pricing justifies.

Gas generation: Further development of CCGT technology with hydrogen turbines. Molten salt fuel cells become an option. Power to gas makes significant contributions.

Carbon capture and storage: Large-scale CC(U)S happens first in the US with an infrastructure developed for CC(U)S – EOR – being used for CC(U)S for coal generation CO_2. This swings power generation in the US back towards coal, with gas going to exports and petrochemicals.

Cyber physical systems (CPS): Competitive markets will promote more CPS as they reduce costs of building and operating systems, make systems safer and more efficient, and allow individual machines to work together to form complex systems that provide additional capabilities (automotive, avionics/aerospace, industrial automation, telecommunications, consumer electronics, intelligent homes, and health and medical equipment, electronics). CPS are functions of R&D and available financing.

Transport intermodal: Individual transport solutions. Solutions are more short term and lack wide perspectives. Rail and bus companies are privatised. Operation of public transport is privatised. High fuel-efficiency measures implemented by operators. Electrification of urban public transport remains dependant on government policy support. Transport options from industrial hinterland to urban centres widen.

Air traffic/freight: High growth of air traffic and freight sector. Dependent on petroleum. Increasing fuel economy. Heavy freight (road and marine) shift into gas.

ICEs: High efficiency ICEs.

Hybrids: Gas internal combustion engine vehicles (ICEVs) increase.

EVs: Oil is still a necessity for most transport demand, even in 2050. Introduction of urban EVs due to air quality concerns in developing country megacities. Intra-city personal transport solutions viable only post-2030. Crucial factors will be battery capacity, charge times and infrastructure, range, performance and cost.

CNGs: Road freight shifts into gas and diesel co-firing engines in some areas because of price competitiveness of natural gas. Because of the requirement by international organization to use low sulphur marine fuel, a similar trend in marine engines also will be seen. Growth increases after 2020.

Fuel cells: There is a small breakthrough with fuel cells as they are still expensive, but with efficient use of fuel, fuel cells may be popular in areas where fuel price is high.

Solar: Solar technologies take off, promoted by future and emerging technologies, subsidies and net pricing in Europe, and tumbling prices. The technologies are used in India, Africa and other countries to bring power to rural and off-grid communities.

Biofuels: Growth depends on the interaction between ethanol and sugar markets, biofuels mandates, tolerance for biofuel crop cultivation in Asia, and price of oil.

High speed rail: Will take off in Asia and North America.

Vehicles ownership: Increasing vehicle ownership.

Aviation, shipping, rail and trucks High growth for both passenger and freight transport, especially in Eastern markets. Electrification of rail. Aviation dependent on jet fuel. Trucks and ships increasingly use gas.

Symphony scenario

The driving forces for technology choices in the Symphony scenario will be national energy and environmental strategies. There will be less development of unconventional gas because a global price does not develop. While national priorities will take precedence, there will be a voter expectation of international negotiations to solve the energy trilemma, which will progress towards cross-border carbon trading and development assistance from developed to developing countries.

Most countries will have proactive energy-efficiency policies, promote smart grids or other demand-side measures to manage the intermittency of supply issues from new renewables, rather than providing consumer benefits.

Some countries will promote nuclear, some renewables wind solar and bioenergy, and some coal with CC(U)S. This means there will be a broad range of technologies adopted; many of them will not be the cheapest options. These government initiatives may have a mixed effect on technology prices.

The different priorities of different countries could result in:

- Some countries developing local renewable technology industries taking advantage of measures such as feed-in tariffs and biofuel incentives.
- Countries that use command and control measures becoming early developers of CC(U)S building an infrastructure which gives them a lead in this area.
- Countries either continuing nuclear development programmes, or deciding to phase out nuclear plants and cancel new developments.
- Countries developing unconventional gas for national markets, while others decide not to explore or exploit their gas.
- Different countries will develop different strategies for decarbonising transport based on some or all of biofuels, electric and hybrid vehicles, fuels cells and a hydrogen infrastructure, and changing transport modes. Local factors such as urban pollution, megacity growth, the mix of the electricity generation fleet and the local energy resources base, will all have an influence.
- Some countries will impose carbon taxes, others will develop or join emission trading schemes, while others will put in place technology or resource targeted plans to abate GHGs.
- In this scenario, more expensive renewables could be favoured with technology developers chasing government subsidies and feed-in tariffs.

Technologies: Governments pick technologies. There is a higher level of low-carbon technology transfer into developing nations. Increased state subsidies sponsor focused research programmes into new transport technologies. High degree of technology transfer into sectors that benefit the public (health, water, energy, infrastructure) – with success dependent on the funding capacity of governments. Multilateral sponsorship programmes are driven by achieving millennium goals.

Clean coal technologies: Government directives drive increases in power-generation efficiencies. Impact is higher in developing countries. Significant drop in share of sub-critical coal fired technologies, while supercritical and ultra-supercritical technologies will increase due to higher efficiency and lower emissions. IGCC and coal with CC(U)S increase (more in developed countries) with government support.

Gas generation: Further development of combined cycle gas turbine (CCGT) technology. Coal is preferred where CC(U)S becomes the norm, and gas supplies are politicised.

Carbon capture and storage: Large-scale CC(U)S happens first in Europe with North Sea nations collaborating to build an infrastructure for storage under the North Sea.

Cyber physical systems (CPS): Lower penetration of CPS as financing and R&D are subjected to government approval and funding. Governments will pick CPS technologies to suit their individual needs.

Transport intermodal: Stronger emphasis on public transport solutions. Solutions are long term with wide perspectives. Public transport monopolies emerge. Electrification of public transport mandated by government policy. Transport links between hinterland and urban centres are more developed than in the Jazz scenario.

Air traffic/freight: Lower growth. Technology remains dependent on jet fuel. Lower fuel economy measures.

ICEs: Slower pace of fuel-efficiency developments in ICEs. Decreasing market share.

Hybrids: Moderately high share of hybrids in light domestic vehicles sector.

EVs: Earlier penetration of EVs and more use of electricity in public transport fleets. Efficiency and performance of electric vehicles transforms the energy demand landscape. The impact is visible after 2025. Lower transport emissions in developed countries (assuming CC(U)S is used for fossil-fired power generation) in the long run. Main emerging economies avoid mistakes of the developed world, thereby 'leapfrogging' technologies. Starts with public transport fleets. Subsidised government incentives for company fleets to be electrified.

By 2050, the WEC expects EVs (both battery electric vehicle and plug-in hybrid electric vehicle (PHEV) to account for around 35% of passenger light domestic vehicles. This is subject to significant improvement of grid systems. Electricity, along with other alternative fuels (natural gas, hydrogen and biofuels) account for over 30% of energy use in cars by 2050, with gasoline consumption around 40% lower compared to 2010, despite more than twice as many cars on the road.

CNGs: CNGs significantly emerge in transport solutions early on, in areas with access to domestic gas reserves. State mandated usage will increase.

Fuel cells: Fuel cell development continues, supported by governments, and vehicle manufacturers responding to government incentives. There are CNG fuelling stations and also conventional gas stations are converted to fuel – both natural gas/gasoline and hydrogen. The heavy transport sector fuel cells are the most economical, replacing diesel engines in the heavy vehicle sector.

Solar: Solar technologies take off, promoted by future and emerging technologies, subsidies and net pricing in Europe, and tumbling prices. The technologies are used in India, Africa and other countries to bring power to rural and off-grid communities. Subsidies for solar are higher in Symphony than they are in Jazz.

Biofuels: Use of biofuels continues as government mandates fuel blending. Success hinges on growth in the second-generation biofuels sector.

High speed rail: Penetration of high-speed rail networks at a larger scale, especially in the second half of scenario period.

Vehicles ownerships: Less car ownerships and more reliance on public transport systems. Strong emergence of car sharing in developed countries.

Aviation, shipping, rail and trucks: More moderate growth levels as global trade is not as high. Rail is highly electrified. Trucks make use of electric engines, but also CNG and LNG technology. Marine engines use CNG technology.

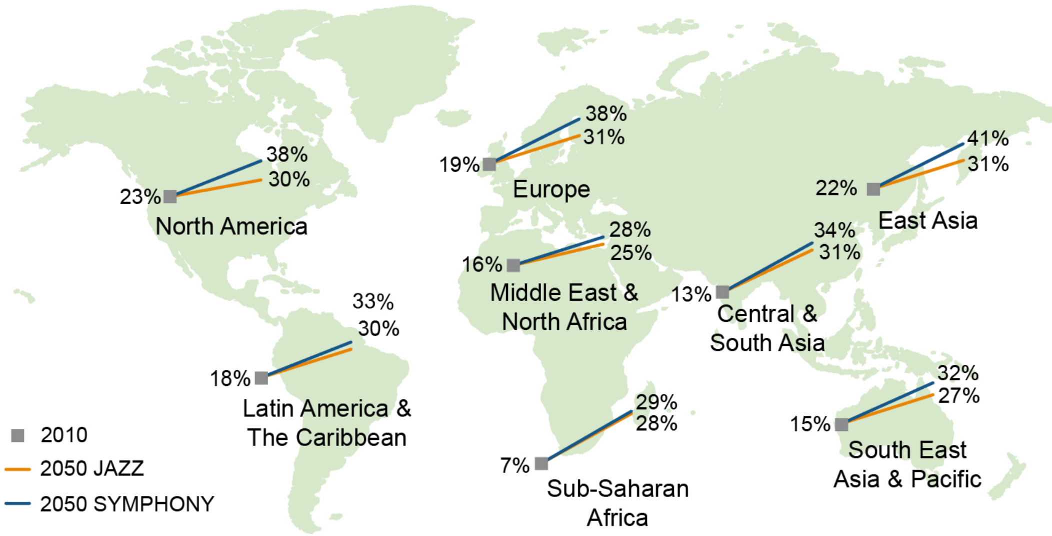
The role of electricity and natural gas in final energy are depicted in Figure 15, together with the WEC's assumptions regarding the percentage of electricity in final energy.

The WEC's assumptions on the percentage of electricity in final energy and the role of electricity and natural gas

Figure 15 – Electrification of demand (% of final energy consumption)

Source: World Energy Council (2013)

Historical data: IEA World Energy Statistics and Balances



Jazz: **Increasing role of electricity**	**Symphony:** **electrification supports efficiency**
• High demand for electric appliances worldwide. • Electrification of industry in non-OECD countries. • Rapid electrification of Africa and Southeast Asia.	• Supports in energy-efficient equipment, cooling/heating appliances in services sectors. • Fuel switching from fossil fuels to electricity to reduce emissions in final consumption.

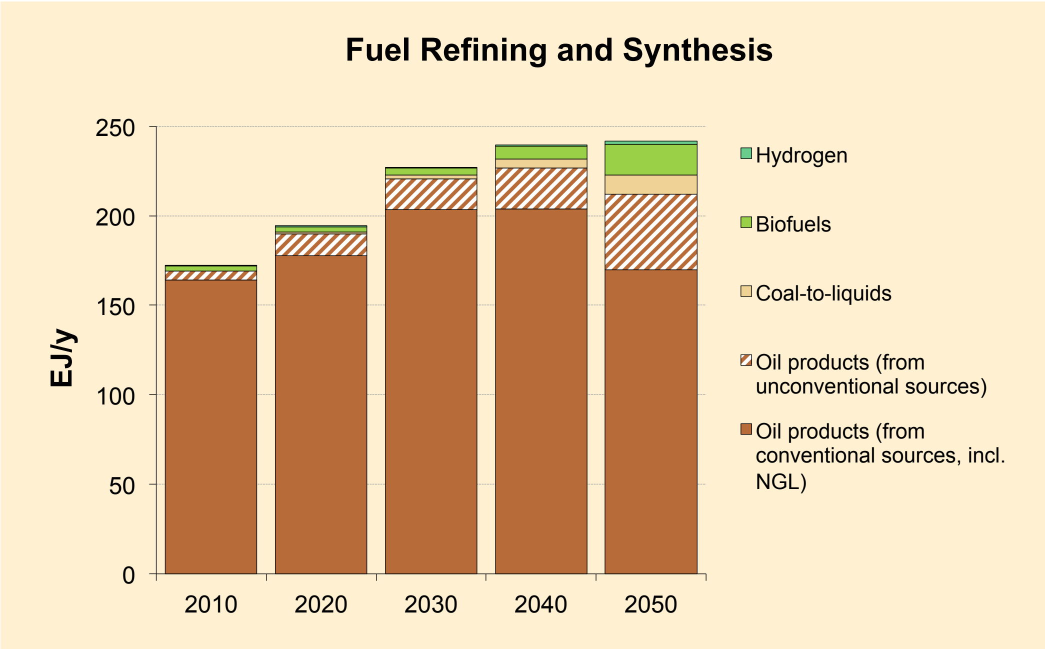
Note: Excluding non-energy uses

The WEC's view on fuel refining and synthesis until 2050

Figure 16 – Fuel refining and synthesis

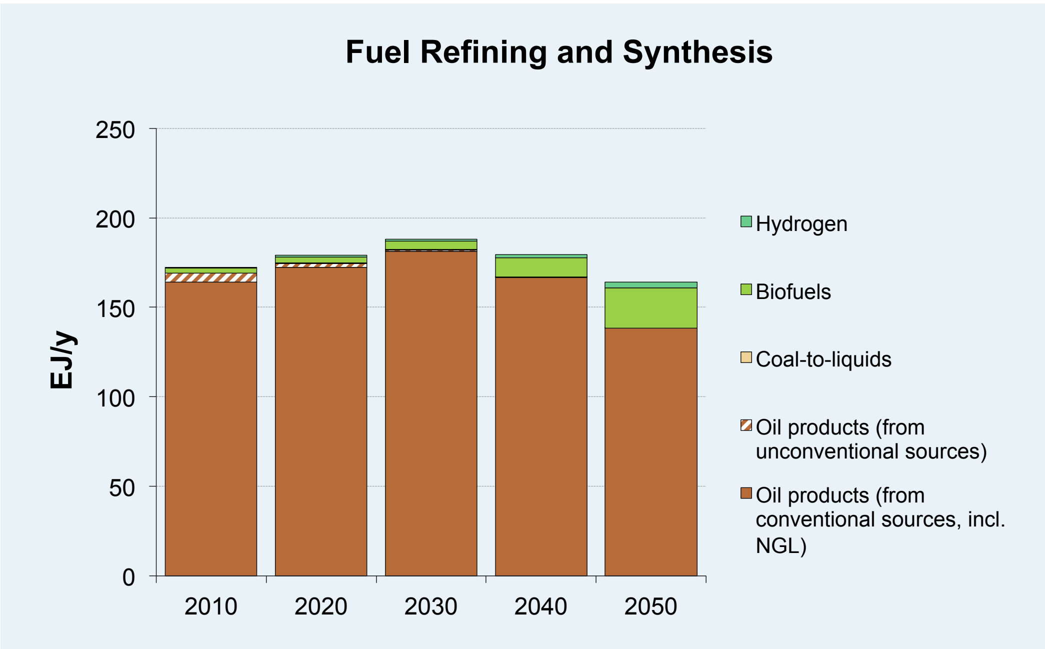
Source: World Energy Council (2013)

Historical data: IEA World Energy Statistics and Balances



Jazz

Supply surge. Increase in infrastructure post-2020. Biofuels depend on ethanol-sugar market, biofuels mandates, tolerance for biofuel crop cultivation, and price of oil.



Symphony

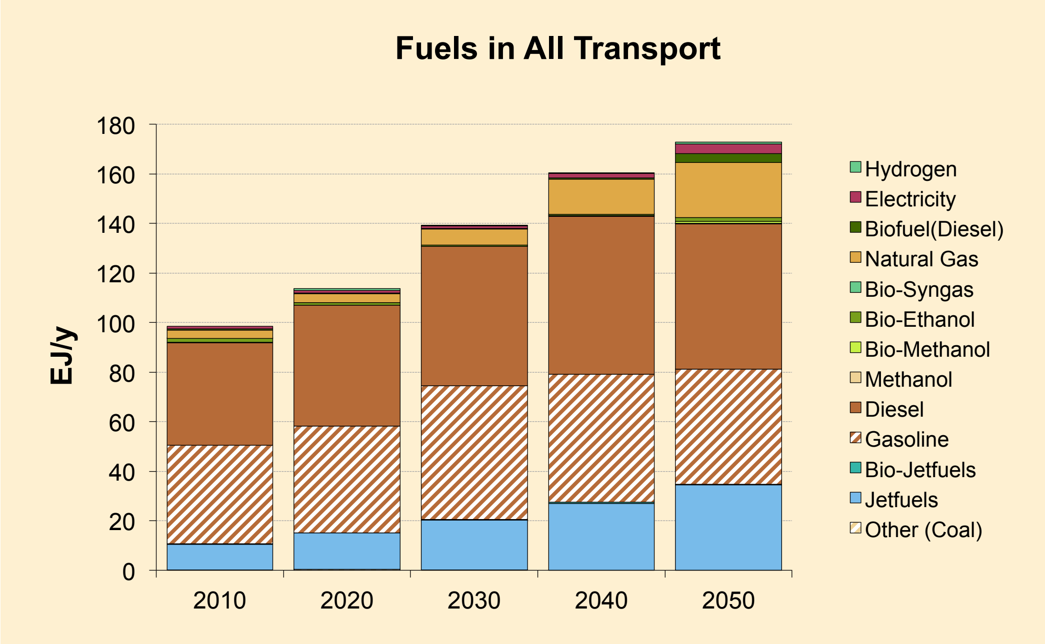
Use of biofuels with government mandates. Increasing contribution of first-generation biofuels. Large contribution of second-generation biofuels in the latter half of the scenario period.

The WEC's view on fuel use in transport until 2050

Figure 17 – Fuel use in transport

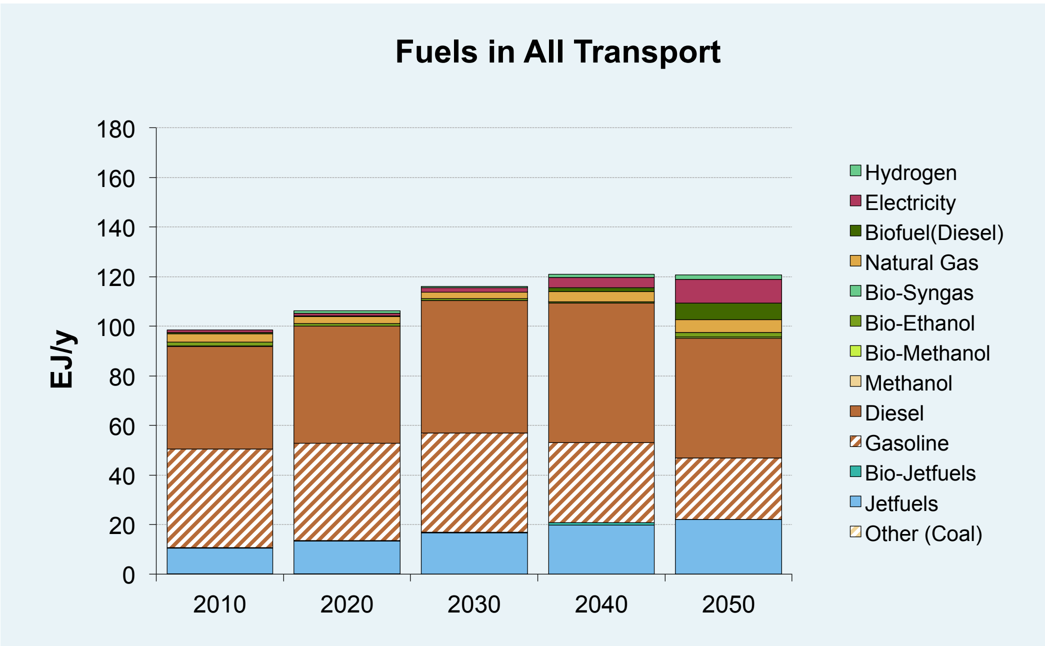
Source: World Energy Council (2013)

Historical data: IEA World Energy Statistics and Balances



Jazz

High growth in air traffic and freight. Road freight shifts to gas-diesel (regional), with increasing car ownership.



Symphony

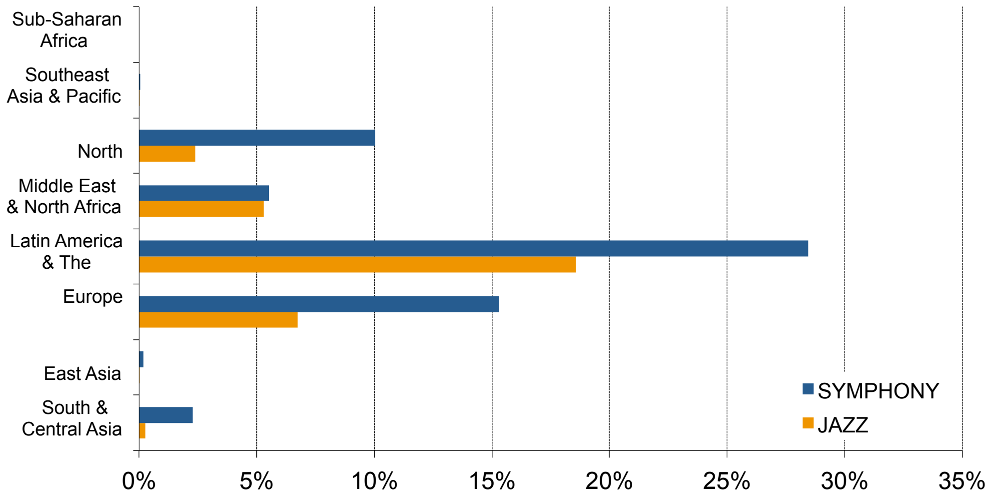
Lower growth in air traffic. Use of biofuels continues (mandates). Light domestic vehicles: smaller increase in car ownership; increased hybrids/EVs.

WEC's view on the share of alternative fuels in transport in 2050 by region

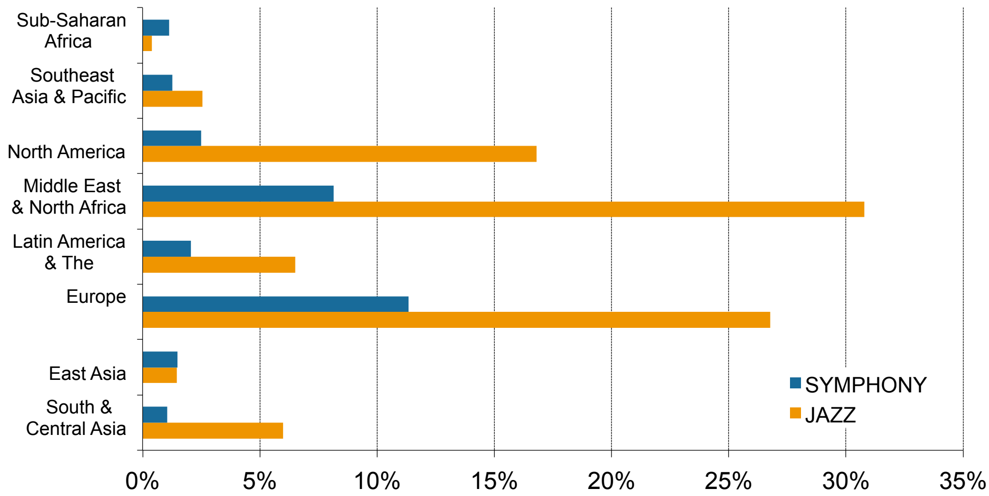
Figure 18 – Share of alternative fuels in transport in 2050 by region

Source: World Energy Council (2013)

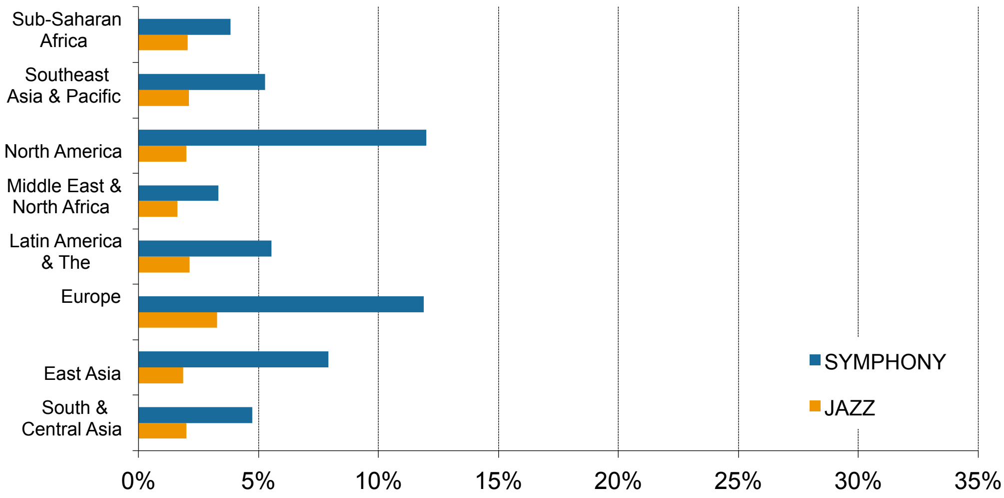
Biofuels



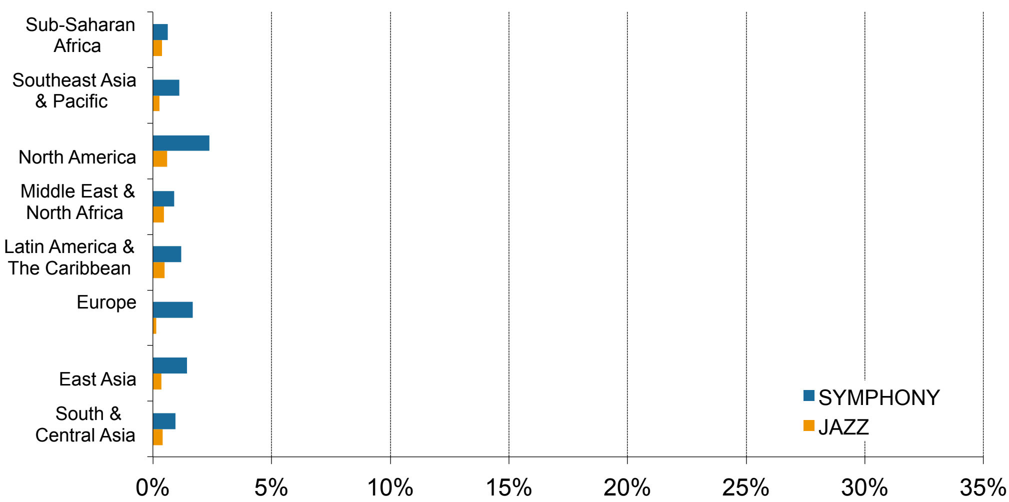
Gas



Electricity



Hydrogen

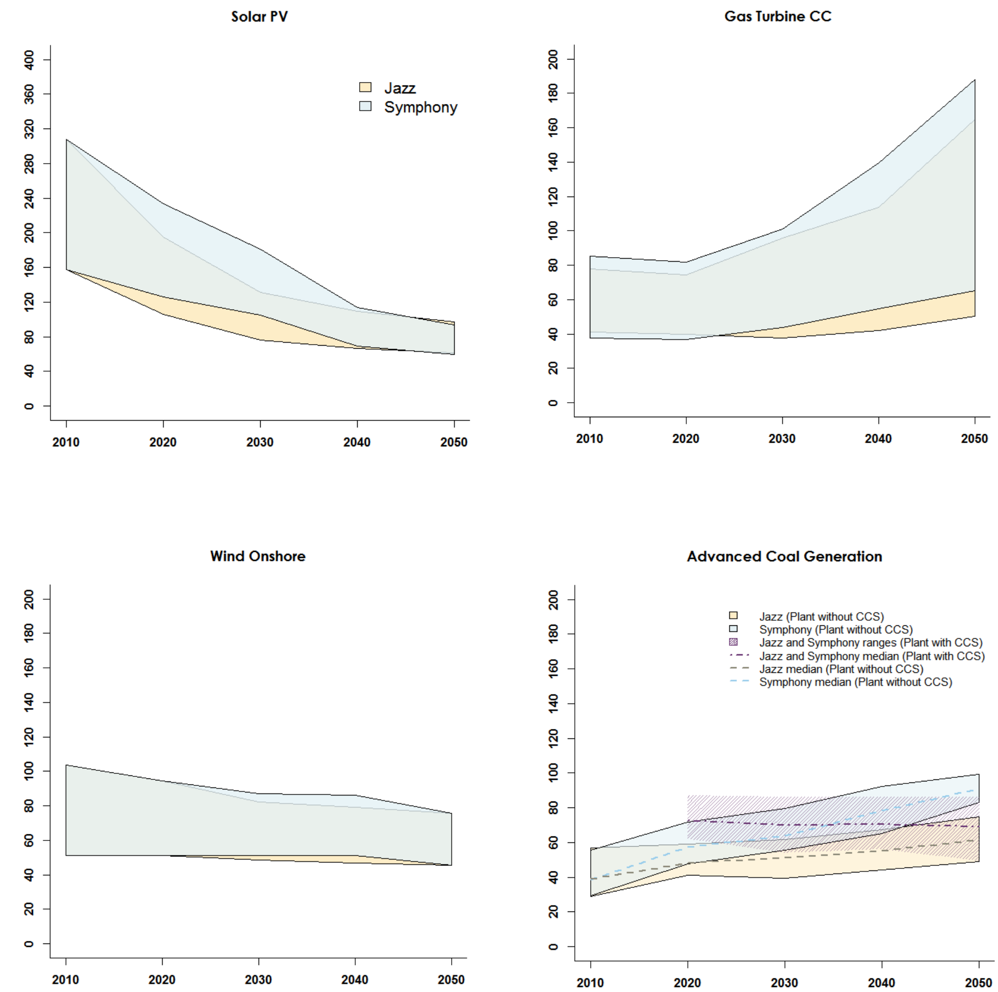


Jazz: Gas in transport	**Symphony: Electrification of transport**
• High efficient ICEs → limited penetration of alternative fuels. • Gas ICEVs increase. • Road freight and marine engine shift into gas and diesel co-firing. • Biofuels emerge in Latin America and Europe.	• Emphasis on public transport solutions (e.g. high speed rail). • Slower pace of efficiency developments in ICEs. • More use of electricity and biofuels to reduce sector's emissions. • CNG emerges but limited compared to Jazz.

The WEC's assumptions of technology cost developments (including endogenous technology learning in terms of their levelised electricity generation costs for selected key technologies, in US$2010/MWh) are displayed in Figure 19.

Figure 19 – Scenario levelised electricity generation costs for selected key technologies (US$2010/MWh)

Source: World Energy Council (2013)



Note: levelised costs for gas- and coal-fired generation include the scenario carbon costs. Subsidies are excluded. The figures show the range of levelised costs across different world regions (representing regional differences in costs, efficiencies, availability factors, and carbon prices). The future levelised costs depend on technology learning, and changes in fuel and carbon costs.

The median CO_2 avoidance costs for fossil electricity generation technologies incorporating carbon capture and storage (post- and pre-combustion coal, post-combustion gas) equate to US$40-–80 (US$2010)/t-CO_2 in 2020, decreasing to around 30–60 US$2010/t-$CO_2$. This includes CO_2 capture, compression, transportation and storage.

Key scenario cluster 10: Security of supply

The WEC's view

Available, reliable, and affordable energy make up the engine that drives a country's economic growth. Without all three, the engine cannot be started. Without one or the other, the engine is limited in how far and fast it can go. So well understood is this concept that treaties are signed, militaries are deployed and wars even fought to ensure that energy resources can be deemed secure and thus markets emboldened to invest and grow. Countries must balance the priorities of economic competitiveness, energy security and environmental stewardship.

While these priorities don't stand in isolation to one another, they are often prioritised depending on the global, regional or national circumstances at any given time. From 1997 to 2001, the Kyoto Protocol seemed to be priority number one. The threat of global climate change was centre stage with mounting scientific evidence and thus international pressures rising to sign treaties to limit and reduce GHG emissions. In addition, the world's economies were booming and the globe was relatively peaceful. Thus, energy security played a secondary or tertiary role to environmental stewardship and economic concerns.

Several developments have begun to turn the attention away from environmentally led policies towards energy availability, reliability and affordability. Such developments include:

- the wars in Iraq and Afghanistan
- scandals about the reliability of the science underpinning the need to address climate change as being man made and an imminent threat
- subsequently failed policies, to curb GHG emissions globally (although, there have been declines in CO_2 emissions in some regions – such as the US – due to a move from coal-fired electricity generation to natural gas-fired generation)
- the earthquake and tsunami-induced nuclear tragedy in Japan
- increasing pressure on policymakers to address the deep, widening and prolonged economic recessions around the world.

Since the wave of worldwide recessions began in late 2008, the topic of energy supply security has made its way back to priority number one. Accordingly, public policymakers around the world have turned their attention to producing more energy from within their borders, accelerating the commercial scale deployment of non-fossil-based fuels, and overall seeking policies that support a broad portfolio of energy sources as part of their overall mix of usable energy.

Energy demand around the world is projected to double by 2050. While it remains unclear how lasting the current economic crisis will be, and the exact impact on such energy demand projections, one thing is clear: countries rely on energy to drive their economies, to feed their populations, and to position themselves for leadership around the globe. Thus, countries will take virtually any means plausible and politically palatable to ensure they have ample and secure supplies of energy to economically prosper.

Jazz scenario

Security of supply for power generation

- **Coal fired:** High electricity demand growth will result in using all possible generation capacities and technologies. Coal-fired power generation is expected to remain dominant in developing China and India. Newly built infrastructure (or 'new build') is increasingly likely to be advanced supercritical or IGCC. Gas will be preferred for new build in developed countries.
- **Gas fired:** Growth in unconventional gas means the share of gas in power generation increases in North America. As the global market for pipeline gas and LNG develops and as further countries develop shale gas resources, there is a global shift to gas from both coal and nuclear. Gas is also a favoured option for backing up intermittent renewable generation.
- **Oil fired:** Oil-fired generation is expected to be eliminated as it is one of the most expensive means to generate electricity.
- **Nuclear:** Bulk of growth in nuclear will come from developing countries and from those countries who already have it (replacement of existing infrastructure, moderate newly built infrastructure. Global scrutiny for safety and design standards means the cost of nuclear will rise.
- **Renewables:** Will remain mostly hydro. Both the share and absolute values are expected to increase. Subsidies in renewables are almost the only remaining subsidies. The growth in solar is expected to remain the highest. Intermittent renewables will be accommodated by market mechanisms at the generator, transmission and distribution markets. Long-term consumer may adapt to price changes via smart grids.
- **Supply sources:** Free trade in energy is promoted, encouraging E&P activity, including unconventionals. Many countries open their upstream sectors, resulting in a surge of supply. (East Africa, Arctic, Australia). Availability of better technologies results in a surge of supply. EOR technological development continues. More security of supply and demand as a result of more producers. Oil and gas pipeline infrastructures are expected to develop on a larger-scale post-2020. Renewables are expected to join the energy mix gradually, depending on cost competitiveness.

Symphony scenario

Security of supply for power generation

- **Coal fired:** The share of coal-fired generation is expected to drop while the absolute value may increase in the early part of the scenario period. This drop is dependent on government policies to promote alternative technologies (renewables, nuclear) and reduce emissions at local levels. Coal-fired technology, especially advanced supercritical, is expected to remain active in the early part of the scenario. CC(U)S increasingly required on new build.
- **Gas fired:** The share of the gas-fired power generation is expected to rise but later drop at the expense of increasing renewables capacity (especially solar and hydro).
- **Oil fired:** This form of power generation will be phased out.
- **Nuclear:** Nuclear will increase in absolute value and share. This decision is led by governments, especially in developing countries. More local and regional scrutiny for safety and design standards.
- **Renewables:** Hydro-power potential in emerging countries will be exploited thanks to government action. New renewable projects are state funded. More stable and quicker transition to renewable energy due to government regulations. Growth in solar PV will be significant. Middle East and North Africa invest in solar

as a cheaper alternative to oil-fired generation. Countries or grids with hydro or diversity of loads can most readily accommodate intermittent renewables.

- **Supply sources:** Tighter supplies as E&P activity is lower. Higher infrastructure costs as early integration of renewable energy occurs. Security of supply and climate change concerns motivate the drive to reduce dependence on fossil fuels. Renewables are expected to capture significant market share thanks to strong government support.

Key scenario cluster 11: China and India

The WEC's view

The WEC believes that China and India will be the most important countries to make the biggest changes to the overall energy landscape up to 2050.

In 2007, the GDP growth rate of India was 9.7%. During the same year, the GDP growth rate of China was 14.2%. The total primary energy demand of China is expected to double by 2035, and that of India to increase by almost 150% during the same period. Both these countries have embarked on a course of high economic growth and will need to fuel that growth into the next decades with increasing consumption of energy resources. Both India and China will continue to consume more and more energy resources, as indicated by their GDP per capita growth and from their energy-use pattern. Both China and India, the two most densely populated countries in the world, are fully aware of the energy challenges they face. They have begun to acquire and invest in oil and gas resources, both domestically and abroad. This competition for energy resources has led to concern in developed countries that if China and India continue to grow at current rates, an oil supply crunch will occur in the near future.

China

China has responded to this by intensifying its overseas investment activities. Chinese overseas energy investment is mainly carried out by the China National Petroleum Corporation, China Petroleum & Chemical Corporation (Sinopec), and China National Offshore Oil Corporation. In 2009, mergers and acquisitions deals by these Chinese companies represented 13% of total global oil and gas acquisitions and 61% of acquisitions by NOCs. In 2010, China spent US$ 29.39 billion on energy acquisitions, an increase of 61% over the previous year.

According to the IEA[9], China's NOCs have expanded their overseas equity shares from 1.1mb/d in 2009 to 1.36mb/d in 2010, while the domestic production in China in 2009 was 4mb/d. A Eurasia report[10] estimates that only about 10% of China's oil imports come from equity oil. The bulk of China's equity oil is sold on international markets. Domestic Chinese oil production has risen steadily and is nearing its peak. China also started construction of international pipelines from Myanmar, Burma, which allows China to import oil and gas without passing through the Strait of Malacca where risks of sea traffic congestion and sea-jacking exist. As a consequence, China is becoming more and more dependent on oil imports. China became a net oil importer in 1993. From 2001, Chinese energy use has sharply increased and shows no signs of slowing.

China has been prospecting for oil resources since 1993, when it acquired a block in Thailand. Since then it has acquired significant assets in Kazakhstan, Sudan, Angola, and Iran. China has also been looking into adding to its portfolio by picking up assets in West Africa, Iraq, and LAC countries like Bolivia, Ecuador, and Venezuela. China has also been expanding its gas portfolio and an important addition has been the Central Asian pipeline which will bring 40 bcm of gas from Turkmenistan's South Yolotan gas field and other Commonwealth of Independent States (CIS) countries (Uzbekistan and Kazakhstan) into China. The capacity of this pipeline exceeds that of Nabucco by 25% and creates a link between the gas markets of Europe and Russia.

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9 Overseas Investments by Chinese NOCs – Jiang & Sinton, IEA 2011.
10 China's overseas investments in oil and gas production, Eurasia Group.

China has also acquired liquefaction projects in Indonesia and Australia so that it can increase its presence in the LNG global market. China aims to increase the contribution of gas in its energy mix from 4% (2009) to 8.3% in 2015.

Apart from investment in conventional energy source, China has also been investing in unconventional energy and in August this year announced that shale gas is a strategic priority. The energy ministry stated that China may hold 31 tcm of recoverable shale gas reserves based on rough estimates, citing an initial appraisal that covered 1.5 million km^2 of shale-gas-rich areas. China has also made investments in the Canadian oil sands sector. SinoCanada Petroleum, a subsidiary of Sinopec is developing the Northern Lights Project along with Total. The latest estimate of contingent resources of the Northern Lights Project is 1.08 billion barrels of bitumen to be recovered using mining techniques. Chinese energy companies and their subsidiaries are said to be heavily invested in the Northern Gateway dual pipeline in Canada which will export around 525,000 bpd of oil from Alberta to the LNG marine export terminal in Kilmat, British Columbia. It will also import condensate at the rate of around 193,000 bpd.

India

The current economic situation in India can be characterised by its rapid population growth, related ageing and urbanisation. There is unparalleled growth in India combined with increasing population growth, due to increasing fertility, rising age expectation and increasing urbanisation. While China is expected to overtake the US to become the world's largest economy by 2020, China is likely to be overtaken by India by 2050. It is anticipated that this will lead to a resource crunch – i.e. a widening gap between domestic energy resources and demand, especially for coal, but also oil and natural gas.

The societal impact will hit India hard. B-S-P – bijli, sadak and pani supporters – might get increasingly impatient due to rising income inequity and the lack - of clean, reliable and affordable energy. These factors might act as deterrents in societal development, potentially leading to social unrest due to persistent energy poverty. There is unmet demand in rural areas, lack of electrification, power outages/scheduled power cuts. And there is a huge latent potential demand for electricity still untapped.

Looking ahead, the power sector faces the following key challenges:

- Coal is the mainstay of India's energy sector and accounts for more than 50% of primary commercial energy supply, 69% of total primary energy supply (TPES) comes from coal-based thermal power stations. India's coal imports have more than doubled over the last five years, leading to growing import dependency.
- Meeting future demand: primary energy supply needs to be increased four to five times and electricity generation capacity/supply by six to seven times up to 2030/31 (as compared to 2003/04), demand could reach 1500 GW by 2050.
- India is one of the lowest GHG emitters in the world on a per capita basis. The country is vulnerable to climate change and has a strong interest in having a fair and equitable global agreement for minimising the risk of climate change. India has announced its intention to reduce the emissions intensity of its GDP by 20–25% over the 2005 levels by the year 2020.

In terms of an outlook for the future:

- India needs to find a way to ensure energy and environmental sustainability without compromising on its economic and social development. Energy has to be available at affordable prices and equitable access to all sections of society has to be ensured.

- India's principal challenge is to manage the demand-supply deficit through the following potential actions: 1) more efficient exploitation of indigenous fuel reserves; 2) the adoption of alternative sources of energy supply including de-carbonisation of electricity generation; and 3) increased energy efficiency across the whole energy value chain.
- Targets and incentives for renewable energy have been laid out in the Prime Minister's National Action Plan on Climate Change: the aim is for 15% renewable contribution to the electricity generation mix by 2020, development of solar power, and blending of biofuels to enhance energy efficiency. R&D spending has to increase across the power value chain.
- Electricity generation: all technologies, including nuclear are a part of the solution.

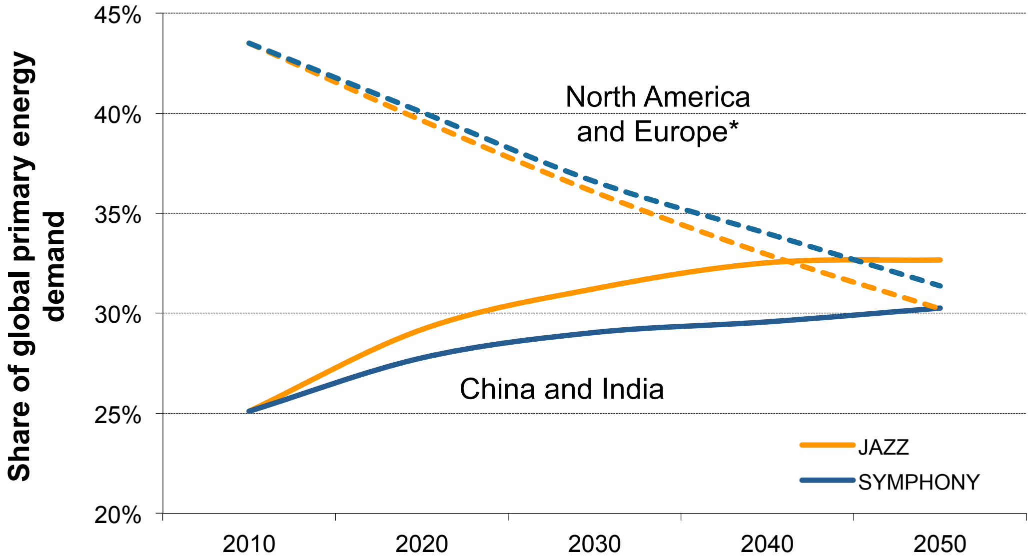
Figure 20 shows the long-term economic development of India and China in comparison to other regions in the world in terms of the share of global primary energy demand and share of primary energy demand. The graphs illustrate how these two countries move up to equal or surpass most of the (combined) developed world as the dominant global energy consumers.

Figure 20 – China and India in comparison to other regions

Source: World Energy Council (2013)

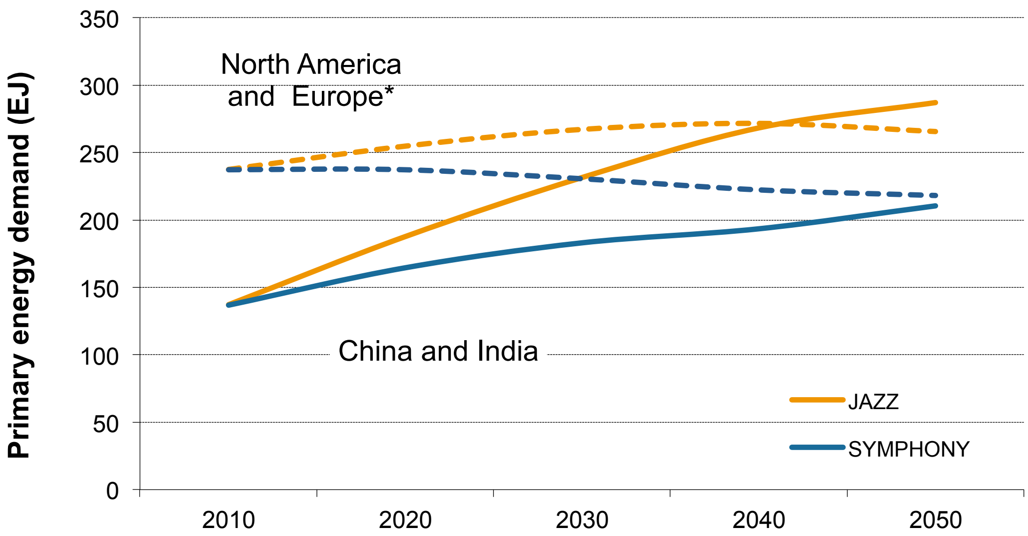
Historical data: IEA World Energy Statistics and Balances

Share of global primary energy demand



* combining Canada, the EU (and all other European countries), Mexico, Russia, Turkey, and the USA

Primary energy demand



* combining Canada, the EU (and all other European countries), Mexico, Russia, Turkey, and the USA

Jazz scenario

China: Demand is domestically driven. China will have to compete with the rest of the developing world for natural resources. Low-cost production is still a strength. Inflationary increases are a problem for state-owned enterprises. China strives to enter product development phase and invests in R&D. There is extensive shale gas development in China.

India: India is facing unparalleled economic growth and increasing demand for oil, gas and coal as relatively cheap forms of primary energy. Natural gas is increasingly becoming important to India. India will become a significant player on the demand side in the global coal market. India will maintain its position as the fourth-largest energy consumer in terms of primary energy up to 2050.

Symphony scenario

Rise of China: Government protectionism to shield local producers will result in emergence of trade barriers. China will line up political and military capabilities to form regional alliances and secure natural resources to fuel its growth into the future.

India: The Indian economy continues to grow, regional governments and the central government put more emphasis on renewable energy sources.

Key scenario cluster 12: Energy poverty

The WEC's view

Energy poverty can be broadly measured by defining an energy poverty line as the minimum quantity of physical energy needed to perform basic tasks such as cooking and lighting. An alternative definition has been proposed, defining the energy poverty line as the threshold point at which energy consumption begins to rise with increases in household income. More concretely, the IEA has defined energy poverty as the lack of access to modern energy services including household access to electricity and clean cooking facilities (e.g. fuels and stoves that do not cause air pollution in houses), with overall energy consumption levels being smaller than 250 KWh per rural household and 500 KWh per urban household.

Approximately 1.267 billion people worldwide lack access to electricity, and 85% of them living in rural areas.[11] Although the UN Millennium Development Goals do not explicitly make a provision for energy, ensuring the availability and affordability of energy access to the world's poor will be a prerequisite to achieving all of the goals. The UN World Energy Assessment Overview: 2004 Update estimates that an annual global investment of US$10 billion will be needed to ensure 10 million new customers obtain access to electricity.

Around 1.3 billion people worldwide live on less than $1 per day. Their low income is not the only cause of their energy poverty; access to modern energy is the other main contributor. There are 2.7 billion people worldwide who rely on traditional fuels for cooking. These fuels mainly consist of firewood and/or animal dung. Related to their use of such fuels, which have an efficiency of 10–12% (compared to around 30–40% for LPG), is a high incidence of smoke pollution which is the main cause of mortality, especially in the sub-Saharan region. The IEA estimates that 1.2 billion people in sub-Saharan Africa, India, and other developing Asian countries will still lack electricity access in 2030. In spite of this continued lack of energy access, world demand for energy is expected to grow. The IEA expects this increase in demand to come from the developing countries – especially India and China. It expects oil to grow by 18% to 99mb/d in 2035, coal by 20%, and natural gas by 44%. Electricity demand is expected to increase by 80%.

As income levels grow, so does the corresponding energy usage. As energy use increases, the work output per unit of energy consumed also increases due to technological advancements, energy-efficiency measures, and amortisation of large-scale electricity generation projects. The share of GDP per unit of energy consumed has been increasing. This has been the same across high-, middle-, and low-income countries. Although the oil price increase in 1989/90 affected this, the trend resumed and has been increasing steadily, and is expected to do so in the future.

Looking forward, East Asia and Pacific and South Asia are the regions which are positioned for significant growth in energy consumption in the future. East Asia, particularly China, will become the future global leader in energy consumption as GDP per capita increases. India, although far behind China in terms of consumption, will be

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11 This estimate for 2010 is based on IEA World Energy Outlook databases on electricity access. This differs from some other estimates, such as those of the World Bank. Both IEA and World Bank estimates are reported in the recent Sustainable Energy for All analysis (World Bank 2013). The discrepancy between these 2010 estimates "can be ascribed to differences in a relatively small number of countries, including Pakistan, Indonesia, South Africa, Thailand, and Gabon, where the IEA uses government data (which typically report more people without access) while the World Bank uses estimates derived from various types of surveys" (World Bank 2013, p112).

increasing their consumption of resources. As the vast populations in these regions demand more and more energy, increasing stress will be placed on the global resource base and providing energy access will become more challenging. Another aspect of the changing energy landscape is the increasing trend towards urbanisation in developing countries.

Jazz scenario

Energy poverty: In the Jazz scenario, access to energy will increase due to the strong improvement of the economic situation. This will allow a lot of families to move above the energy poverty line. That is explicitly the case for urban areas where access to energy increases strongest in this scenario, due to the growth of megacities and high levels of urbanisation. In rural areas, the opening up of new off-grid markets with distributed generation technologies such as solar and wind will reduce energy poverty. In Jazz the number without access to energy drops to about a quarter of today's levels, mostly in sub-Saharan Africa.

Energy is not subsidised in Jazz, so affordability will still be an issue for the poor in most countries.

Symphony scenario

Energy poverty: In the Symphony scenario, government financing of infrastructure projects will result in an increase in energy access for the poor. Energy access may be limited due to government budgetary constraints. Governments may choose to invest in off-grid distributed generation to combat energy poverty in rural areas.

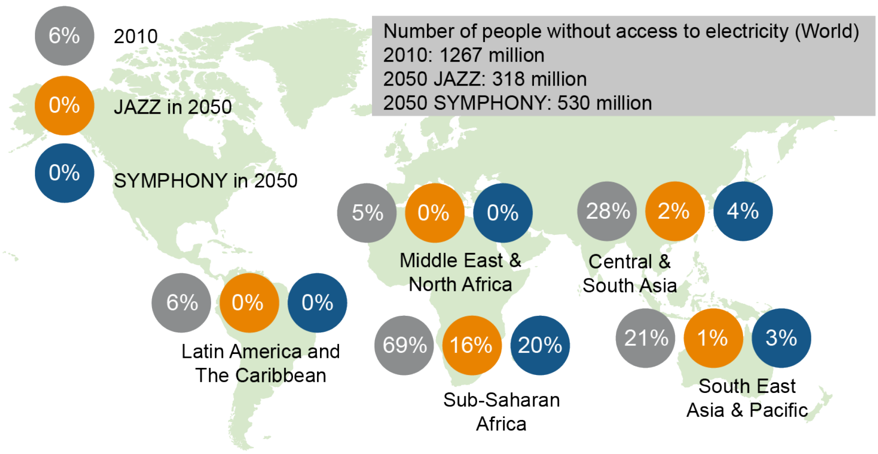
Because of lower economic development, access to energy only drops by about 50%, mostly in sub-Saharan Africa, but also in China and India. Fewer families will move across the energy poverty line, although this will be offset by energy subsidies and government helping energy affordability.

The WEC's view on the share of population without access to electricity in 2050

Figure 21 – Share of population without access to electricity

Source: World Energy Council (2013)

Historical data: IEA WEO 2000–2012



Jazz: **Increase in energy access**	**Symphony:** **Moderate increase in energy access**
• Good economic situation; high levels of urbanisation, but problem is not solved due to limited government role in infrastructure spending.	• Government financing of infrastructure projects, but access is limited due to government budgetary constraints.

Table 13 – Population without access to electricity (in millions)

Source: World Energy Council (2013), Historical data: IEA WEO 2000–2012

	1970	**1980**	**1990**	**2000**	**2010**
South & Central Asia	595	695	775	822	471
East Asia	565	576	455	47	22
Latin America & The Caribbean	129	130	108	55	29
Middle East & North Africa	90	94	94	29	20
Southeast Asia & Pacific	229	256	266	193	135
Sub-Saharan Africa	269	340	433	515	589
World	**1,877**	**2,091**	**2,131**	**1,662**	**1,267**

	Jazz				**Symphony**			
	2020	**2030**	**2040**	**2050**	**2020**	**2030**	**2040**	**2050**
South & Central Asia	341	226	124	45	380	264	181	102
East Asia	1	0	0	0	3	0	0	0
Latin America & The Caribbean	5	1	0	0	7	3	1	1
Middle East & North Africa	4	1	0	0	6	2	1	0
Southeast Asia & Pacific	90	49	21	8	106	74	44	26
Sub-Saharan Africa	570	455	341	266	596	542	433	401
World	**1,012**	**733**	**486**	**319**	**1,098**	**885**	**660**	**530**

Key scenario cluster 13: Energy sources in terms of reserves

The WEC's view

The WEC has comprehensively addressed the issue of resource availability in its World Energy Resources publication. The good news is that the world's energy resources endowment – both conventional and unconventional – is enormous. These resources are becoming increasingly challenging and expensive to access, produce, convert, and deliver to where they are needed in a cost-effective, secure, and environmentally benign manner.

Oil reserves

As of 1January 2011, proved oil reserves were estimated at 1,526 billion barrels. Almost a half (49%) of these reserves are located in the Middle East. The majority (83%) of the world's proved reserves are concentrated in 10 countries, of which only Canada, Russia and Kazakhstan are not OPEC members. Proved reserves have more than doubled since 1980 and have increased by one-third over the last decade. Half of the increase between 2000 and 2009 is due to Canadian oil sands reserves; the revisions in OPEC countries (particularly Iran, Venezuela and Qatar) of proved reserves is the other major factor. Unconventional oil resources are huge; most of them are located in Canada and Venezuela. Their exploitation is economically viable if and when the oil price is in line with IEA projections, even if their production costs are very expensive.

Gas reserves

Proven reserves of gas have increased steadily since the 1970s, as reserve additions have outpaced production by a wide margin, but have not evolved much over the past nine years (+10%). The largest increase over this period occurred in Turkmenistan, which has overtaken Saudi Arabia in the world ranking list. Remaining resources are large enough to meet the projected increase in global demand.

Oil and gas interdependence

Given the recent developments in unconventional oil and gas in North America, the world's largest energy market – the US – is moving towards self-sufficiency in these fuels. As a result, traditional suppliers from the Middle East are looking towards the fast-growing markets of China and India. The US gets most of its oil today from Canada and that percentage is set to grow as more pipelines are planned from the oil sands to the American markets. Given the development in US shale gas (shale gas is projected to be 60–70% of US gas production in 2020) the US has the potential to become independent from reliance on Middle East (Qatari) gas in the near future. The concern therefore that fewer resources have to be shared among more players is of more relevance to Europe than North America. The role of Russia in this context remains important. At present, Europe receives its gas mainly from Norway, Algeria, and Russia. The contribution of Russian gas to Europe will increase in the future and has already begun with the supply of gas to Germany via the Nord Stream. Gas consumption in the EU has doubled over the past 25 years and is set to be 60% higher by 2030. Looking ahead, the link between Russia and the EU will become stronger. Therefore, it remains unclear if a worldwide price for gas will be reached. If the US begins to rely on its cheap domestic gas supplies and if the Middle East continues to set high margins for the Asian markets, then neither party will want to affect their price structures. US gas producers are promoting LNG export to East Asia by converting the existing import terminal. The earliest project, Freeport LNG, obtained governmental permission to export LNG to Japan from 2017 to target the high-return markets of Japan and South Korea. It is likely that it will take another decade before a worldwide price for gas is reached, and will depend on the physical connection between Asian and European markets.

Coal reserves

Coal resources represent 82% of the world's non-renewable energy resources according to the German Federal Institute for Geosciences and Natural Resources. Reserves are divided into three types of coal: 405 billion (47%) is classified as bituminous coal (including anthracite), 260 billion (30%) as sub-bituminous and 195 billion (23%) as lignite. Reserves are sufficient to meet demand for many decades.

Coal provides 42% of the world's electricity and provides 29.6% of global primary energy needs. World consumption of coal is around 4,050 megatonnes annually. It is used in power generation, iron and steel production, cement manufacturing, and as a liquid fuel – coal to liquid (CTL). The bulk of coal used worldwide is in power generation – steam coal or lignite, and iron and steel production – coking coal. Around 49% of electricity in the US and 79% of the electricity in China is generated from coal thermal plants. Two-thirds of world steel is produced in blast furnaces which use coke while the remaining third is produced in electric arc furnaces which use electricity generated from coal.

World coal production has increased by 38% over the past 20 years. Much of this increase has been in Asia, where demand for iron and steel and electricity are rising sharply. Since coal is an input in both these sectors, both domestic production and imports of coal have risen. European use of coal has been decreasing sharply as coal-powered generation gives way to gas CCGTs under the EU climate change regulations. This trend might be reversed with cheap coal becoming available from North America in light of the current 'shale gas revolution' taking place in the US (predominantly) and Canada (to an extent).

In the WEC's view, coal will continue to remain important for many countries into the future. According to the World Coal Association, consumption of steam coal is projected to grow by 1.5% per year over the period 2002-2030. Lignite, also used in power generation, is expected to grow by 1% per year. Demand for coking coal in iron and steel production is set to increase by 0.9% per year over this period. The World Coal Association expects world consumption of coal to grow by 53% over the next 20 years. Indian demand for thermal coal is expected to increase by 90% in the next five years with shortage estimates reaching 200 million tonnes by 2012. The demand for coal will primarily be driven by the developing economies of India and China and the developed economies of Japan and South Korea due to a lack of energy resources.

Other resources: rare earths elements, biofuels

Rare earth elements

New demand has recently strained supply, and there is growing concern that the world may soon face a shortage of rare earth elements (REEs). These concerns have intensified due to the actions of China, the major supplier, even though it has only 37% of proven reserves, which has announced regulations on exports and a crackdown on smuggling by establishing quotas officially justified by the conservation of scarce resources and the protection of environment.

At the end of 2010 China announced that the first round of export quotas in 2011 for REEs would be 14,446 tonnes which was a 35% decrease from the previous first round of quotas in 2010. Behind the official factors of China's regulation policy, geo-political considerations are obviously taken into account by Chinese leaders.

Regulating their exports of REEs is indeed a way to push Chinese manufacturers up the supply chain, so they can sell valuable finished goods rather than lowly raw materials. It is also a means of putting pressure on countries such as Japan which is highly dependent on Chinese exports. Indeed, during territorial disputes between the two countries last year, China temporarily blocked rare earths shipments to Japan.

Therefore, there is an ongoing search for alternative sources in other countries. Mines in many countries such as Australia, Brazil, Canada, South Africa or the US, which were closed when China undercut world prices during the 1990s, are starting to reopen. Dozens of projects are in the pipeline: the Mountain Pass rare earth mine in California, which is projected to reopen in 2011, the Mount Weld project in Australia, and others.

China accounts for over 97% of global rare earth supply. In July 2010, China announced that it would be cutting its rare earth export quotas by 70%, taking the total for 2010 to 30,258 tonnes. For 2011 the export quota was set at 30,184 tonnes, down about 40% in two years, with annual output capped at 93,800 tonnes. The result of China squeezing output for exports has had an inflationary effect on the global prices of light rare earths like praseodymium and neodymium, which have increased by around 700% between 2002 and 2008. Heavy rare earths have also been experiencing prices increases, dysprosium oxide and terbium oxide have increased by 500% and 300% between 2002 and 2008 respectively. According to a US Energy Department report, dysprosium, crucial for clean energy products, rose to US$132 a pound in 2010 from US$6.50 a pound in 2003. Other than China, the other countries mining for rare earths are Russia, India, Brazil, and Malaysia. Since the US closed the Mountain Pass mine in 2002, it has become dependent on China, along with other countries requiring REEs.

Farmland, biomass and biofuels

Recent rises in food prices have been attributed to the growing use of first-generation biofuels, derived from the edible parts of food crops which are often blended with petrol. If the new generation of fuels could be used in combination with improved land-use strategies and increased agricultural yields, they might take us beyond the point where people are forced to choose between food and fuel. Future biofuels technology may rely on dedicated energy crops and agricultural and timber wastes instead of food crops, potentially reducing the pressure on food crop prices and contributing to the supply of more environmentally friendly supplies of liquid biofuels.

By 2050 it is expected that there will be an extra 2 billion people to feed worldwide. Currently, some 1 billion people suffer chronic food shortages globally, while another 1 billion are characterised as substantial over-consumers. It is expected that most of the population growth up to 2050 will occur largely in Africa and Southeast Asia. Given the fact that the Southeast Asian region is experiencing economic development, one possible outcome in the future is that these people will want to consume as much nutrition as today's developed countries. If this is the case, then global food production will have to rise by 110% over today's levels in the next 40 years. Although global crop yields increased 115% over 40 years from 1967 to 2007, the area of arable land increased by just 8% in the same period.[12] This implies that global food demand has been met by an increase in productivity and not an increase in the amount of farmland.

12 UK Government Office for Science: Foresight Project on Global Food and Farming Futures: Synthesis Report C2: Changing pressures on food production systems, UK Government's Foresight Project on Global Food and Farming Futures, London 2011.

As populations increase and commodity prices surge, developed countries have been looking towards arable land resources in developing and underdeveloped parts of the world. The OECD estimates that around 1.6 billion hectares of arable land in Africa can be used to grow food crops. Of late there has been an increased amount of activity around large-scale farmland acquisitions by Middle Eastern and Western companies. This has not only increased the price of farmland but has also resulted in a backlash by local farmers against governments and foreign companies. Looking ahead, competition for farmland will increase, prices will go up and the competition for either food production or use for energy will increase significantly up to 2050.

As far as the potential role of biomass is concerned – both solid for thermal and electricity generation, and liquid biofuels for transport – the WEC does not anticipate that biomass will play a significant role in the energy mix. Biomass has long been considered as the panacea to everything. But with considerations on sustainability and the conflict with alternative uses such as food, feed, and so on, the expectations regarding biomass have changed dramatically.

The WEC's assumptions about global resource availability are depicted in Figure 22, followed by views and analysis on depletion rates for oil and natural gas.

The WEC's view on the depletion of natural gas resources until 2050

Figure 22 – Global resource availability – in exajoule (EJ)

Source: World Energy Council (2013)

Source: World Energy Resources (2010), BGR 2012; GEA 2012

	Coal	
	Hard coal & Lignite	
	Reserves	Resources
Sub-Saharan Africa	745	2,008
Middle East & North Africa	32	997
Latin America & the Caribbean	286	939
North America	6,103	181,664
Europe	4,897	97,831
South & Central Asia	2,476	11,149
East Asia	4,664	130,314
Southeast Asia & Pacific	2,058	45,488
World total	**21,260**	**470,390**

	Gas			
	Conventional[a]		Unconventional	
	Reserves	Resources	Reserves	Resources
Sub-Saharan Africa	243	145	0	764
Middle East & North Africa	3,194	2,085	0	559
Latin America & the Caribbean	275	384	0	1,441
North America	271	2,073	105	2,100
Europe	2,027	4,887	0	1,717
South & Central Asia	657	623	3	155
East Asia	106	1,026	2	1,068
Southeast Asia & Pacific	372	319	31	778
World total	**7,145**	**11,542**	**142**	**8,581**

	Oil			
	Conventional[b]		Unconventional	
	Reserves	Resources	Reserves	Resources
Sub-Saharan Africa	378	578	0	29
Middle East & North Africa	4,725	1,443	0	179
Latin America & the Caribbean	552	406	927	2,677
North America	260	990	1,119	7,718
Europe	535	1,148	0	237
South & Central Asia	326	321	0	309
East Asia	84	676	0	32
Southeast Asia & Pacific	116	209	0	103
World total	**6,976**	**5,772**	**2,047**	**11,284**

a. including tight gas

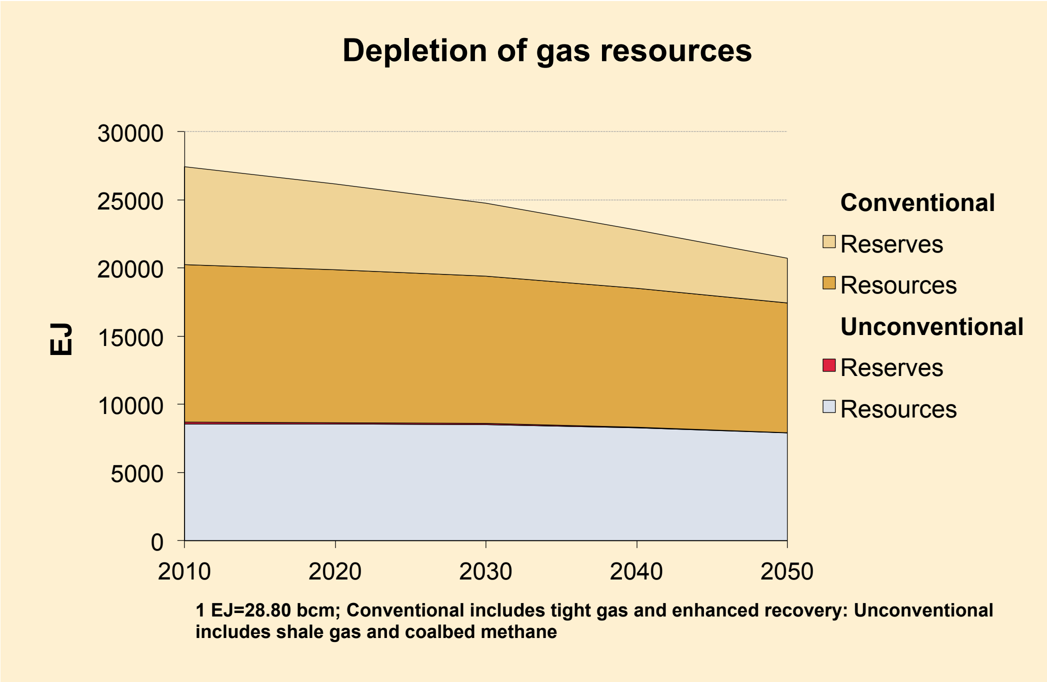
b. including enhanced oil recovery from conventional sources

The WEC's view on the depletion of natural gas resources until 2050

Figure 23 – Depletion of natural gas resources

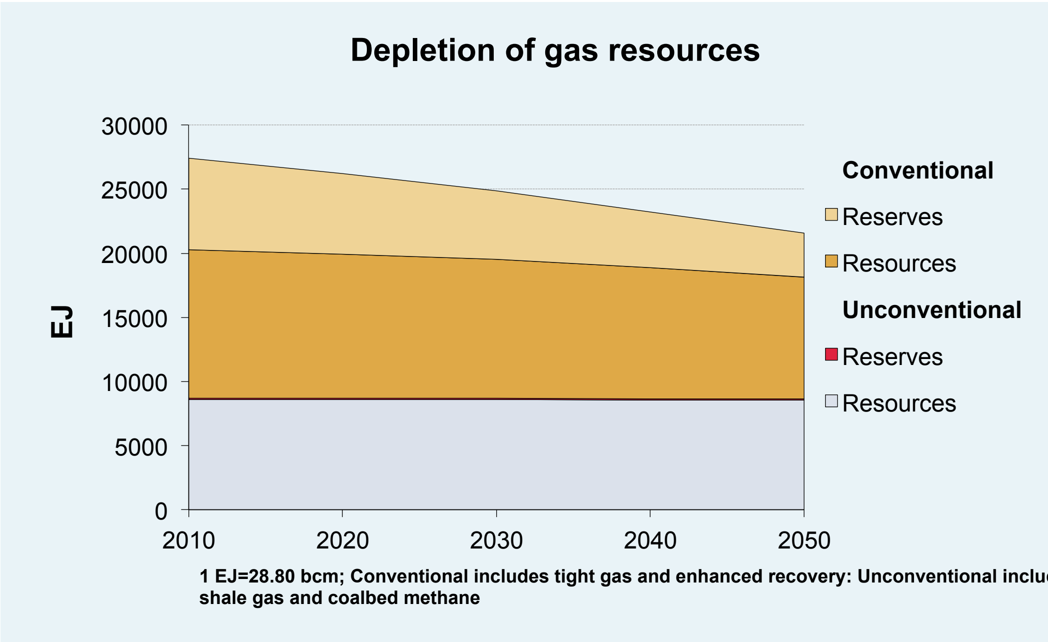
Source: World Energy Council (2013)

Jazz



Higher depletion of natural gas resources in Jazz – in line with higher energy demand and higher economic growth.

Symphony



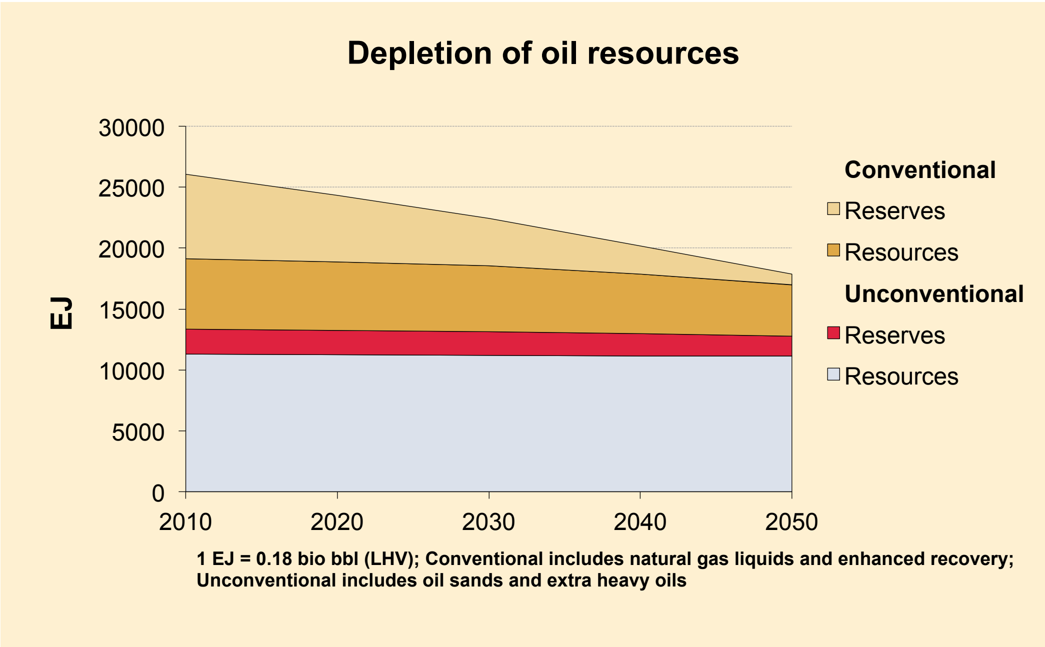
Lower depletion of natural gas resources in Symphony – in line with lower energy demand and higher economic growth.

The WEC's view on the depletion of oil resources until 2050

Figure 24 – Depletion of oil resources

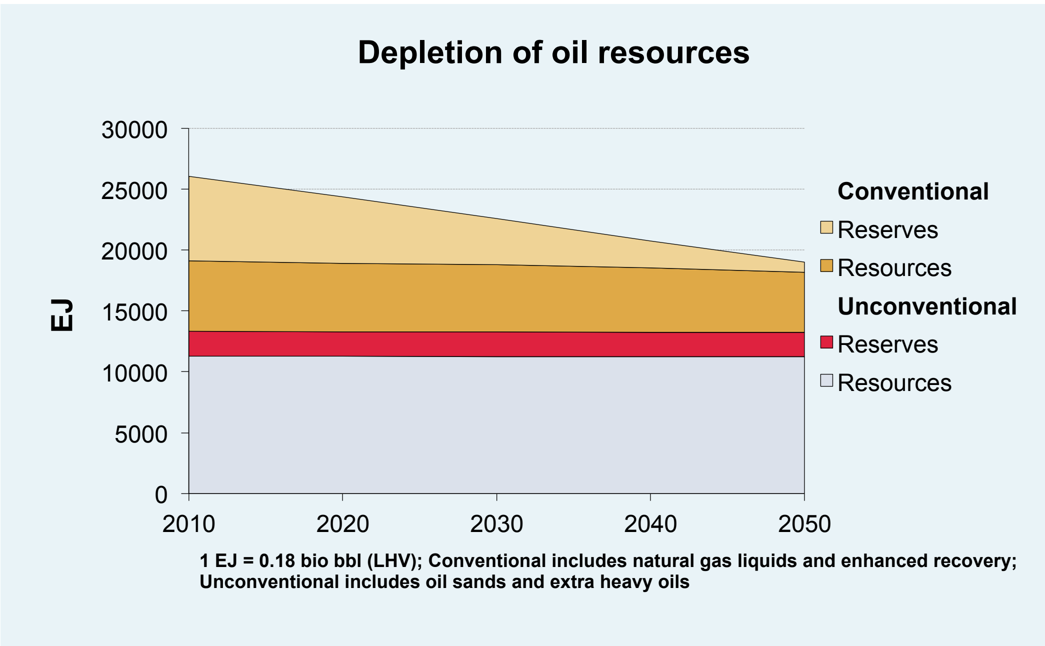
Source: World Energy Council (2013)

Jazz



Higher depletion of oil resources in Jazz – in line with higher energy demand and higher economic growth.

Symphony



Lower depletion of oil resources in Symphony – in line with lower energy demand and lower economic growth.

Jazz scenario

In the Jazz scenario the priority (especially in developing countries) is to fuel economic growth with the best available energy sources. Energy sources are being exploited and used on the basis of their relative cost levels. As a result, energy sources will compete on price, quality and availability, and since there is less government support for low-carbon energy technologies, governments will facilitate the role of the private sector to drive competition and lower prices even further. Higher demand for energy resources creates more global competition for resources. As a result, the influence of NOCs grows and more blocks are opened to E&P. The resulting competition creates cost-effective solutions, as a consequence, encouraging new unconventional energy sources when prices are right – for example, shale gas, oil sands and NGLs.

Symphony scenario

In the Symphony scenario, governments begin to put nationally suited regulations in place which support the development of low-carbon technologies, like renewable energy and CC(U)S projects. As a result, the use of certain energy sources is preferred over others, based on a wider range of considerations – most importantly, energy equity and environmental impact mitigation. As a result, there is less competition over energy resources, especially as regional interconnection increases, even leading to the formation of energy trading blocs to support the trade of renewable electricity. Irrespective of costs, governments will promote certain energy sources for non-economic reasons, namely energy security (e.g. nuclear, coal with CC(U)S).

Key scenario cluster 14: Competition for resources

The WEC's view

Based on the scenario work done by others and its own comprehensive assessment of available resources – both globally and regionally (most importantly in its most recent edition of the World Energy Resource publication) – the WEC believes that there will be an increasing competition for resources in the following areas, despite the fact that resources are available in abundance due to increasing and competing demand for:

- Oil and gas
- Coal
- Rare Earth Elements (REEs)
- Farmland

Subsequently, there will be changing balances between importers and exporters of energy.

The WEC's own findings are in line with the figures reported by others, such as IEA and Shell. The IEA estimates that, by 2035, total global primary energy demand will increase by 47%[13] with an annual (compounded) growth rate of 1.4% to 18,048 Mtoe. Of this increase, 79.5% is expected to come from developing countries, with 8.4% of the increase attributed to developed countries. The total primary energy demand of China is expected to double by 2035, and that of India to increase by almost 150% during the same period. Both these countries have embarked on a course of high economic growth and will need to fuel that growth into the next decades with increasing consumption of energy resources.

Shell estimates that global energy demand could triple by 2050 from its 2000 level. Their 2011 scenarios[14] state that "a gap between business-as-usual supply and business-as-usual demand gap of around 400 EJ/a" exists. This calculates to a 2050 world (annual) oil production of 8 billion tonnes. From 1965 (1.5 bn tonnes) to 2009 (3.8 bn tonnes) over a period of 44 years, total annual world oil production has increased by 145%. By 2050, i.e. over the next 37 years, world oil production needs to double. Hence, there is a need to bring additional capacity online and invest in technologies which will meet growing demand.

Based on its own analysis (see previous chapter) the WEC sees the competition for resources develop in the following way up to 2050:

Oil and gas

- Demand for oil will continue to grow, especially in China and India as they experience increased motorisation rates. Developing economies worldwide will also continue to consume more oil as freight rates increase and trade activity rises.
- Both India and China are experiencing year-on-year increases in demand for electricity. In order to service this demand with the inclusion of gas-fired CCGTs in the future, gas consumption is projected to increase.

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13 Current Policies (BAU) Scenario, World Energy Outlook 2010.
14 Signals & Signposts – Update to Scramble & Blueprint Scenarios, 2011

- The developing economies of India and China, along with the mature economies of Japan and South Korea in Asia, will increase their reliance on LNG imports from the Middle East, especially Qatar, and Africa.
- Europe is seeking to diversify its gas supply from Russia, but this will take some effort as most CIS gas-rich states are falling under the influence of Russia. The added complication of pricing gas under long-term contracts or spot prices will add uncertainty and time to the construction of transnational pipelines.
- With the development of unconventional oil and gas resources in North America, the US and Canada have now got the potential to shield themselves from any oil/gas price volatility in the future. Canada is currently seeking to further develop its export market in order to maximise rent from unconventional oil.
- Australia's gas deposits once fully developed will depress the price of LNG in the Asia region. It is possible that the region may experience an overabundance of gas if suitable industries/sectors in India and China are not fully developed.
- Moving forward, Middle Eastern oil and gas producers will increasingly supply the growing markets of China and India. Europe will have to compete for resources and align itself strategically to ensure energy prices remain affordable.

Coal

- Coal consumption worldwide has been increasing at an average annual rate of 2.36% since 1981. Since the 90s, most of the growth has been coming from India, China, South Korea, and Japan.
- The main reason behind growth in India and China is due to increasing use of coal-fired thermal power stations to meet the demand for electricity. A large portion (79%) of electricity generated in China and India is from coal. This will grow as China and India have been increasing imports and also developing their national resource base.
- The steel industry worldwide is very closely correlated with growth in the coal industry. It has seen a downward trend due to the recent financial recession and has been propped up by demand from China. Once demand recovers, a rise in coal consumption will occur.
- Coal consumption for power generation will decrease in Europe due to climate - change regulations which make it costly for thermal plants to operate. The US will also cut back on its coal consumption, but at a much slower rate.

Rare earth elements

- Due to China's policy of limiting REE exports, prices of these rare earths have skyrocketed. This will have an immediate impact on the cost structure of the cleantech industry which is dependent on REE for manufacturing magnets and solar PVs.
- Investment in reopening mines and developing resources in countries like the US, Canada, Australia, and others will bring down prices, but not in the short term.

Farmland, biomass, and biofuels

- As developing countries like India and China increase their consumption of meat and agricultural commodities, farmland has become a valuable asset. Food exporting countries prosper.
- Middle Eastern countries whose populations are booming have begun to look overseas for growing crops needed for domestic consumption. Sovereign wealth funds and food companies have begun to invest in Africa, buying up fertile land.
- Countries like Brazil and Australia have experienced price increases (up to 20% over 2009) in the cost of acquiring farmland. Local backlash has prompted these governments to move towards banning foreign ownership of land.

- Western investment funds have begun investing in farmland – this has had an inflationary effect on the price of land, in turn driving up the price of agricultural commodities.
- As populations continue to grow, more pressure will be put on land, water, and forest resources. Demand for fertilisers will also increase, driving up the price of oil.

The WEC's view on the different roles of different energy carriers in final energy up to 2050 are stated in Table 14 and Figure 25.

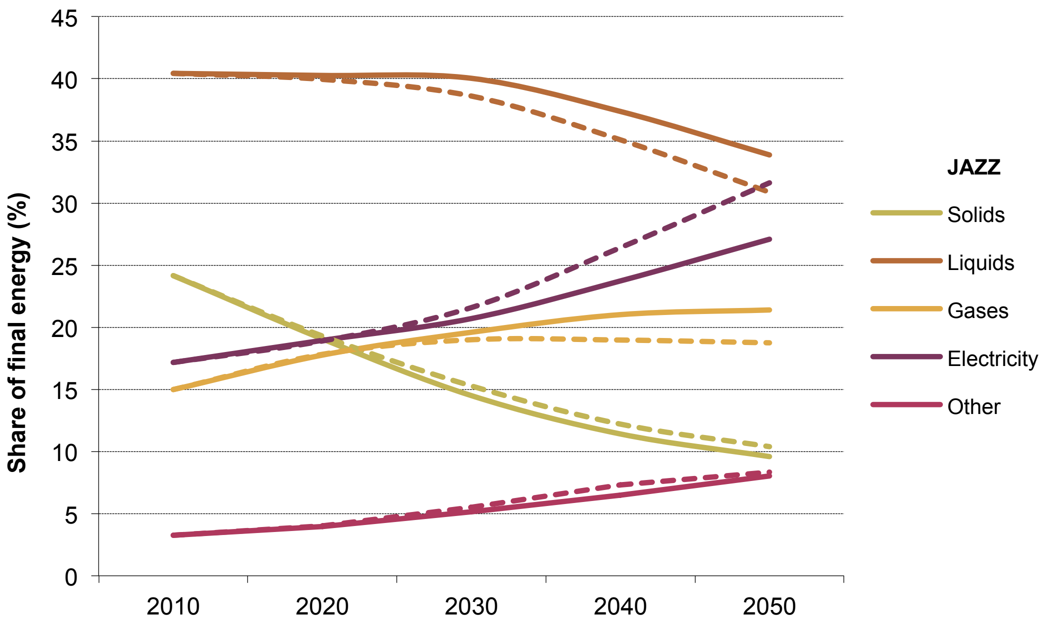
Table 14 – The WEC's view on the role of different energy carriers in final energy

Source: World Energy Council (2013)

	2010	2020	2030	2040	2050
Jazz					
Solids	24%	19%	15%	11%	10%
Liquids	40%	40%	40%	37%	34%
Gases	15%	18%	20%	21%	21%
Electricity	17%	19%	21%	24%	27%
Other	3%	4%	5%	6%	8%
Symphony					
Solids	24%	19%	15%	12%	10%
Liquids	40%	40%	39%	3%	31%
Gases	15%	18%	19%	19%	19%
Electricity	17%	19%	22%	26%	32%
Other	3%	4%	6%	7%	8%

Figure 25 – Role of different energy carriers in final energy

Source: WEC/PSI projections (2013)



Jazz	Symphony
• Increasing role of gas and electricity.	• Switching away from fossil fuels. • Electrification supports efficiency.
• Competition for resources (unconventional fossil). • Enhanced oil recovery technique development.	• Shift away from fossil fuels. • Renewables: significant shares. • CO_2 reduction obligations. • Energy security.

Assessment: Symphony: Less use of unconventional fossil resources

Notes: Final energy includes coal use in coke ovens, blast furnaces and gas works. Final energy also includes non-commercial biomass.

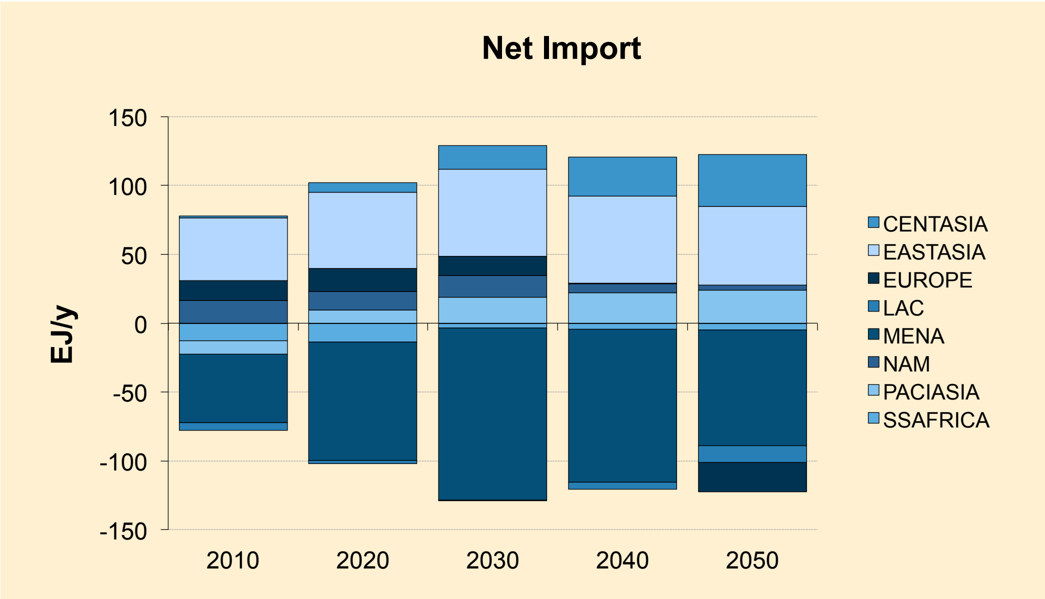
The WEC's view on the global geopolitics developing between net energy importers and net exporters until 2050

Figure 26 – Net energy importers and net exporters until 2050

Source: World Energy Council (2013)

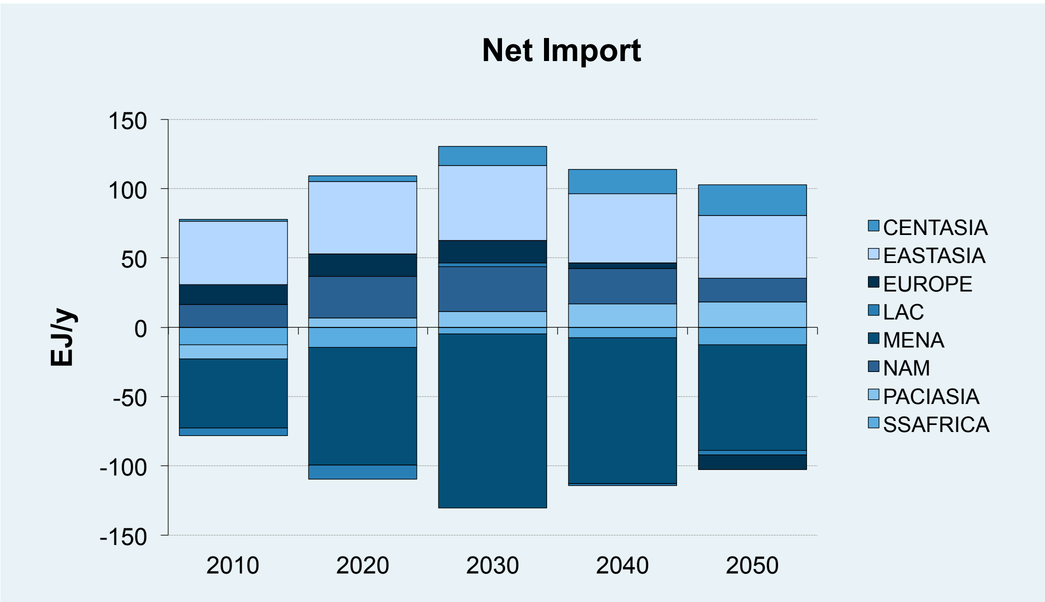
Regions: CENTASIA = Central and South Asia; EASTASIA = East Asia; EUROPE = Europe + Russia; LAC = Latin America and The Caribbean; MENA = Middle East and North Africa; NAM = North America; PACIASIA = Pacific Asia; SSAFRICA = sub-Saharan Africa

Jazz



With free and expanding international trade with fewer barriers (not specifically energy trade), energy trade is higher (up to 20%) in Jazz.

Symphony



Higher trade restrictions, trade is focused, with a small set of selected countries (not specific energy trade).

Jazz scenario

Competition for resources: In the Jazz scenario, there will be intensified competition for resources due to higher GDP growth combined with high energy demand. Non-conventional sources will reduce competition for coal, gas and oil. As demand increases we can expect increased E&P from the resources industry.

Competition for REEs and farmland will intensify. Critical rare earth metal shortages in the short term will have an impact on the manufacture of permanent magnets used in wind turbines, elements used in the manufacture of NiMH (nickel metal hydride) and Li-ion (lithium ion) batteries, and PV films which use phosphors and indium. This implies that, in the short term, most of the clean energy technologies will have at least one REE used in its manufacture, in short supply. A shortage in rare earth metals will have a detrimental impact on the wind and solar industry. As costs increase, international mining conglomerates will invest in new rare earth metal mines, and junior exploration companies will also look for opportunities. Competition for land between biofuels and agriculture will intensify, but first-generation biofuels will find it difficult to compete against a rising demand for food without subsidies or incentives. This will drive the development of second-generation biofuels from biomass grown on marginal land.

Symphony scenario

Competition for resources: In the Symphony scenario, competition for resources is, to an extent, less strong than it is in the Jazz scenario. Governments will invest in resource development and control exports to ensure national energy security. Government will reduce the dependence on imported oil and coal by investing in or mandating an increasing share of renewables.

To ensure sufficient supply of REEs at low cost (due to China's restriction on exports), governments will ensure that mines in the US, Australia, Canada, Vietnam, and India are developed in the medium- to long-term to prevent a supply crunch.

Competition for land between biofuels and agriculture will intensify. The problem will be aggravated when countries import biodiesel, ethanol and wood pellets to meet biofuel renewable mandates. Development of second-generation biofuels from biomass grown on marginal land could be set back by badly designed renewable incentives or subsidies.

The WEC's projection for the share of net imports in primary energy supply together with the assumptions regarding the diversity of primary energy supply are stated as part of WES' trilemma analysis in the chapter WEC's World Energy Scenarios to 2050 and the energy trilemma.

Key scenario cluster 15: Skills shortage

The WEC's view

The issue of skills shortage is closely related to demographic change and the 'war for talents'. Europe will face a challenge due to: lack of skilled and motivated people/talent; and the ageing population. The principal issue facing Europe is an ageing populace combined with declining population growth rates. According to the UK government, 45% of employers in the UK are concerned that they will not fill posts in their organisations that require graduate or higher level Science, Technology, Engineering and Mathematics (STEM) qualifications.

The potential impact on the energy industry can be twofold – in manufacturing, for example of nuclear power plants, newly built infrastructures could be affected through lack of welders, and other skilled jobs, but also for experienced engineers with project experience. This is also the case in Africa where it has been reported that less young Africans are willing to study 'hard' science subjects, such as STEM subjects, and where graduate numbers are also declining. The issue of skills shortage also has to be seen in the context of changing demographics, and in conjunction with the 'war for talent'. This can have implications for innovation and economic growth and prosperity.

With both high GDPs per capita and diversified economies, the central issue for European countries is how to maintain the economic growth levels with an ageing population. Demographic analysts believe that immigration, along with the increased use of technological solutions, can mitigate some of the negative consequences of the population decline. The WEC therefore expects to see group movements within the EU-28 itself to respond to labour shortages. The EU-28 will look like a labour arbitrage market with EU members from less wealthy countries migrating to more wealthy countries looking for job opportunities.

The WEC expects that the European population will be more ethnically diverse by 2050 in response to the shifting need for certain types of workers as the overall population ages. This shift in demographics could have profound economic, political, and social implications. Therefore, skills shortage is not presently deemed to be a major barrier towards the energy market functioning up and until 2030 – it might be later in the scenarios between 2030 and 2050. It is recognised that smooth market function requires low-cost access to good information and the requisite skills for all concerned. In specific markets, skilled personnel who can install, operate and maintain renewable energy technologies may not exist in large numbers. Project developers may lack sufficient technical, financial and business development skills. The lack of skills and information may increase perceived uncertainties and interfere with decision making.

Jazz scenario

Education: Education is dependent on market requirements. Technical skills come at a premium in the first half of the scenario period (due to lack of technical training institutes). Education quality improves as competition between educational institutes increases. There is an increase in vocational training. The focus is on providing the skills required by industry.

Employment: Unemployment is closely correlated and more responsive to economic performance of markets. There is a lack of suitably qualified people in skilled sectors in the early part of scenario.

Population: With higher economic growth rates and higher average income per capita, population growth slows down, resulting in significant demographic structure changes in the longer term. Population growth in India slows. Africa and the Middle East regions still experience high population growth. Overall lower population growth.

Symphony scenario

Education: No significant change from present. There is a slower growth in technical degree holders (in response to market demand).

Employment: Unemployment improves in areas with large infrastructure investment. Core unemployment remains high as the capacity of governments to support all sectors is limited.

Population: Life expectancy improves. Population growth is higher due to lower economic growth rate.

4. Accounting for uncertainty

'Wild cards' and 'black swans'

When devising its scenario stories, the WEC has included a number of key critical uncertainties and so-called 'wild cards' or 'black swans' into them. In scenario modelling terms, a wild card is an event or a factor that can be thrown into existing scenarios that are highly unpredictably but possibly of a high impact. Such events or factors can change the scenario landscape significantly and to a greater extent than can be predicted today. One reason why it is almost impossible to derive statements about these wild cards is that they can be once-in-a-lifetime events, or that the technological development required for these factors to take place is not fully developed. An example could be another Fukushima disaster or significant technological changes that will have an impact on how we consume energy up to 2050.

The WEC has examined the issue of wild cards in its scenarios and identified two potentially unpredictable, but highly significant issues, in terms of their impact:

- Rapid growth of a carbon capture, utilisation and storage (CC(U)S) infrastructure
- A breakthrough in energy storage, including power-to-gas technologies, and a changing paradigm of end use involving smart grids consumer engagement and demand-side management.

Carbon capture, use and storage

CC(U)S as a technology

CC(U)S is an environmental technology, an 'end of pipe' technology which specifically addresses an environmental issue at an energy cost. It is a technology to prevent large quantities of CO_2 from being released into the atmosphere from the use of fossil fuel in power generation and other industries. The technology involves:

- collecting or capturing the CO_2 produced at power stations and large industrial plants using fossil fuel (coal, oil and gas)
- transportation to a suitable storage site
- pumping it deep underground to be securely and permanently stored away from the atmosphere in rock.

CC(U)S is the only technology available to mitigate GHG emissions from large-scale fossil fuel usage in power generation, fuel transformation and industry. CC(U)S has been identified as an important part of a decarbonisation portfolio. Without CC(U)S reducing CO_2 levels in the atmosphere will be significantly more expensive. In addition to storing the CO_2 underground, the use of CO_2, e.g. in enhanced oil recovery or other industrial processes, can also help reduce GHG emissions.

In WEC's analysis, CCS includes all CO_2 storage, including utilisation for enhanced recovery which leads to CC(U)S. More exotic forms of utilisation (e.g., CO_2 used for fuel synthesis or in the chemical industry) are not modelled explicitly as these were considered of minor relevance given that the energy density of CO_2 is low and so it cannot be easily converted to useable energy. More broadly speaking, CCS is addressed by optimising cost and creating carbon markets. The scenario storylines envisage the emergence of carbon prices and markets (at different times and with different global cooperation depending on the scenario). The model incorporates these carbon prices in cost optimisation to determine technology deployment (including CC(U)S deployment).

For a number of reasons, CCS and CC(U)S in particular are both critical uncertainties and so are both black swans in the WEC's World Energy Scenarios to 2050.

Barriers to CC(U)S

Policy frameworks: CC(U)S will always be an added cost. Climate policy designed to reduce emissions is the most important step for commercial deployment of low-carbon technologies such as CC(U)S, because it will create a stable, long-term framework for private investments. A concerted effort to properly address financial, economic, technological, legal, institutional and social barriers will enable CC(U)S to be a viable climate change mitigation option that can, over time, play an important role in reducing the overall cost of meeting emissions reduction targets.

CC(U)S costs

A wide range of uncertainty exists around CC(U)S project costs, particularly upfront capital costs. Emerging information from projects and new studies indicate increasing estimated costs for all capture technologies. The WEC has also analysed the cost of avoided CO_2. This cost in coal and gas plants equipped with CCS ranges from around 40-80 \$/tCO_2 in 2020 down to 30-60 \$/tCO_2 in 2050 in both scenarios.

CO_2 storage

Over the long term, CO_2 can be stored in a number of geological formations such as depleted oil reservoirs, depleted natural gas fields, deep saline aquifers and unmineable coal seams. Together these are estimated to have a global storage capacity of 1000–10,000Gt CO_2 according to the IPCC. With current world energy-related emissions of about 27Gt CO_2 per year, there is sufficient storage capacity around the world, enabling CC(U)S to play a major role in emissions abatement. We need to better understand and assess viable storage sites with suitable geology, capacity and ability to inject CO_2 into the ground. In the longer term, as carbon constraints tighten, the associated investment in commercial CO_2 capture plants and common user infrastructure will increasingly depend on access to suitable storage solutions.

CO_2 networks for CC(U)S: large-scale CC(U)S will require new infrastructures of the same order of magnitude as the current oil and gas exploration infrastructures. New networks established will need to be specifically for CC(U)S. These CO_2 networks will introduce additional costs and risks.

Regulatory requirements for CC(U)S projects

Longstanding regulatory programmes are being adapted in various jurisdictions around the world to meet the circumstances of CC(U)S, but limited experience and institutional capacity may hinder the implementation of CC(U)S-specific requirements.

Key legal issues are long-term liability, associated property rights, post-closure site stewardship, and the increasingly important requirement by many sovereign governments for new coal-fired plants to be 'CC(U)S ready'.

The WEC's view on the potential scale of CC(U)S projects: Implications for Jazz and Symphony: Global adoption of CC(U)S

The best and most cost effective CC(U)S opportunities will be in non-OECD countries such as China and India. For CC(U)S to become viable and deployed at a large scale, it will need established frameworks to collect and share knowledge created from publicly funded demonstration projects in a number of regions across the globe. The cost of CC(U)S will have to be transferred to energy consumers and not carried by energy producers. A lack of public acceptance could be a real barrier to CC(U)S. For CC(U)S to work it will be vitally important to engage and inform the public in CC(U)S project developments. Good public engagement could help to provide project proponents with an understanding of the factors affecting the development of effective public engagement strategies.

Energy storage in conjunction with smart grids and changing demand patterns

Energy storage can be defined as a set of technologies used to store energy in the form of chemical, kinetic or potential energy and then discharge this energy whenever required. Various energy storage technologies are helpful in providing the basic services like balancing the demand and supply fluctuations, deferring cost of upgrade of transmission and distribution (T&D) infrastructure. Moving forward, energy storage technologies will play a major role in the implementation of the smart grid as they resolve many issues related to the efficiency and reliability of the power system. The term 'smart grid' means a grid which is more advanced than the legacy grid. Conversion of a legacy grid to a smart grid involves:

- increasing the grid's operational efficiencies
- improving electric service reliability
- increasing utility customer satisfaction and retention
- optimising capacity expansion (generation, transmission, and distribution)
- optimising asset utilisation.

Smart grid is also meant for managing the T&D infrastructure in an efficient manner by introducing functionalities such as voltage control and frequency control, among others. Energy storage systems can be a solution for smart grids to overcome any disturbances related to the grid. The storage systems can provide ancillary services such as load following, area regulation, voltage and frequency regulation. These mechanisms are helpful in reducing transmission congestion and in avoiding the additional costs of T&D upgrades. Apart from this, energy storage technologies have been used by utilities for the integration and optimisation of all types of distributed energy resources.

The smart grid narrative also describes smart grid technologies as including or enabling power storage technologies as a means to integrate intermittent renewable power production and deliver GHG emissions reductions. Storage of electricity remains substantially more expensive than the cost of additional conventional power supply.

The energy storage technologies in a smart grid can be divided in to two broad categories: mature energy storage technologies and emerging technologies.

Mature energy storage technologies are old technologies that have been used on a large scale compared to the other technologies. These technologies have been in use on a commercial basis since 1970s and have low capital cost per unit of output. Examples are:

- Conventional pumped hydroelectric storage
- Compressed Air Energy Storage
- Lead-acid batteries.

Emerging technologies in the field of energy storage encompass:

- Super conducting magnetic energy storage
- Advanced batteries, including greater scalability and more cost effectiveness for:
  - sodium sulphur (Na-S) batteries
  - zinc bromide (Zn-Br) batteries
  - lithium-ion (Li-ion) batteries
  - vandium redox (VR) batteries
  - Mg-Sb liquid metal batteries

- Fly wheels
- Electrochemical capacitors.

Energy storage technologies have wide applications in maintaining grid stability and efficiency. They help by removing the discrepancies related to T&D – like voltage drop, frequency regulation, and load shedding – and therefore represent an important aspect in the renewable energy landscape. Apart from the numerous benefits for the grid and the whole electricity value chain from energy storage, some notable challenges are also associated with them.

- High cost from research to development to final deployment (scalability), including high installation cost per kWh.
- Lack of regulations for the development of storage technologies and their connection to the grid.
- Limited risk/rewards-sharing mechanism, i.e. less motivation towards the deployment of energy storage technologies.
- Limited knowledge and experience with new and emerging storage technologies.
- Lack of financing.
- Inadequate storage infrastructure.
- Potential shortages in the availability of rare earth metals.

Given the high cost and low scalability at present, these storage technologies have been considered as critical uncertainties.

Power-to-gas technologies

In scenario terms, power-to-gas (P2G) represents another key uncertainty or black swan. P2G encompasses a wide range of procedures and different technologies, such as methanisation, i.e. conversion of organic material into methane, such as bio-methane and the use of methane as a fuel for transport. More specifically, P2G encompasses: (i) hydrogen production; (ii) hydrogen storage; (iii) the conversion of hydrogen into electricity; (iv) feeding hydrogen into the natural gas network; and (v) use of residual heat, e.g. for residential heating.

P2G can be used for closing the carbon cycle, integration of renewable energy sources and is therefore effective in decarbonisation of electricity generation and energy usage in general. Furthermore, existing network infrastructure can be used by linking existing power and natural gas grids.

In Germany, several demonstration P2G plants have gone online. The plants are designed to store excess electricity generated by renewable sources. Examples are Niederaussem, Germany and Falkenhagen, Germany.

The Niederaussem P2G plant uses electrolysis to split water into hydrogen and oxygen using electrical energy. The Falkenhagen plant banks excess power that is generated by wind farms' hydrogen and feeding the hydrogen into natural gas pipeline at around 2% by volume, at a maximum operating pressure of 55bar. This is effectively storing and transporting surplus renewable energy. Hydrogen can then be used in the same way as natural gas and taken off the grid.

It is envisaged that P2G could start to establish itself as a flexible storage technology in power grids as more electricity is produced from renewable sources by the latter part of this decade – 2015–2020.

Demand flexibility and demand responses in deregulated electricity markets

From 'consumers' and 'producers' to 'prosumers'

Consumers are demanding more from their energy providers as they seek to conserve energy, save money and reduce their environmental impact. In the future consumers who were passive recipients from sole source providers will become active participants. The emergence of energy 'prosumers', both energy customers and power producers from their own generation sources at home or business, will be an important element of change in any future energy system, especially with the emergence of smart grids.

The electricity smart grid has become a focal point as a key component to modernisation of energy supply. The smart grid consists of the digitalisation of the electricity network enabling near real-time monitoring, remote control and decision optimisation. The smart grid promises to modernise failing infrastructure, reduce energy losses, and drive a new industry around energy technologies. The complexity of the transformation presents huge challenges for utilities to replace key operational and information systems and redesign operations. Customer acceptance is needed to fund new technologies and participate proactively in energy management, and global economic instability may restrict the availability of the enormous funding required to build the smart grid.

A crucial factor that will help to drive the development of smart grids will be the demonstration of measurable benefits to consumers. Consumer expectations are high at this point, but benefits are hard to prove as projects are in early stages and benefits accrue over time. Convincing consumers of the value of the smart grid, will be crucial for driving smart grid forwards.

Consumer engagement and demand-side management

Ultimately, this also has an impact on consumer interest in new technologies and energy demand management or demand-side management. There is potential for consumers to drive new technologies forward. The degree to which consumer demand drives the market for new technologies will increase the functionality and speed at which smart grids are being built and implemented. The rate of adoption of PHEVs, and their ability to serve as both energy storage devices and distributed generation is one example. If PHEVs gain traction (Southern California Edison estimates 200,000 to 1 million PHEVs in their territory by 2020), meeting current peak load and the creation of additional load peaks will place stress on grid management systems. As more small commercial and residential customers participate in demand response programmes, utilities will gain more control over load and adopt more flexible load management capabilities that will improve both economic dispatch and grid reliability. The same is true for any other form of consumer engagement and demand-side management, including behavioural changes and adaptations.

- Adverse behaviour: Increasing numbers of solar PV panel: consumers might buy air conditioning units as the electricity from their roof tops is perceived as free of charge.
- Increasing number of electronic gadgets, such as mobile phones, and other electronic devices ('gadgetisation').

Regional differences in demand-side management initiatives

Both countries and regions are looking for smart grids to meet different objectives in terms of their future energy system design. It is well recognised that smart grid deployments must reflect regional needs and conditions in their design. While developed economies are investing in incremental improvements, emerging economies are looking to leapfrog directly to smart grid infrastructure. As smart grids incorporate existing infrastructure and technologies in a journey towards integration, a 'one-size-fits-all' approach does not apply and regional drivers to adoption will guide the adaptation of smart grids including:

- demographics and growth rates
- regional priorities
- ability to leapfrog to smart grid infrastructure, rather than 'tradition' network infrastructure.

Some of the regional priorities which have been identified in smart grid discussions include:

- Africa: Increased access to energy is the overwhelming priority, and smart technologies could provide access to low-cost distributed technologies developed in the wave of innovation. Recovery of high levels of losses in urban areas could also close some of the gap.
- Asia: A dramatic increase in consumer demand, making the goal the ability to leapfrog older technologies and implement technologies quickly. Adhering to environmental considerations is a challenge, and smart technologies could provide greener means of supplying expanding populations and economies.
- Latin America: Trends of increasing standards of living for large sections of the population create the need for major infrastructure build-out and high growth rates for energy demand.
- Europe: Over 200 smart grid projects are underway representing investment of €5.5 billion according to the EC Joint Research Centre. Increased integration leads to opening of electricity markets, increased options and a reduction in cost. If this grid achieves the scale anticipated by its proponents, it could meet as much as 15% of Europe's electricity demand.
- North America: Focus on creation of an energy secure future and a sustainable energy system at a national policy level could prompt regional and state regulators to increase investment.

Incorporation of technology wild cards into the World Energy Scenarios to 2050

Jazz scenario

CC(U)S: Adoption and technology

The WEC has made the following assumptions regarding CC(U)S in the Jazz scenario:

- The commercial use of CC(U)S in EOR projects increases and CC(U)S infrastructures are developed in the US and Europe, speeding up adoption.
- CC(U)S is possibly ready at commercial scale by 2035.
- CC(U)S will not be adopted initially due to low carbon prices and high upfront investment costs.
- Industry R&DD in CC(U)S is important for its commercialisation.
- A wider adoption of CC(U)S will happen at a later stage – i.e. post-2040.

Energy storage

The WEC has made the following assumptions regarding energy storage in the Jazz scenario:

- Batteries still are expensive.
- R&D will slowly drive battery prices down.
- Competitive markets facilitate new business models for battery replacement.
- Pumped-storage remains limited to hydropower locations.
- Depending on the R&D breakthroughs, other forms of storage (hydrogen, molten salt, flying wheels, pressurised reservoirs, etc.) may prove feasible at a commercial scale post-2030.

Power-to-gas

The WEC has made the following assumptions regarding P2G in the Jazz scenario:

- Breakthrough in P2G technologies takes only place after 2035.
- Without government subsidies, R&D cost into the scalability of P2G projects remains high. Upscaling of demonstration projects remains a challenge.
- P2G remains one of the potentially biggest game-changers in the scenarios.

Demand-side responses

The WEC has made the following assumptions regarding demand side responses in the Jazz scenario:

- Higher electrification among consumers leads to higher demand for electricity.
- The world will witness an increasing ‘gadget boom’: trends to own more and more electric devices – e.g. household appliances, air conditioning units – and a tendency for consumers to have two or three mobile phones per user.
- There is an increasing number of technical appliances, including air conditioning units, per household.

Symphony scenario

CC(U)S: Adoption and technology

The WEC has made the following assumptions regarding CC(U)S in the Symphony scenario:

- The entry of CC(U)S occurs earlier due to governmental intervention and international political pressure.
- The cost of CC(U)S remains high and is mainly dependent on government funding.
- Government promote CC(U)S demonstration, deployment and infrastructure proactively.
- The use of CC(U)S in EOR provides added incentive for governments to fund CC(U)S infrastructures.

Energy storage

The WEC has made the following assumptions regarding energy storage in the Symphony scenario:

- Governments subsidise or invest in R&D in batteries and other storage to help the integration of renewables.
- As a result, these technologies become available sooner in the scenarios time period.

Power-to-gas

The WEC has made the following assumptions regarding P2G in the Symphony scenario:

- Governments subsidise R&D activity into P2G and hence promote these technologies proactively.
- P2G becomes commercial sooner in the Symphony scenario than it does in the Jazz scenario.
- The emergence of commercially viable and scalable energy storage and P2G technologies facilitates increasing RES-E generation.

Demand-side responses

The WEC has made the following assumptions regarding demand-side responses in the Symphony scenario:

- There is a government-induced focus on smartness, including smart grids and smart meters.
- Governments place increasing emphasis on energy conservation and hence a reduction of energy usage.
- Increasing efficiency, energy conservation and the reduction of energy usage leads – among other things – to overall lower levels of energy demand in the Symphony scenario, than in the Jazz scenario.

5. Quantification of the scenario stories: Global results

The WEC's quantification of the scenario stories

The Jazz and Symphony scenario storylines describe a coherent set of future economic and social drivers of the global energy system. The scenario storylines cover aspects such as population, GDP, technological development, resource availability and energy policies.

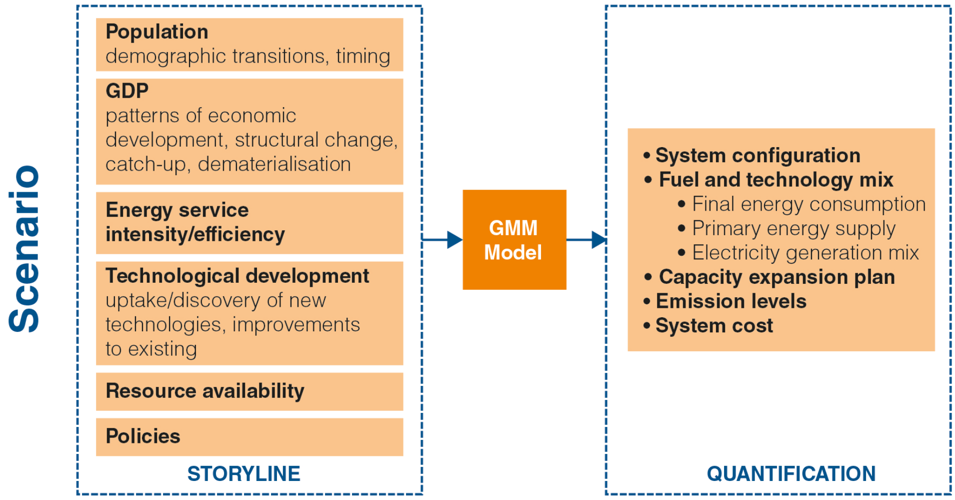
To model and quantify each scenario, these drivers were clustered in specific groups and then translated into quantified inputs such as energy demands, technology characteristics and deployment/availability, energy resource accessibility and extraction costs, CO_2 prices and others.

Policy measures and behavioural aspects of the scenario assumptions were translated into additional modelling constraints and parameters, for example, assumptions on unconventional fossil resources, biofuels, and climate policy. The storyline development and quantification steps sought to account for the interdependence between different drivers and input assumptions (e.g. energy demand, which depends on GDP, structural developments and energy efficiency, which in turn relies on policy and other factors).

The scenario drivers are used as input to an energy system model, which: (i) models the structure of the underlying energy system; (ii) is based on numerical data and time series; (iii) follows a specific mathematical structure;(iv) includes information on boundaries and constraints based on user-defined relationships; and (v) can accommodate different scenarios and strategies.

Figure 27 – WEC scenarios quantification: Use of a GMM MARKAL model

Source: World Energy Council (2013)



The energy system model employed by the WEC to quantify its scenario stories is based on the well-established MARKAL (MARket ALlocation) framework.[15] More specifically, the WEC uses the global multi-regional MARKAL (GMM) model maintained by the Paul Scherrer Institute (PSI). GMM is a cost-optimisation model that yields least-cost solutions for the global energy system under a given set of scenario assumptions and constraints. It is a dynamic partial-equilibrium model; the shares of technologies and of energy carriers used for extraction and for conversion as well as the final energy demands are determined endogenously by the model, whereas the demands of useful energy (services) are scenario inputs.

The GMM model allows the world to be subdivided into different regions so that different regional splits can be analysed. The model also considers a long-term horizon (to 2050 and potentially beyond) allowing the analysis of future energy issues of resource depletion, climate change policy, economic development and technology learning.

GMM is a bottom-up model that reflects the WEC's decentralised approach towards developing the scenario stories; the model contains a detailed representation of resources, technologies, energy flows, and assumptions regarding technological change, learning, cost and efficiency improvements over time.

For a more detailed description of the GMM model, see Appendix 2.

15 The MARKAL modelling framework is widely used in over 250 institutions in approximately 70 countries; the framework is part of IEA's Energy Technology Systems Analysis Program (ETSAP).

Comparison of Jazz and Symphony scenarios assumptions

Based on the scenario stories derived, the WEC has made the following assumptions in Jazz and Symphony when quantifying the scenarios.

Table 15 – Quantification assumptions

Source: World Energy Council (2013)

	Jazz	Symphony
GDP growth	Higher (strong focus on growth) 3.54% p.a. CAGR, PPP	Lower (relative), but still substantial 3.06% p.a. CAGR, PPP
Population	Lower (lower fertility, driven by higher incomes, education) 2050 = 8.7 billion	Higher (in line with UNDP medium) 2050 = 9.3 billion
Efficiency	Increasing market driven (higher prices/efficient markets) -2.27% p.a. primary, PPP	Increasing more strongly govt. focus on efficiency and savings -2.38% p.a. primary, PPP
Climate policy	Limited (but more diversity) Prices (2050): 23–45 US\$2010/tCO_2	Stronger (with global convergence) Prices (2050): 70–80 US\$2010/tCO_2
Resources	Better access to unconventional resources (esp. gas)	More expensive unconventionals (less competition, regulation, water)
Technology support	Limited; energy choice based on free markets only limited nuclear, CC(U)S, large hydro	Government support for nuclear, large hydro, CC(U)S and renewables
Technology innovation	Further development of CCGT decentralised power (solar PV), wind, gas vehicles, EVs	Focused R&D programmes, especially CC(U)S demonstration, nuclear, solar PV

Table 16 shows how different government policy measures have been implemented in Jazz and Symphony.

Implementation of government policy measures in Jazz and Symphony

Table 16 – Government policy measures (comparison)

Source: World Energy Council (2013)

		Jazz	Symphony
Hydro		**Limited support**	**Action to exploit potential, esp. in emerging countries**
	Developed:	1% p.a. max. deployment	1–2% p.a. max. deployment
	Emerging:	2% p.a. max. deployment	2–6% p.a. max. deployment
Nuclear		**Limited support**	**Promotion of nuclear**
	Developed:	<0–1% p.a. max. deployment*; not all plants under construction are completed	0.5–1% p.a. max. deployment*; plants under construction completed
	Emerging:	0.5–1% p.a. max. deployment*; not all plants under construction are completed	0.5–2% p.a. max. deployment*; plants under construction completed
Carbon capture, use and storage		**Limited action** Limited deployment until after 2030; slower expansion	**Promotion of CC(U)S infrastructure, demonstration and deployment** Earlier (from 2020) and faster expansion
New renewables		**Market driven**	**New renewables are state funded** Solar PV and solar thermal: support equivalent to 10–13 cents/kWh (2020) reducing to 2.5–5 cents/kWh (2050) Wind (onshore and off-shore): support equivalent to 1–1.5 cents/kWh

* except for plants under construction

Results from the global scenarios quantifications are displayed in Figures 28 to 40.

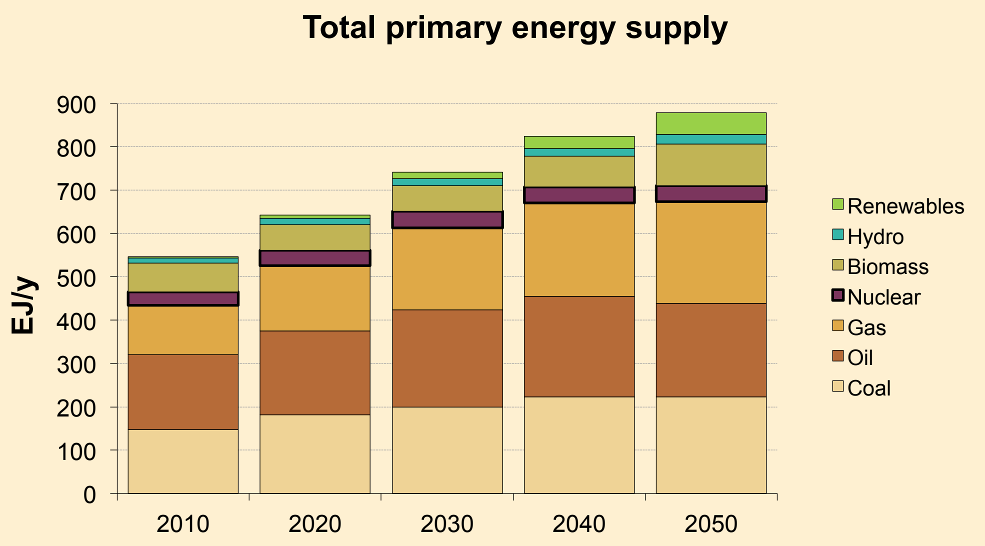
Total primary energy supply by fuel type

Figure 28 – Total primary energy supply by fuel type

Source: World Energy Council (2013)

Historical data: IEA World Energy Statistics and Balances

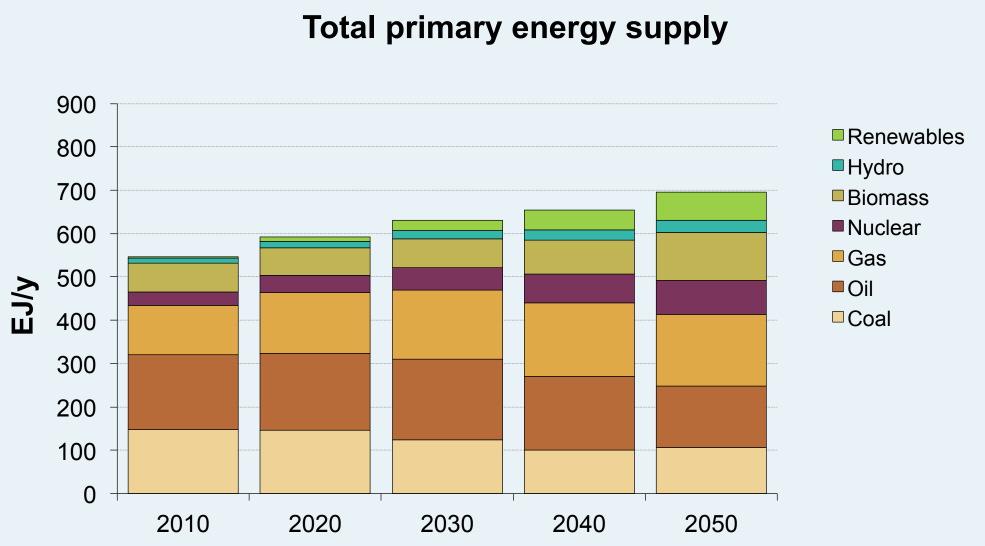
Jazz



Renewables: output of electricity and heat; Biomass: primary supply incl. waste; Nuclear: 33% efficiency

Upstream liberalised and technology development: consequently, supply surge/more producers; coal remains dominant in some regions.

Symphony



Renewables: output of electricity and heat; Biomass: primary supply incl. waste; Nuclear: 33% efficiency

Tighter supply (lower E&P), higher infrastructure costs, energy security drives reduced fossil use.

Total primary energy supply by region

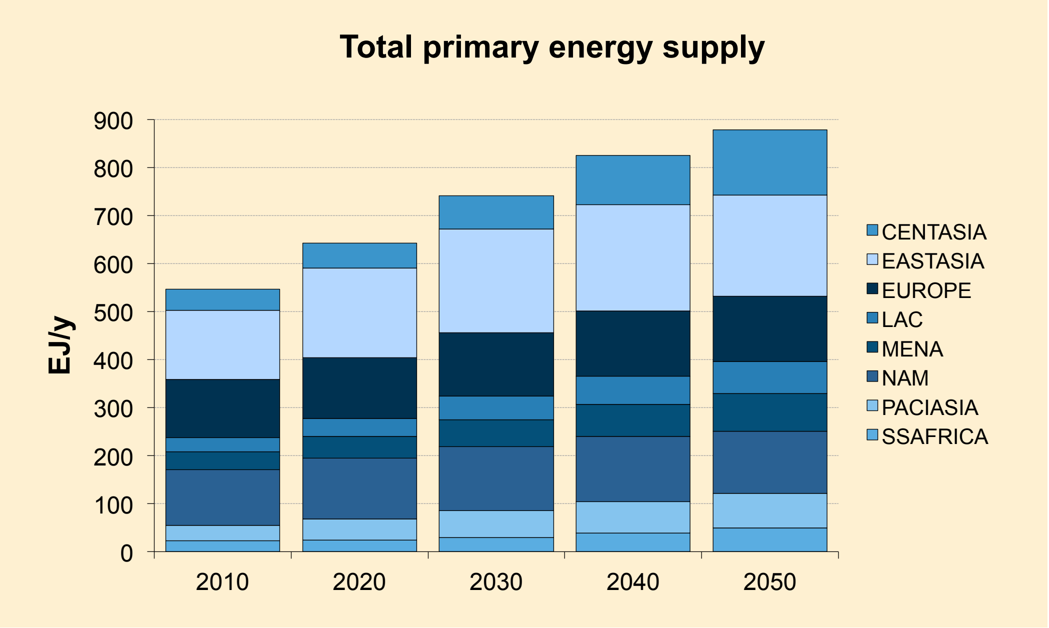
Figure 29 – Total primary energy supply by region

Source: World Energy Council (2013)

Historical data: IEA World Energy Statistics and Balances

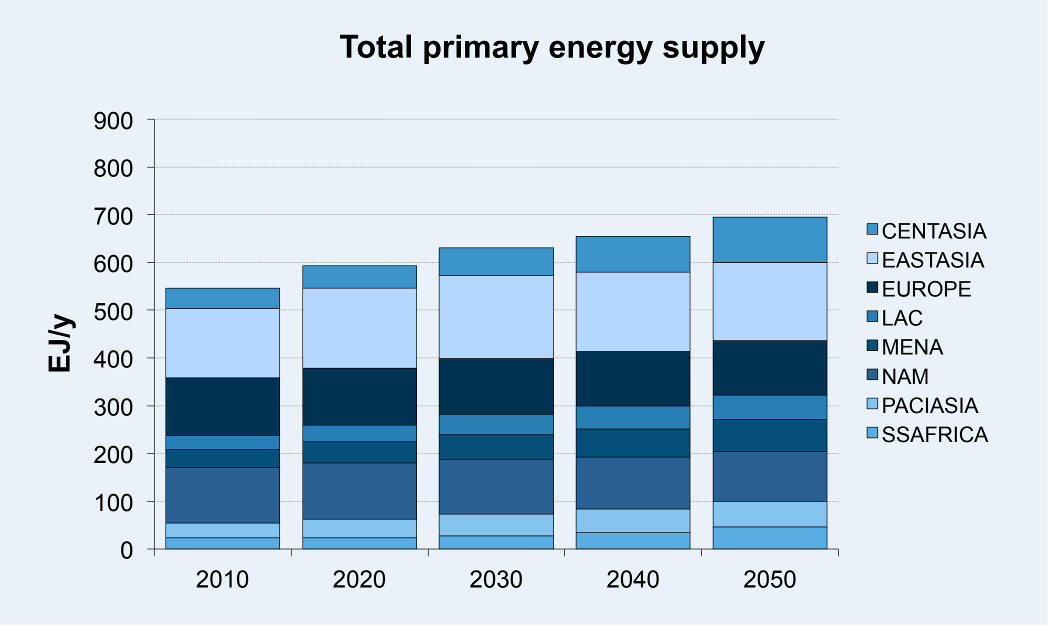
Regions: CENTASIA = Central and South Asia; EASTASIA = East Asia; EUROPE = Europe + Russia; LAC = Latin America and The Caribbean; MENA = Middle East and North Africa; NAM = North America; PACIASIA = Pacific Asia; SSAFRICA = sub-Saharan Africa

Jazz



India and China continue to grow. Growth in North America from cheap gas. Africa, Latin America grow strongly from a low base.

Symphony



Lower economic growth, resulting in lower energy demand.

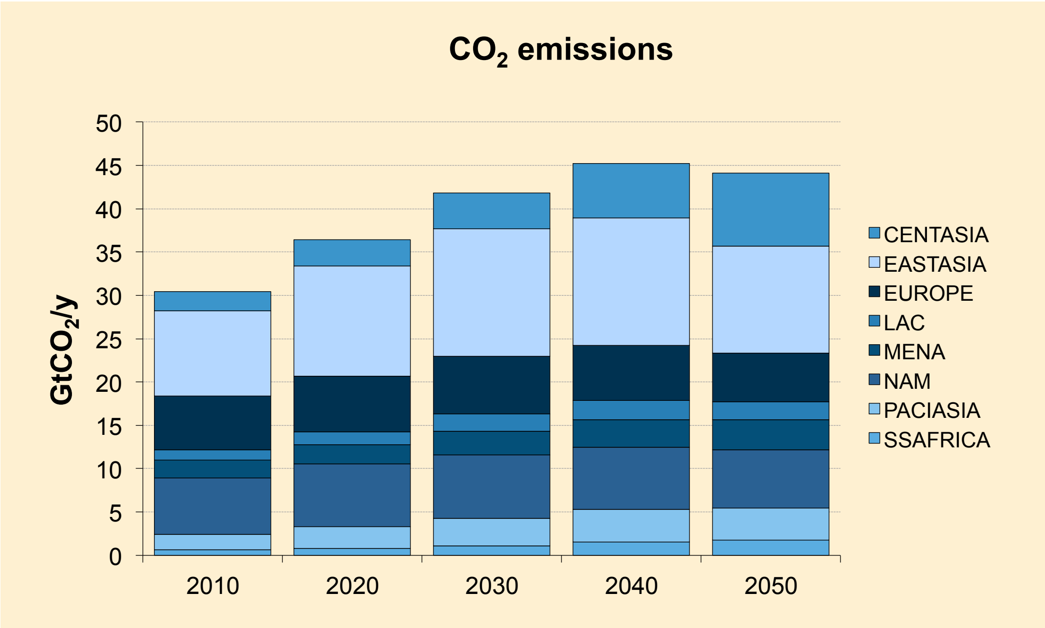
CO_2 emissions by region

Figure 30 – CO_2 emissions by region

Source: World Energy Council (2013)

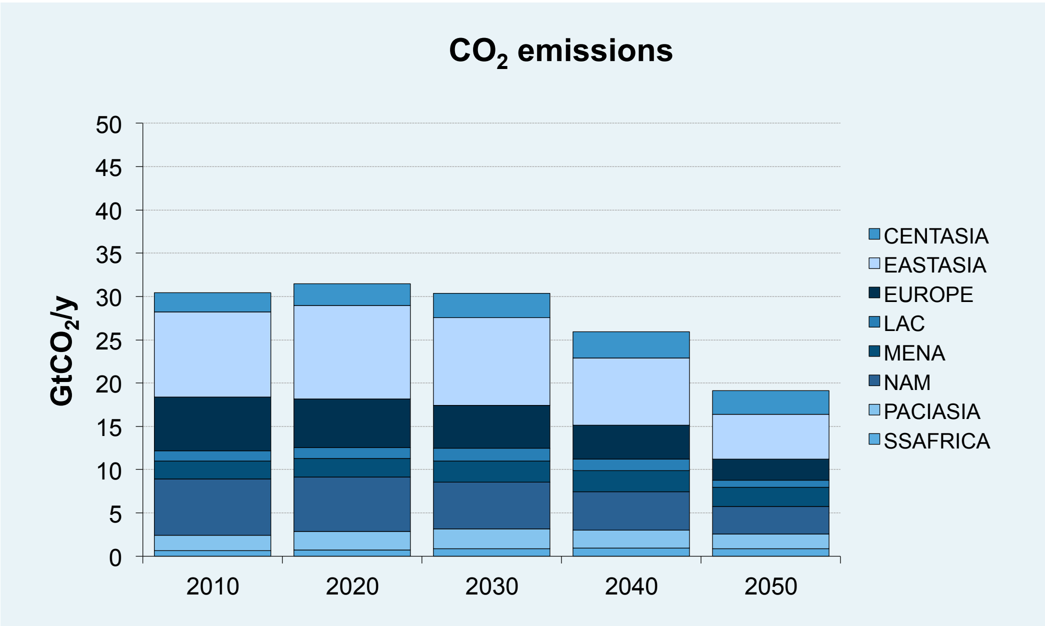
Historical data: IEA World Energy Statistics and Balances

Jazz



Energy choice based on price, quality and availability (free markets), limited regulations supporting low-carbon energy (but regional diversity). Consequently, carbon pricing only after significant income growth.

Symphony



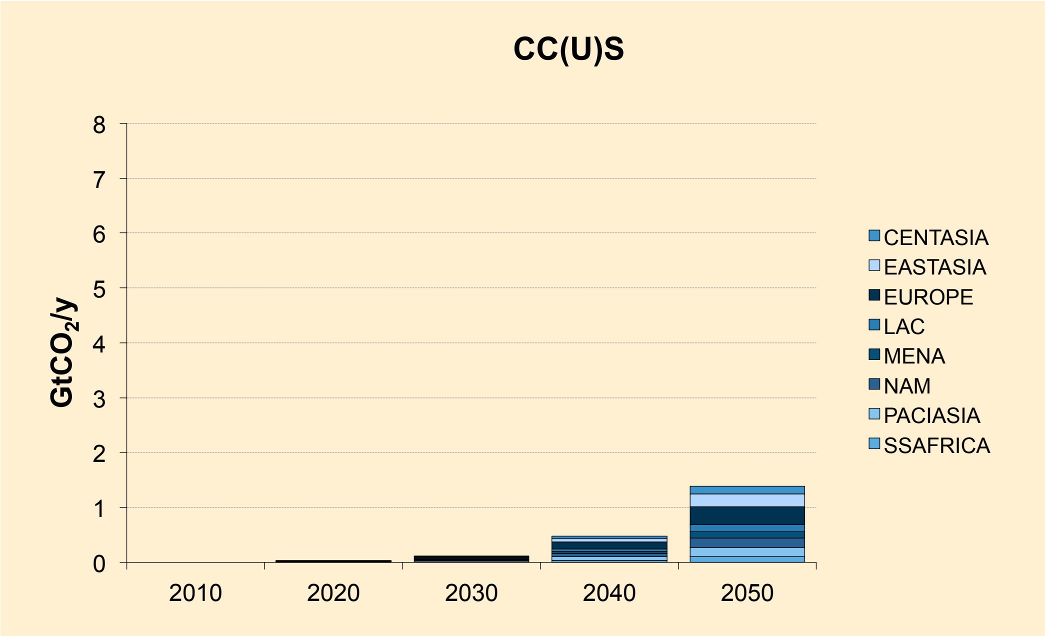
Priority to environmental sustainability, CO_2 reduction obligations, carbon taxes, CC(U)S mandates, renewable energy subsidies. Consequently, global carbon price emerges.

CC(U)S by region

Figure 31 – CC(U)S by region

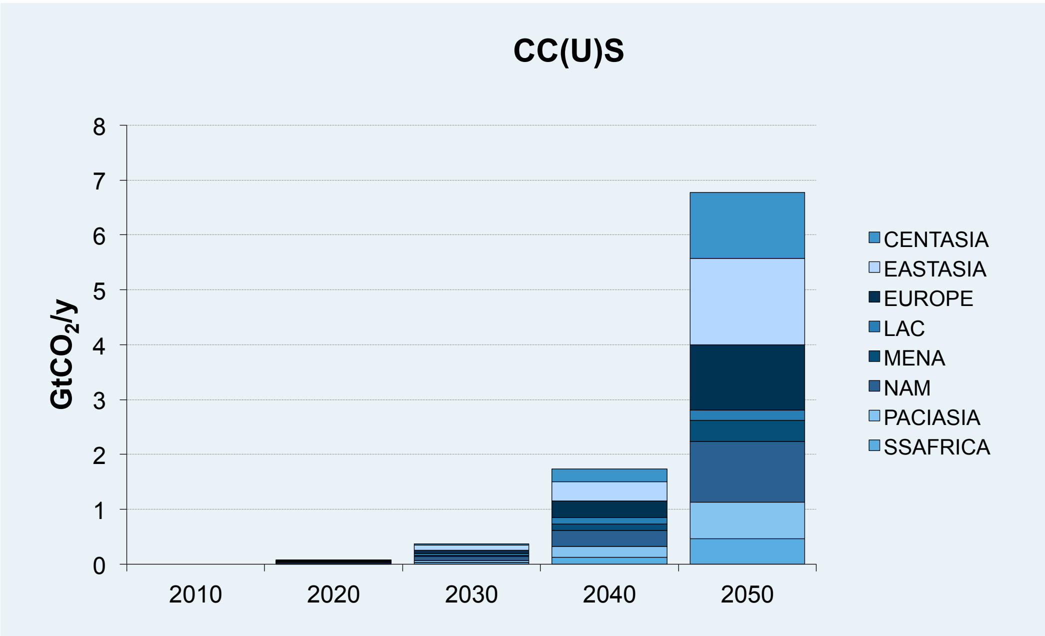
Source: World Energy Council (2013)

Jazz



Possibly ready at commercial scale by 2035. CC(U)S not adopted initially due to high costs/low carbon price. Commercial use in enhanced oil recovery. Wider adoption of CC(U)S post-2040.

Symphony



Entry of CC(U)S earlier due to government intervention. Government promotion. CC(U)S increasingly required on coal new build, also, CC(U)S in enhanced oil recovery.

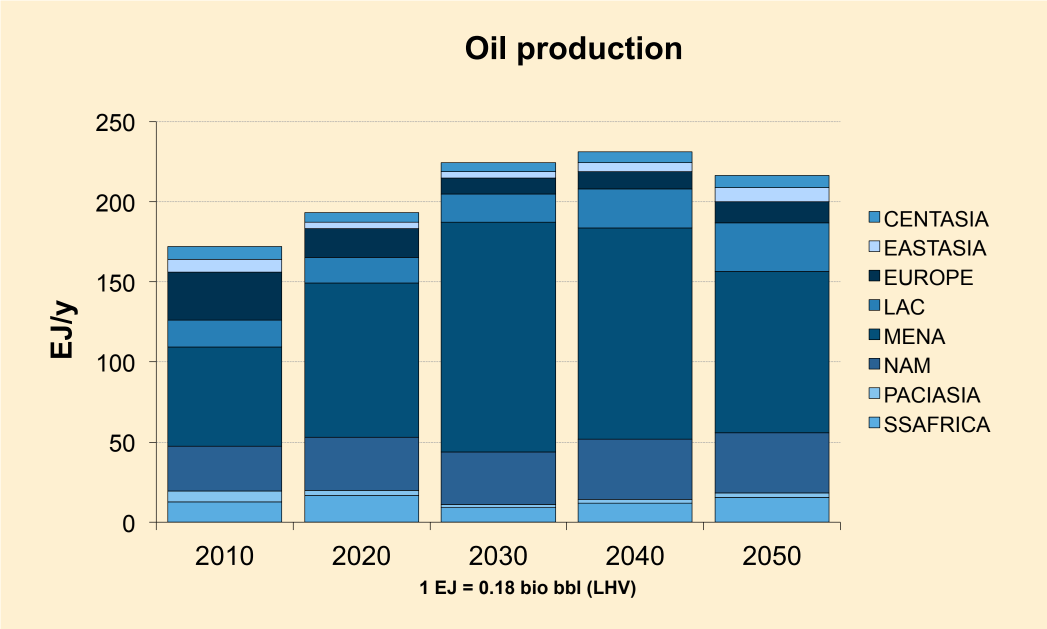
Production of oil by region

Figure 32 – Oil production by region

Source: World Energy Council (2013)

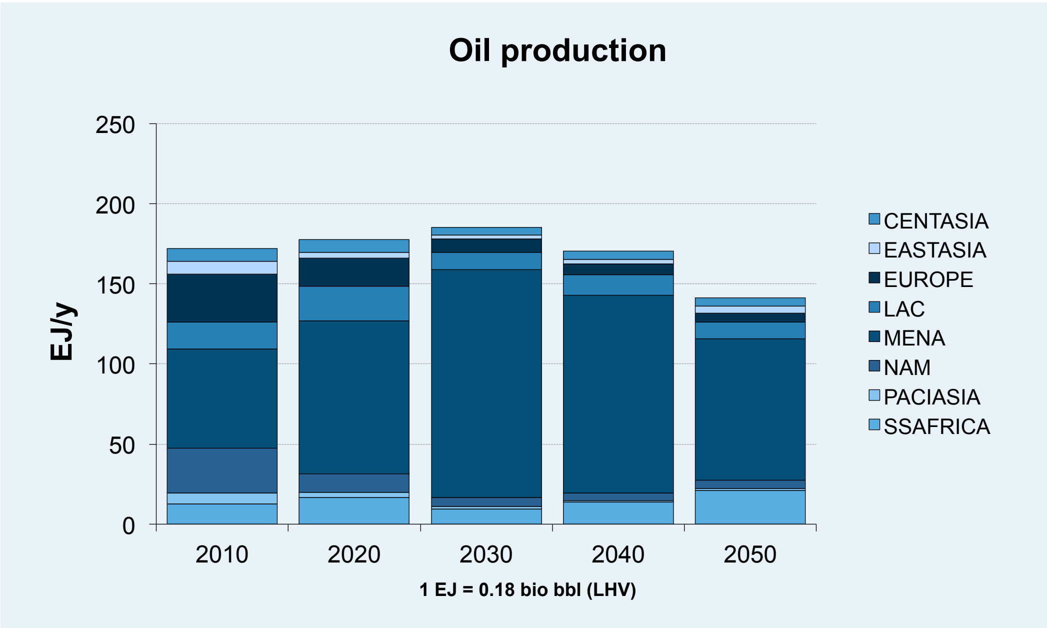
Historical data: IEA World Energy Statistics and Balances

Jazz



EOR technology development continues. Infrastructure on larger scale post-2020. Influence of NOCs increases. More E&P. Tighter markets until new producers enter.

Symphony



Less competition for energy resources, with tighter supply (lower E&P).

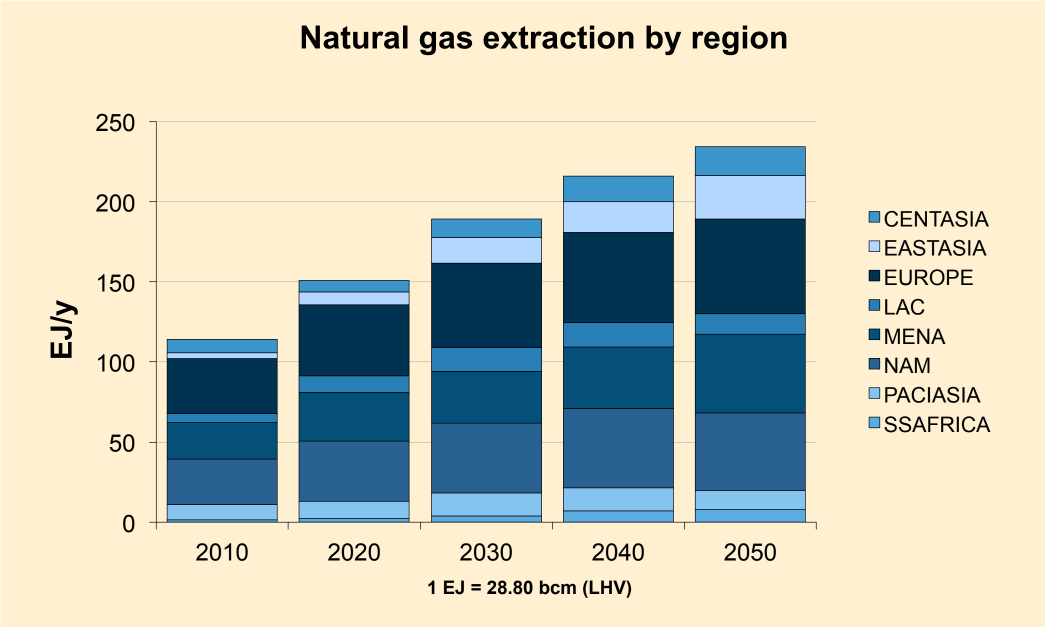
Natural gas extraction by region

Figure 33 – Natural gas extraction by region

Source: World Energy Council (2013)

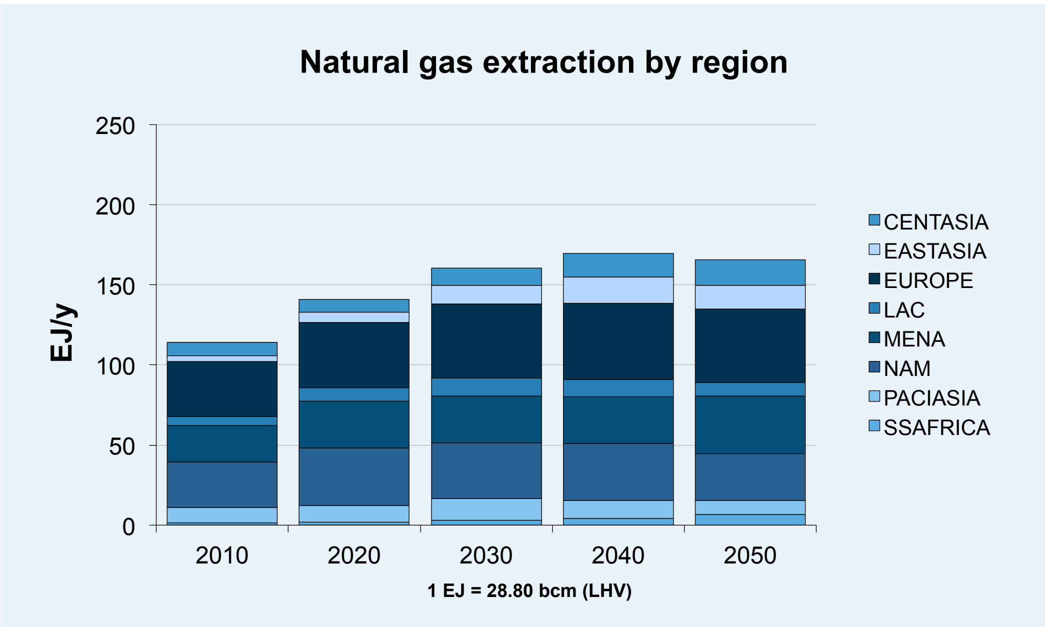
Historical data: IEA World Energy Statistics and Balances

Jazz



Infrastructure on larger scale post-2020. New unconventional energy kicks in when competitive, cheap gas is available in North America.

Symphony



Limited competition. Use of water in shale gas production will be a challenging constraint.

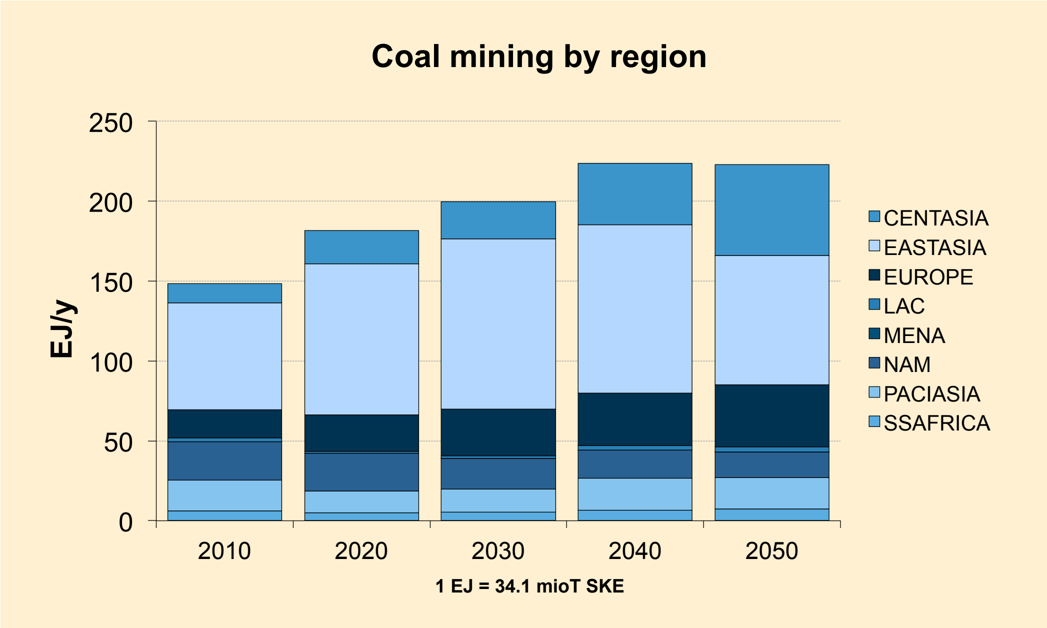
Coal mining by region

Figure 34 – Coal mining by region

Source: World Energy Council (2013)

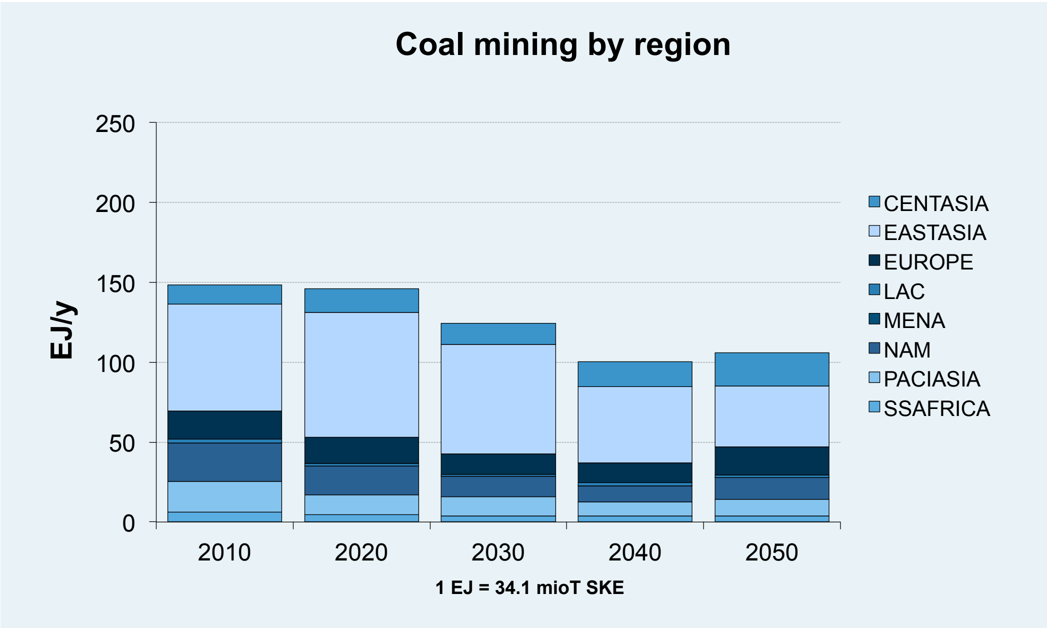
Historical data: IEA World Energy Statistics and Balances

Jazz



Coal-fired power to remain dominant in China and India. Shift to more advanced (efficient) coal generation.

Symphony



Share of coal in electricity generation expected to drop. Promoted for non-economic reasons, CC(U)S is increasingly needed for coal plants.

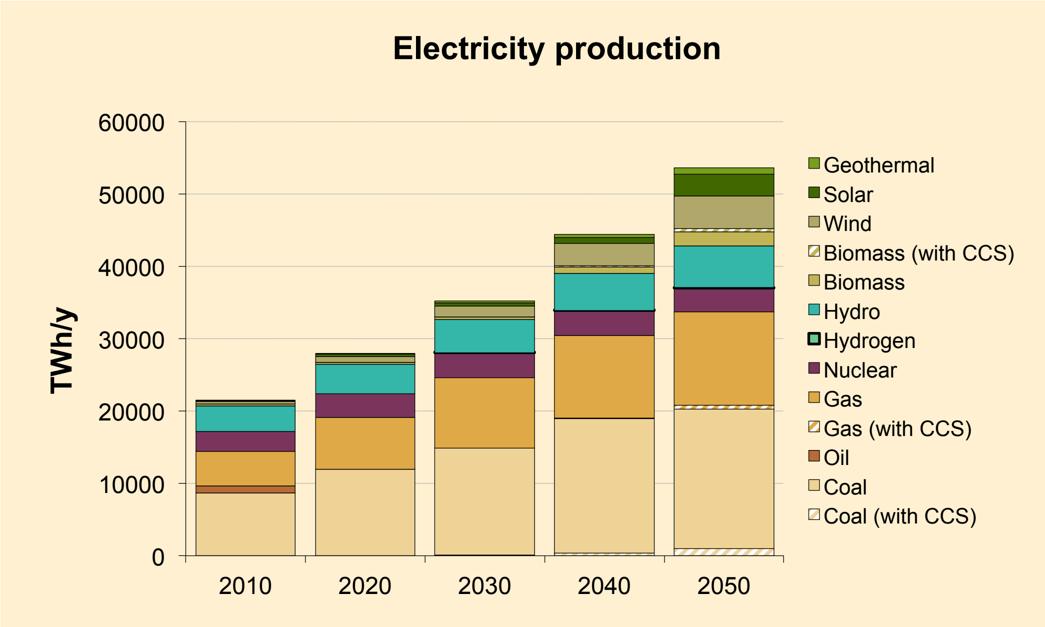
Electricity production by fuel type

Figure 35 – Electricity production by fuel type

Source: World Energy Council (2013)

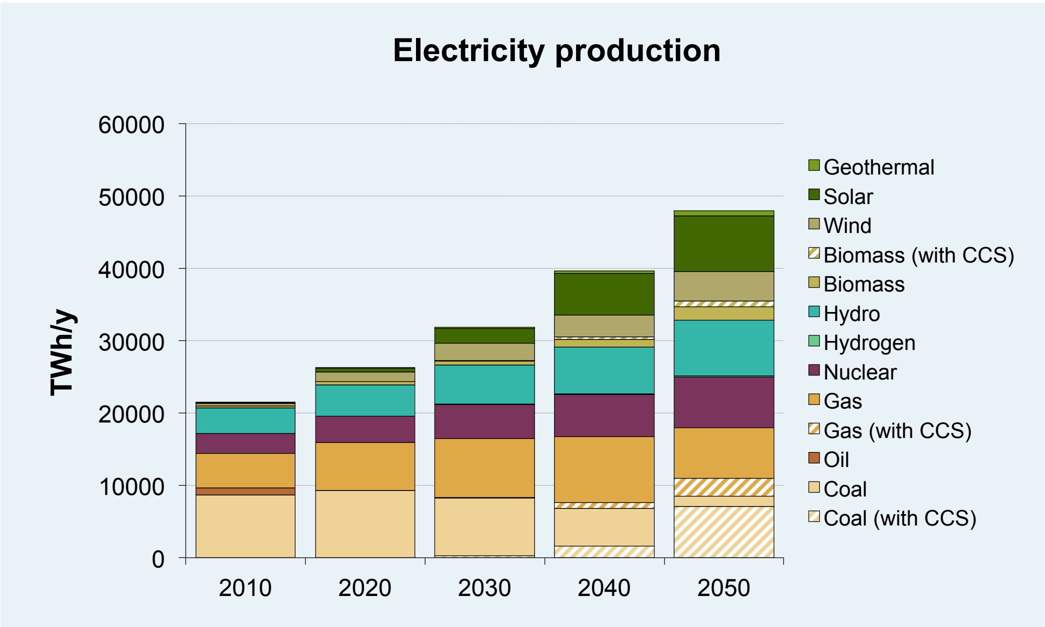
Historical data: IEA World Energy Statistics and Balances

Jazz



Coal: expected to remain dominant (regional). Supercritical, gas: share increases (especially in North America). Nuclear: mainly non-OECD. Renewable share increases, remains mostly hydro. Growth in solar the highest (12% pa vs. 7% wind/geothermal, 5% biomass, 1% hydro).

Symphony



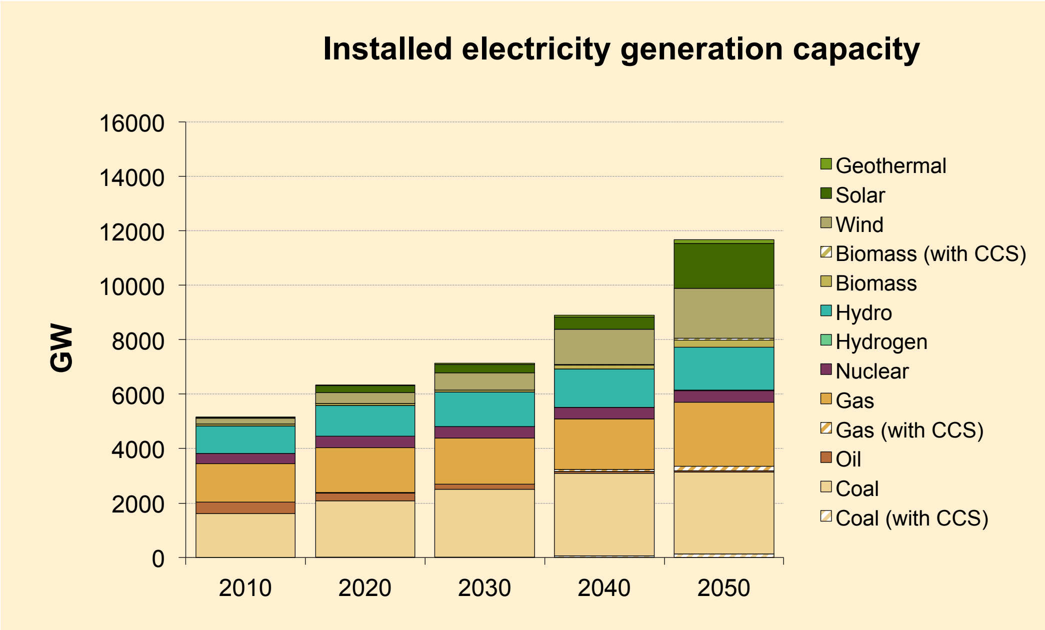
Coal: share drops. CC(U)S increasingly required on new build. Gas: share increases then drops. Nuclear: increasing, led by governments, more stable and quicker transition to renew. More hydro, especially in emerging countries. Growth in solar significant (15% p.a.).

Installed electricity generation capacity by primary energy type

Figure 36 – Installed electricity generation capacity by primary energy type

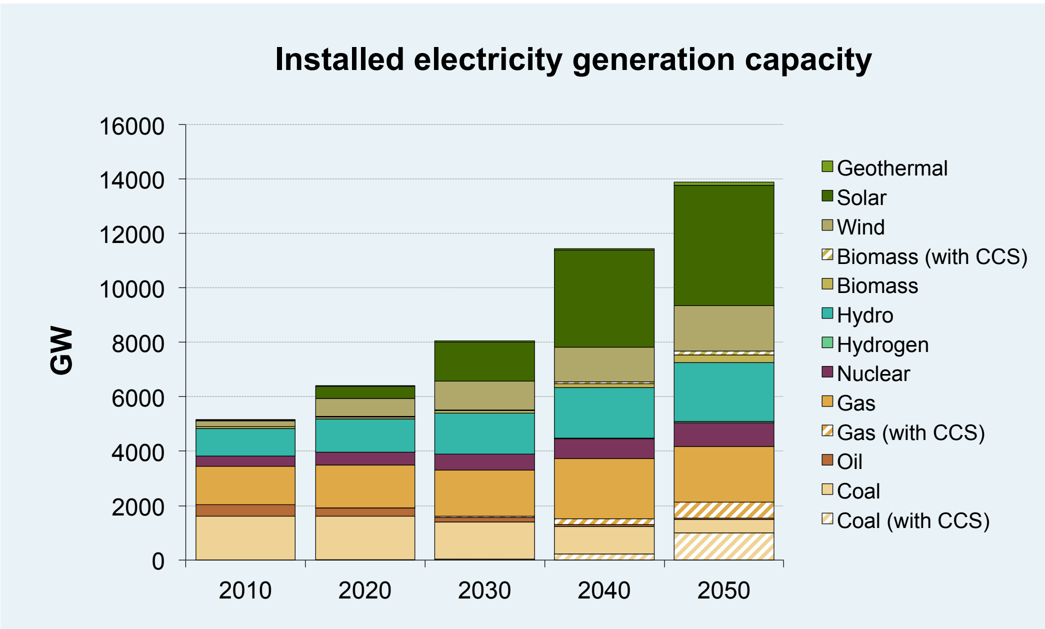
Source: World Energy Council (2013)

Jazz



Investment primarily based on economics. Existing coal plants to be replaced with supercritical, gas (CCGT).

Symphony



Government policies promote alternative technologies (renewables, nuclear). Investment directed/supported by governments. Limited private investment.

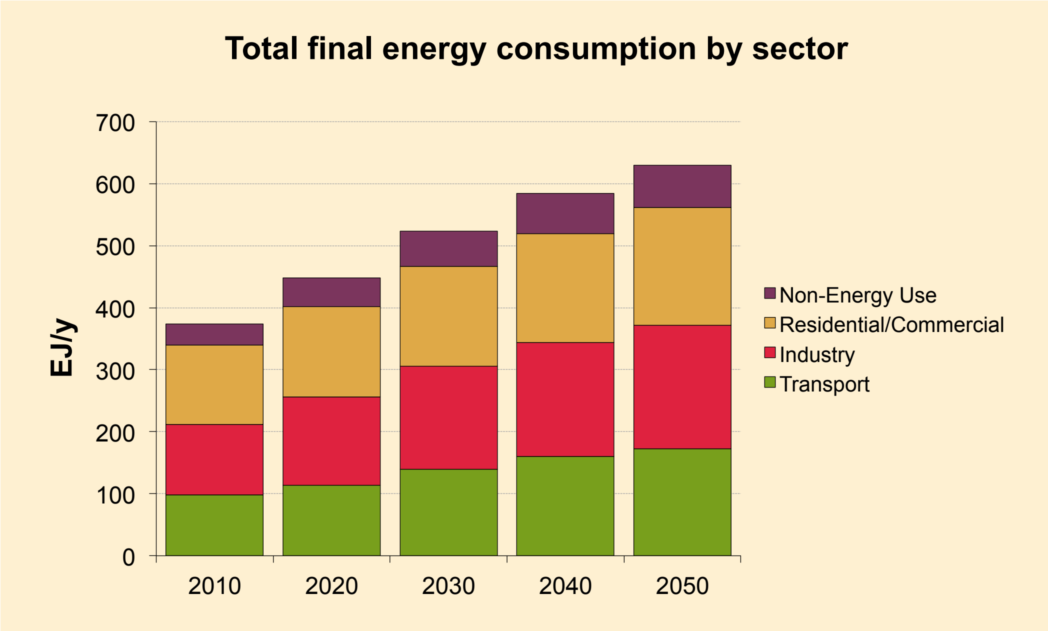
Total final energy consumption by sector

Figure 37 – Total final energy consumption by sector

Source: World Energy Council (2013)

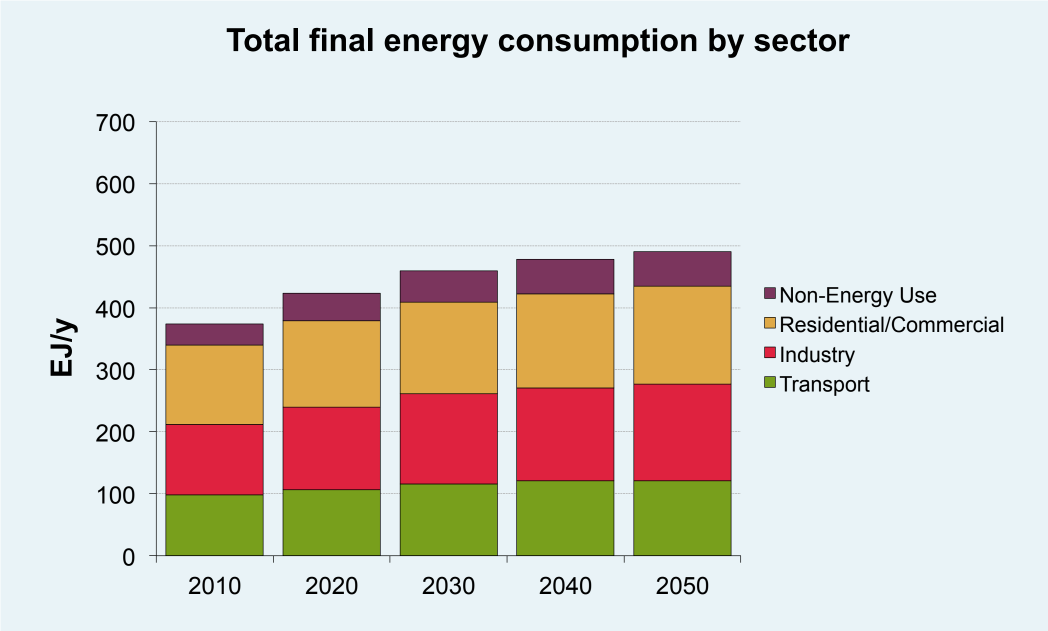
Historical data: IEA World Energy Statistics and Balances

Jazz



Industry: energy consumption linked to growth; reaches an all-time peak. Buildings: higher demand for air conditioning; more efficient in OECD countries.

Symphony



Industry: more moderate growth. Buildings: increase in savings, in all regions, especially emerging building codes.

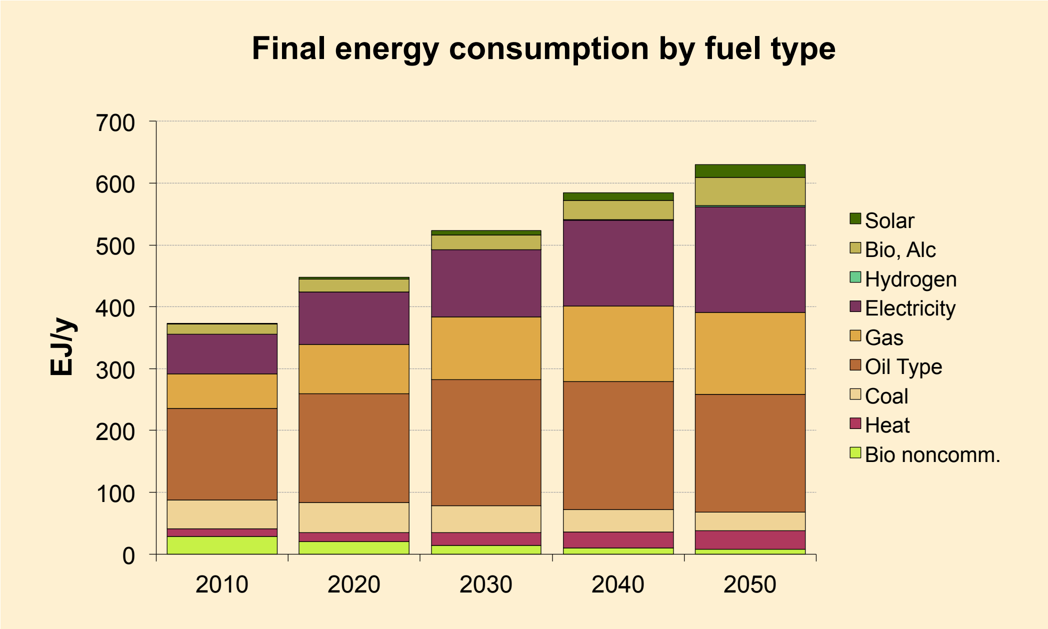
Final energy consumption by fuel type

Figure 38 – Final energy consumption by fuel type

Source: World Energy Council (2013)

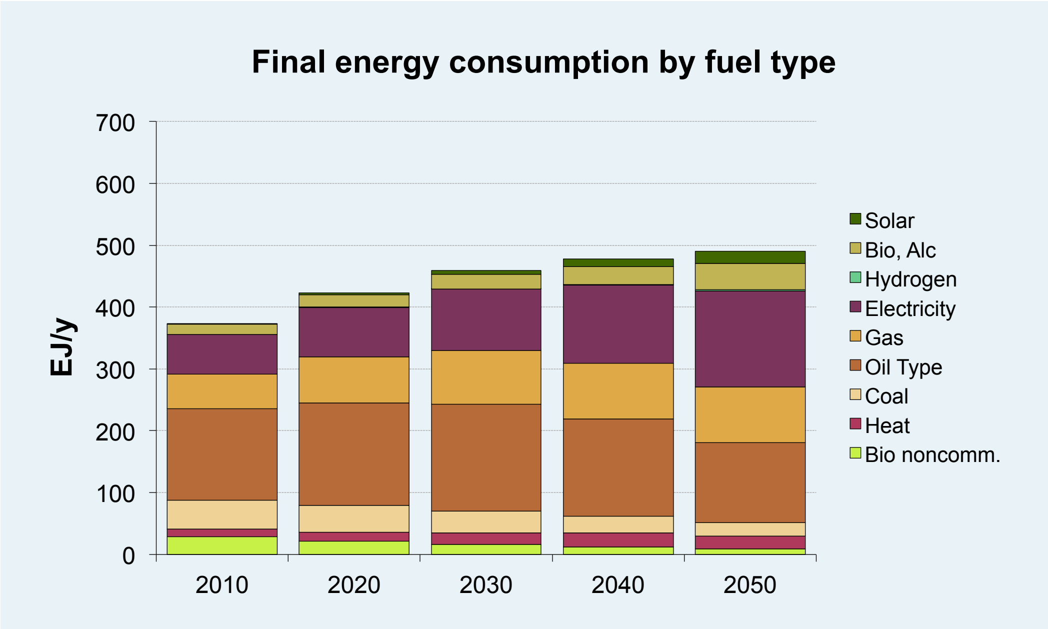
Historical data: IEA World Energy Statistics and Balances

Jazz



Higher economic growth, consequently higher energy consumption, and improved access to energy.

Symphony



Lower energy consumption, high impact of energy saving (and lower growth), switching away from fossil fuels (peak in 2030).

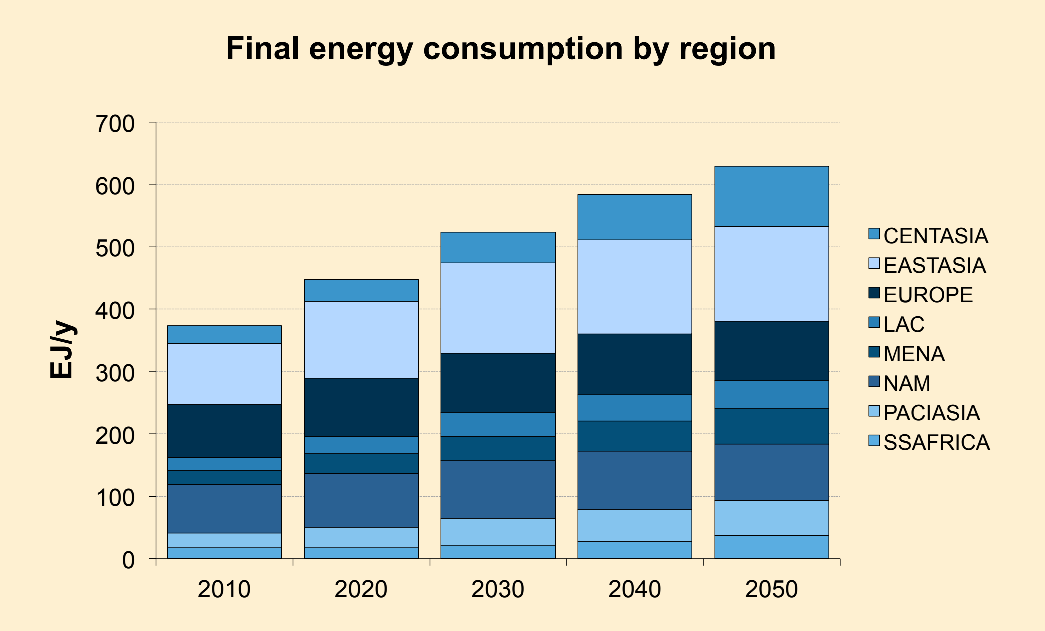
Final energy consumption by region

Figure 39 – Final energy consumption by region

Source: World Energy Council (2013)

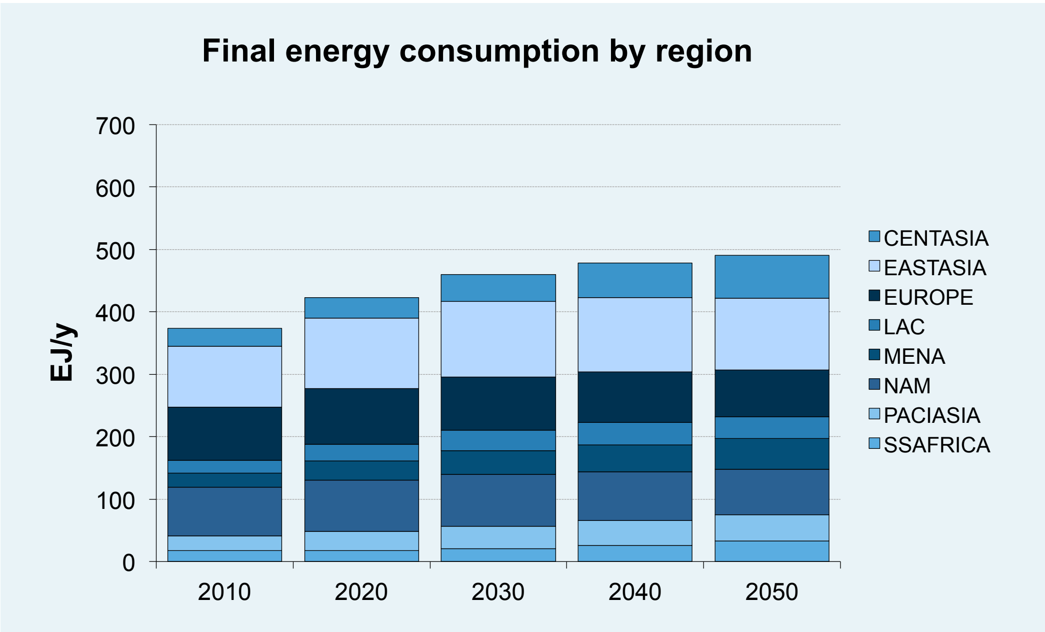
Historical data: IEA World Energy Statistics and Balances

Jazz



Growth to remain low in developed regions, higher in emerging economies. More efficiency in developed regions. Industrial demand high in manufacturing countries (USA, China), increasing efficiency, especially in emerging economies.

Symphony

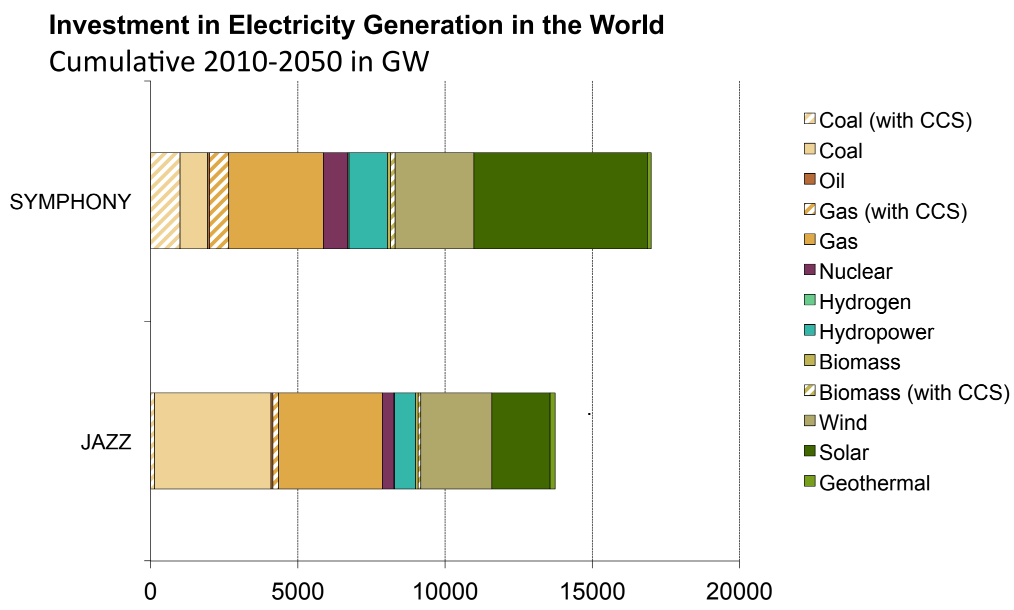


Energy saving/efficiency to increase (especially in emerging economies. Building codes, moderate growth.

Cumulative global investment needs by 2050

Figure 40 – Cumulative global investment needs by 2050 in electricity generation infrastructure

Source: World Energy Council (2013)



Symphony cumul. undiscounted investment:	**25.7**	**trillion US$2010**
Jazz cumul. undiscounted investment:	**19.3**	**trillion US$2010**

Jazz 2050	Symphony 2050
• Approximately US$19.3 trillion (US$2010)	• Approximately US$25.7 trillion (US$2010)

Table 17 – Cumulative global investment needs by 2050 in GW in electricity generation infrastructure

Source: World Energy Council (2013)

World	Jazz	Symphony
Coal (with CCS)	124	994
Coal	3,952	932
Oil	73	73
Gas (with CCS)	198	643
Gas	3,515	3,229
Nuclear	405	823
Hydrogen	15	41
Hydropower	726	1,312
Biomass	87	110
Biomass (with CCS)	80	146
Wind	2,409	2,679
Solar	1,980	5,892
Geothermal	179	129
Total	**13,743**	**17,003**

Note: Calculation of investment needs is for power generation only.

Table 18 – Global investment needs by 2050 (by region, in US$2010): Jazz scenario

Source: World Energy Council (2013)

	South & Central Asia	East Asia	Europe	Latin America & The Caribbean	Middle East & North Africa	North America	South-east Asia & Pacific	Sub-Saharan Africa	World
Coal (with CCS)	21	39	46	18	11	31	28	8	**203**
Coal	2,264	2,544	750	94	30	582	512	177	**6,953**
Oil	3	23	19	6	5	30	4	0	**90**
Gas (with CCS)	32	46	0	0	27	3	8	27	**143**
Gas	99	322	440	185	342	316	190	156	**2,050**
Nuclear	33	376	372	11	53	164	0	6	**1,013**
Hydrogen	15	1	0	2	0	0	4	5	**28**
Hydropower	229	556	371	309	13	291	100	82	**1,951**
Biomass	21	24	93	65	1	28	10	20	**261**
Biomass (with CCS)	9	23	82	26	13	45	28	13	**239**
Wind	155	375	767	169	9	985	159	96	**2,716**
Solar	164	707	267	382	153	148	545	581	**2,947**
Geothermal	42	73	47	79	17	154	239	70	**720**
Total	**3,087**	**5,108**	**3,254**	**1,346**	**676**	**2,777**	**1,826**	**1,241**	**19,314**

Note: Calculation of investment needs is for power generation only.

Table 19 – Global investment needs by 2050 (by region, in US$2010): Symphony scenario

Source: World Energy Council (2013)

	South & Central Asia	East Asia	Europe	Latin America & The Caribbean	Middle East & North Africa	North America	South-east Asia & Pacific	Sub-Saharan Africa	World
Coal (with CCS)	308	401	285	27	50	293	166	94	**1,623**
Coal	333	819	241	9	10	114	76	55	**1,656**
Oil	3	23	19	6	5	30	4	0	**90**
Gas (with CCS)	84	120	33	11	86	14	53	94	**494**
Gas	145	467	402	116	272	316	194	65	**1,978**
Nuclear	128	834	552	30	100	296	56	20	**2,016**
Hydrogen	62	0	0	8	0	1	12	22	**105**
Hydropower	535	1019	507	480	4	492	229	259	**3,525**
Biomass	46	24	95	116	9	28	11	10	**339**
Biomass (with CCS)	65	93	87	44	22	65	44	22	**441**
Wind	580	423	1021	111	3	986	68	84	**3,275**
Solar	1,111	3,161	1,122	360	845	1,603	859	598	**9,660**
Geothermal	62	30	29	1	11	212	103	70	**517**
Total	**3,461**	**7,413**	**4394**	**1,317**	**1,415**	**4,450**	**1,875**	**1,393**	**25,718**

Note: Calculation of investment needs is for power generation only.

6. WEC regional scenario stories: World Energy Scenarios to 2050

Regional scenario stories and regional scenario quantifications

The WEC as an organisation is committed to its members and to adopting a bottom-up approach when it comes to assessing and evaluating regional energy trends and forming its view on the future energy landscape.

To gain a better understanding of past energy trends, the WEC has assessed key energy issues both globally and regionally – most recently in its 2013 World Energy Issues Monitor. This publication is the latest of the WEC's annual assessment of the issues impacting on the global and regional energy sector, based on the views of the WEC's energy leadership community. These findings have provided the basis for the WEC's view moving forward. When doing so, the WEC has identified key global issues of high uncertainty and high impact that will shape the energy landscape until 2050, in particular:

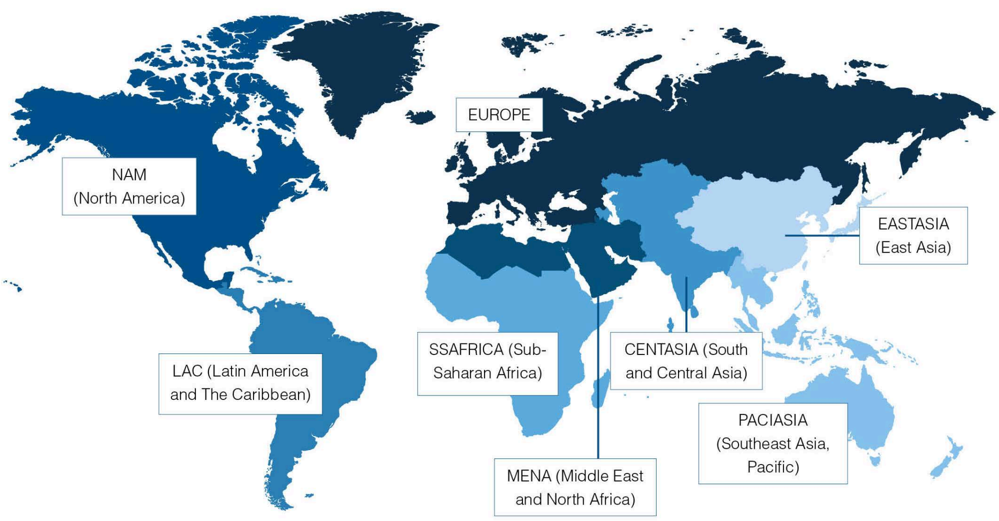
- The post-Fukushima nuclear future.
- The game-changing shale gas, especially in North America.
- Supply uncertainty and price volatility related to the 'Arab Decade' in the MENA region.
- The shift of demand to the East, in particular East Asia.
- Tumbling solar cell prices and related trade disputes between Europe and China or the US and China.
- Climate framework uncertainty.
- Global economic trends and the global recession.

The WEC's World Energy Scenarios to 2050 portray a picture of global energy. The model also looks at a defined set of regions, broken down as follows in alphabetical order and shown in Figure 41.

- Asia:
  - East Asia
  - South and Central Asia
  - Southeast Asia and Pacific
- Europe
- Latin America and The Caribbean
- Middle East and North Africa
- North America
- Sub-Saharan Africa

Figure 41 – WEC World Energy Scenarios to 2050: Regional breakdown

Source: World Energy Council (2013)



When carrying out its regional scenario workshops, the WEC has discussed and analysed the key drivers for the regional development in each of the eight regions in its scenario stories in great detail and translated them into regional scenario assumptions. These assumptions are presented in this section, together with the results from the quantifications with special focus on the regional energy mixes and the investment needs at a regional level up and until 2050 in power generation only. The figures for investment needs stated therefore only reflect the investment needs in power generation.

In the following section, the scenario assumptions are presented for each region, together with key results from the quantifications on a regional level. The full list of countries in each region can be found in Appendix 4.

Regional scenario stories and quantification results: Asia

Asia in general is the region that has witnessed strong and rapid economic growth in some of its states, including China and India. The WEC has comprehensively assessed the overall economic situation in all Asian countries and evaluated the potential impact on energy supply and demand going forward up to 2050.

Broadly speaking, the energy landscape in East Asia will be described by the development in China and, most importantly, in Japan and Korea. Meeting its energy demand and climate change considerations will dominate the energy agenda in China. The renewable energy growth, pilot ETS and energy-efficiency targets in China may also have some influence over the future energy policy and economy in this part of the world.

In South and Central Asia, India – as the biggest energy consumer in that region – will significantly shape the energy landscape up to 2050. India also needs to address the trilemma of meeting growing energy demand for its people, protecting the environment and ensuring sustainability. India's Perform, Achieve and Trade (PAT) energy-efficiency trading scheme might function as a role model for other regions. Growth in Vietnam and Myanmar (Burma) has been high and will continue to be so.

In Southeast Asia and Pacific, Australia and New Zealand will move closer together with the possible emergence of a regional market for CO_2. Australia will play a significant role as an energy exporter for LNG and coal. This has potentially spill-over effects on Japan and Korea.

The WEC's assumptions regarding the future development of Asian economies can be summarised at a glance as follows:

- The main engines of growth in the Asian region will be China and India – despite the high debt/GDP ratio in India and a slowing down of economic development in China.
- The region is diverse, with developed economies (Japan, Australia, Singapore, Hong Kong, New Zealand), developing economies (China, India, Thailand, Indonesia, Malaysia), and economies in transition.
- Energy consumption in the region is set to increase – per capita energy consumption in China and India is currently among the lowest in the region.
- Coal will be the dominant fuel, due to the reserves and infrastructure in place.
- The electricity gap will be dependent on nuclear.
- Oil continues to be increasingly important as societies become more motorised.
- Urban centres continue to grow in size as rural-to-urban influx continues.
- Water and food stresses grow as demand increases, with supply gaps becoming clear.
- Demographics become a concern in Japan (decline), China (future decline), and India (present increases).
- Energy access and dependence on non-commercial forms of energy continue to be poverty-related issues.
- Renewables with the greatest impact are hydro and biomass.

Asia as a region faces severe challenges, including:

- Increasing populations, especially in India, Southeast Asia (excluding China), and hence increasing demand for energy, minerals, ores, together with increasing demand for food and meat which increases the stress on land, feedstock, water, fertiliser and potential food and water shortages. Increasing food stresses vs. biofuel crop cultivation.
- Geopolitical tensions and uncertainties, including: (i) the supply of Russian gas to China – the construction of strategic pipelines, where Asian energy demand may be directly competing with European demand; (ii) Chinese conflict with Japan and Philippines over islands, gas fields, and Chinese sovereignty over Taiwan; (iii) Chinese border conflicts with India; (iv) the US manoeuvring in Asia aiming at maintaining its authority and demonstrating its power.
- Uncertainty over the availability and access to resources, including a potential minerals boom in Mongolia, with Afghanistan rising as a potential place for future mining operations. Growing Chinese control over rare earth metals could lead to potential shortages in the global market.
- Rising political uncertainty, e.g. in China, with challenges to the Chinese Communist party executive committee ushering in a multi-party system and the demand for change outpacing policy responses.
- Economic uncertainties, e.g. due to the rise of the middle class in China and India which leads to increasing demand for high-end services and products. Feeding people as they move into cities, leaving rural farming populations, will become a challenge. At the same time, the current pattern of agriculture with small land holdings is not suitable to maximise output. This has to be seen in conjunction with increasing urbanisation and hence the rise of the urban sprawl and a widening income gap across societies in transition economies: both factors will impact significantly on the overall economic development going forward.
- Growing interdependence in the region, with China being at the potential centrepoint of this development. The Australian mining industry might become heavily dependent on China, and almost all Asian economies will depend on Chinese growth/consumption in the future.
- Further uncertainties, such as increasing seismic activity and hence increasing risks for energy infrastructure/industry.
- Investment needs in infrastructure, including an electricity deficit (lack of capacity) in India.
- A question of who is going to deliver services and the question of whether the private sector will be meeting the needs of the population and hence displacing government services, i.e. a trend towards privatisation or private-public-partnerships.

The WEC's key assumptions regarding the overall development in all three Asian sub-regions are summarised in the following sections.

Regional scenario stories: East Asia

Jazz scenario

China continues to grow. Domestic demand for goods and services increases. The Chinese government liberalises the economy gradually and allows foreign companies to acquire majority stakes. The political system is also slowly overhauled, leading to more diversity and representation of views.

Japan experiences lower growth in the first part of the scenario period due to uncertainty around the country's energy policy. In the latter part of the scenario period, Japan opens its markets and liberalises its sectors and relaxes its immigration policies in the face of an ageing population and declining birth rates. These policies lead to a revitalisation of the Japanese economy, resulting in a higher growth rate in the latter part of the scenario period.

A carbon market in Korea emerges and the region develops stronger links to other carbon markets in Southeast Asia and the Pacific, most importantly Australia and New Zealand.

Symphony scenario

There will be a resurgence of nuclear in Japan. Nuclear in Japan will re-emerge in the later part of the scenario period as public opposition decreases. Gas will be used in the early part of the scenario period and will give way to the resurgence of nuclear power. Research into renewable energy will be carried out to ensure that it offers a clean and competitive solution to relying on fossil fuels. Geothermal energy emerges as a low-carbon power generation option.

The Chinese government continues to play a very central role and coordinates all aspects of policy. State-owned enterprises dominate the landscape and are supported by the government.

Regional quantification results: East Asia

Total primary energy supply: East Asia

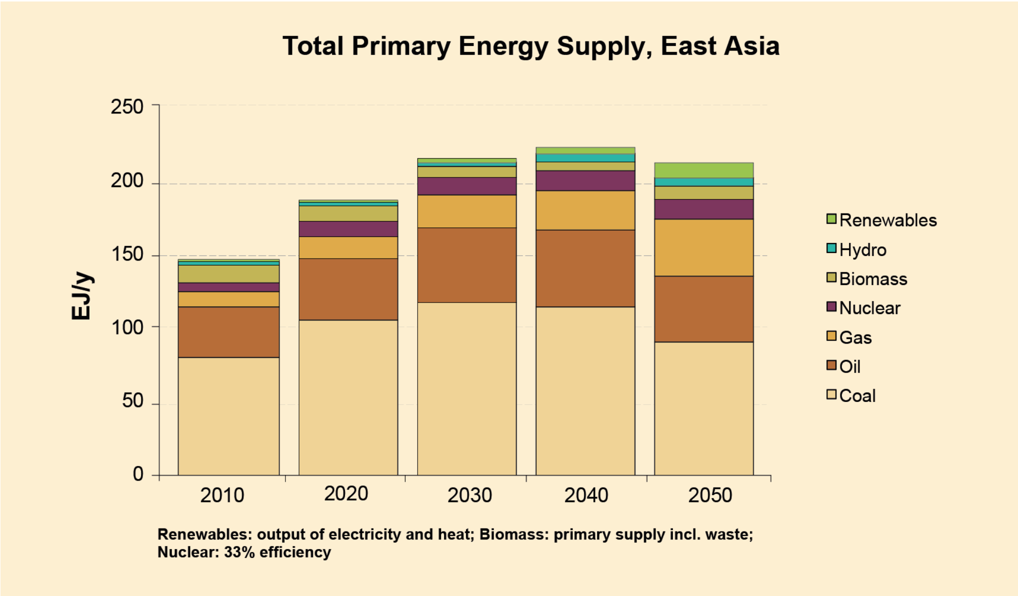
Total primary energy supply is taken as equivalent to the total primary energy consumption of each region.

Total primary energy supply for this region up to 2050 is shown in the following graphs.

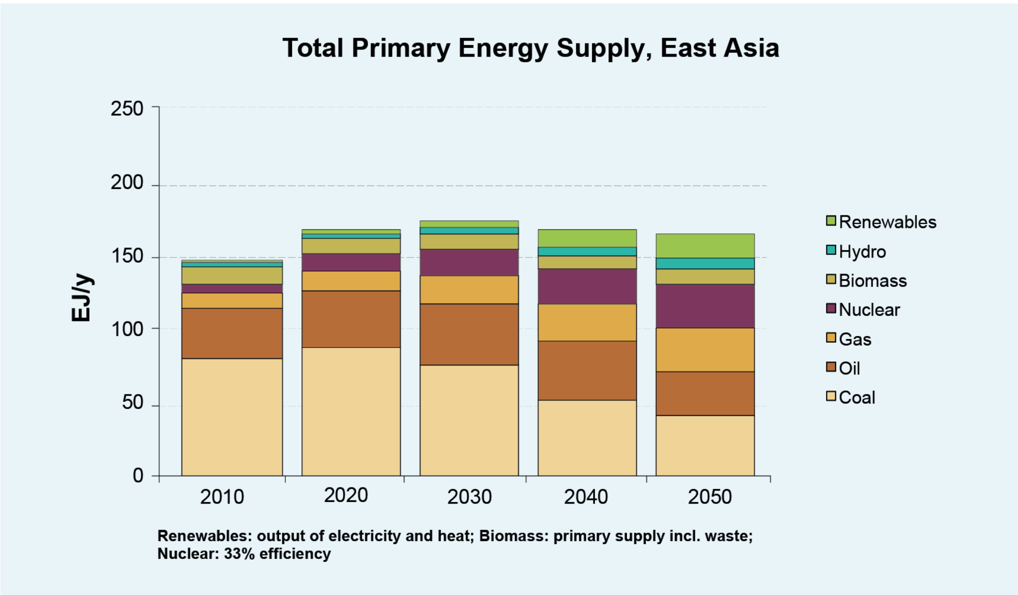
Figure 42 – Total primary energy supply (EJ/y) by fuel type: East Asia

Source: World Energy Council (2013)

Jazz



Symphony



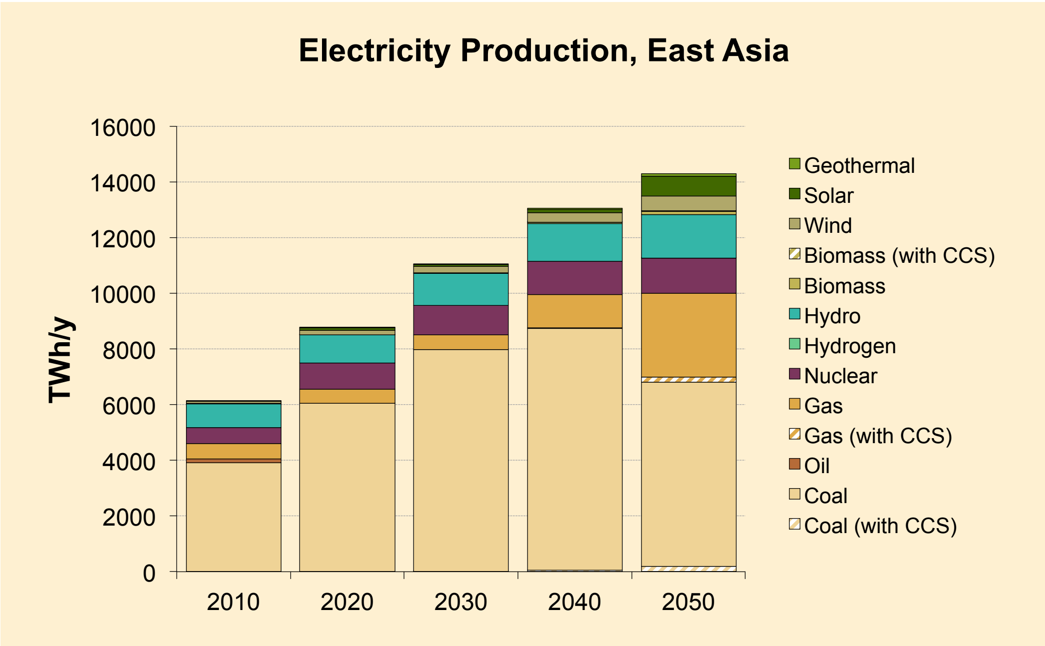
Electricity production and generating capacity by primary energy: East Asia

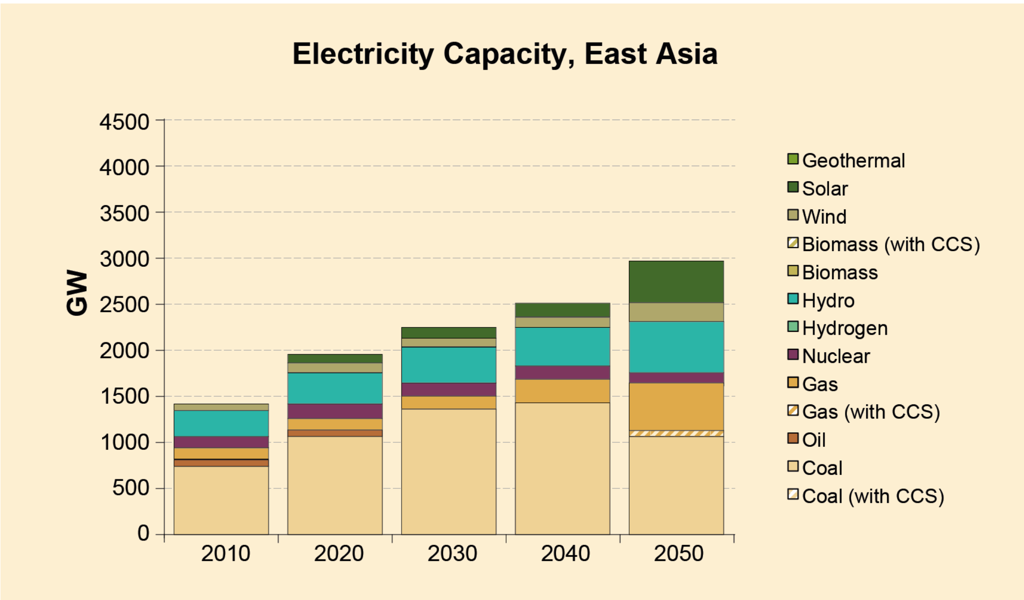
Figure 43 – Electricity production (TWh/y) and electricity generating capacity (GW) for East Asia in the Jazz scenario

Source: World Energy Council (2013)

Historical data: IEA World Energy Statistics and Balances

Jazz





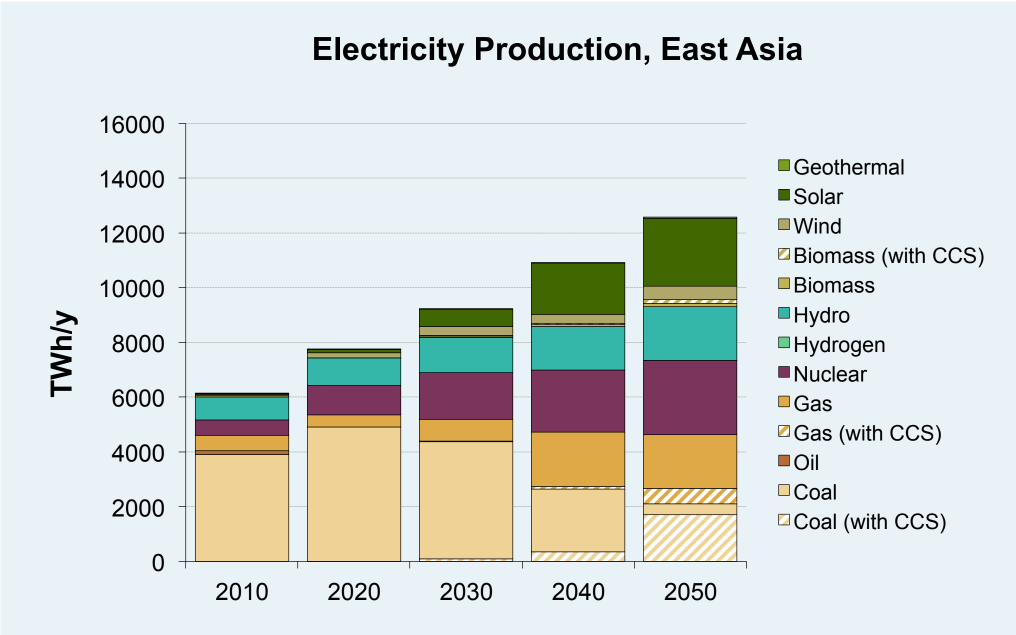
Dominance of supercritical coal generation. Penetration of gas from 2030 onwards.

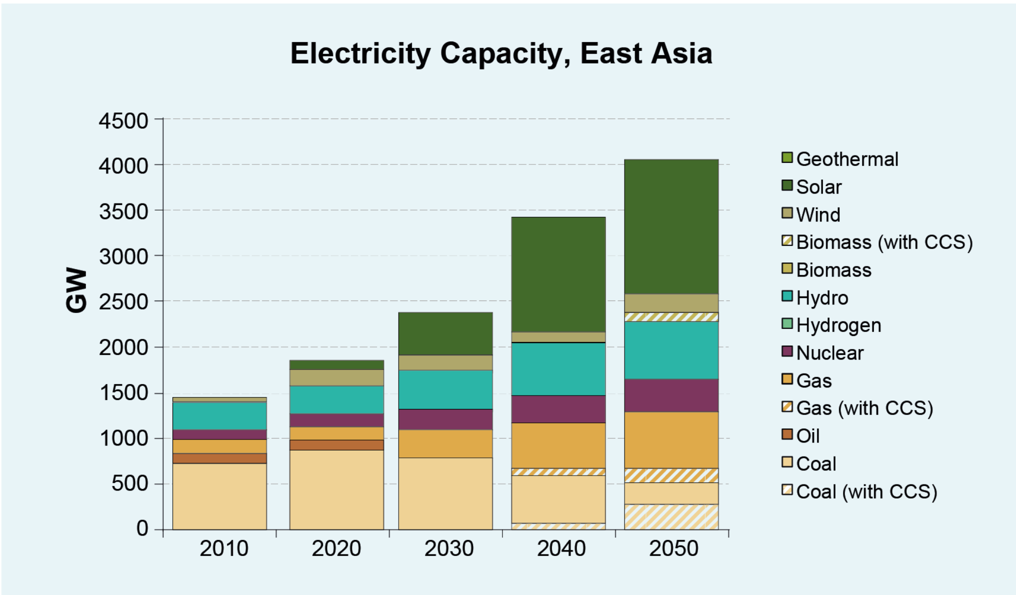
Figure 44 – Electricity production (TWh/y) and electricity generating capacity (GW) for East Asia in the Symphony scenario

Source: World Energy Council (2013)

Historical data: IEA World Energy Statistics and Balances

Symphony



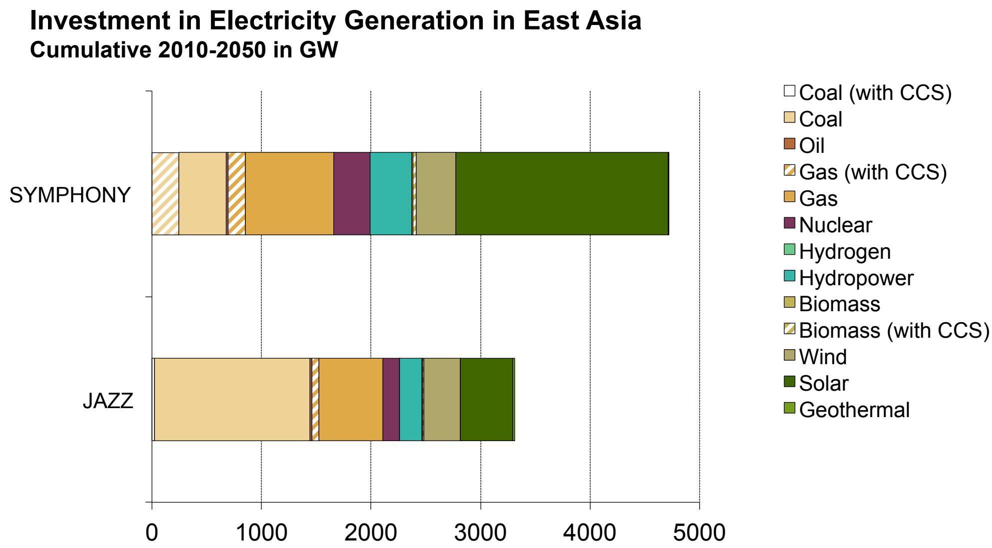


Coal generation switches to IGCC with CC(U)S in 2050. Nuclear share increases (led by governments). State investment is made in renewable energy.

Investment needs to 2050: East Asia

Figure 45 – Cumulative investment needs by 2050 in East Asia in electricity generation infrastructure

Source: World Energy Council (2013)



Symphony cumul. undiscounted investment:	**7.4**	**trillion US$2010**
Jazz cumul. undiscounted investment:	**5.1**	**trillion US$2010**

Jazz 2050	Symphony 2050
• Dominance of supercritical coal generation. • Penetration of gas from 2030 onwards.	• Coal generation switches to IGCC with CC(U)S in 2050. • Nuclear share increases (led by governments). • State investment is made in solar and other renewable energy.

Table 20 – Cumulative investment needs by 2050 in East Asia in GW in electricity generation infrastructure

Source: World Energy Council (2013)

	Jazz	Symphony
Coal (with CCS)	24	246
Coal	1,417	433
Oil	18	18
Gas (with CCS)	63	157
Gas	585	804
Nuclear	150	336
Hydrogen	1	0
Hydropower	207	379
Biomass	7	7
Biomass (with CCS)	8	31
Wind	337	362
Solar	476	1,940
Geothermal	18	8
Total	**3,311**	**4,721**

Note: Calculation of investment needs is for power generation only.

Regional scenario stories: South and Central Asia

Jazz scenario

Central Asia: Central Asian countries increase their gas output and supply more gas to the EU.

India continues to grow despite high debt levels. Indian growth remains heavily dependent on infrastructure investment which is assumed to occur in this scenario.

Symphony scenario

Central Asia: This region will become increasingly important as a source of gas to Europe.

The Indian government faces mounting pressure to meet the demands of an increasingly urbanising and developing country. State investment is made in renewable energy technologies and their share in the primary energy mix slowly increases. Fossil fuels continue to remain dominant well into the middle part of the scenario period. CC(U)S is adopted thanks to significant international financial support.

Regional quantification results: South and Central Asia

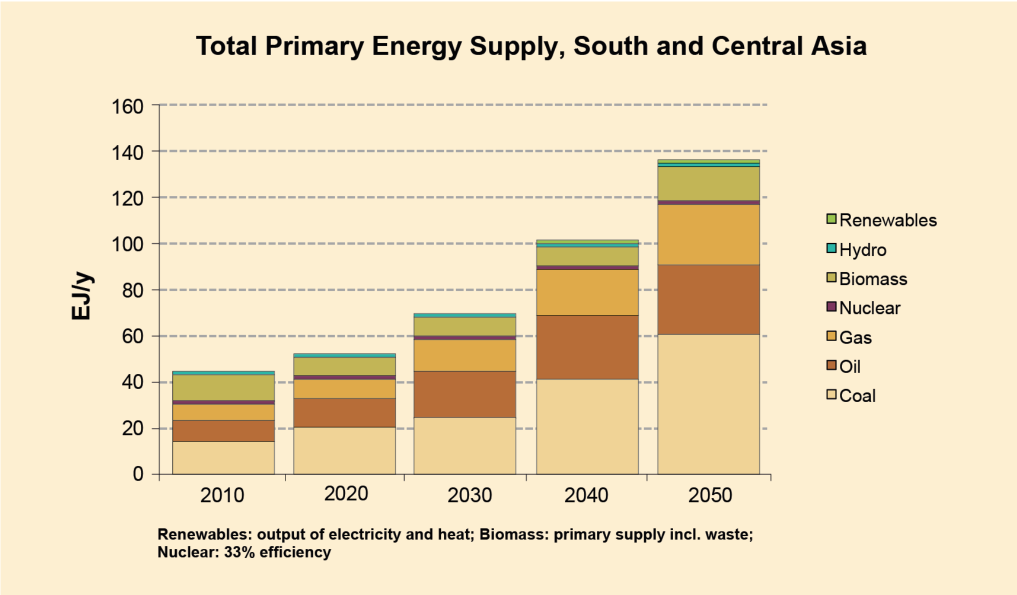
Total Primary Energy Supply: South and Central Asia

Total primary energy supply for this region up to 2050 is shown in the following graphs.

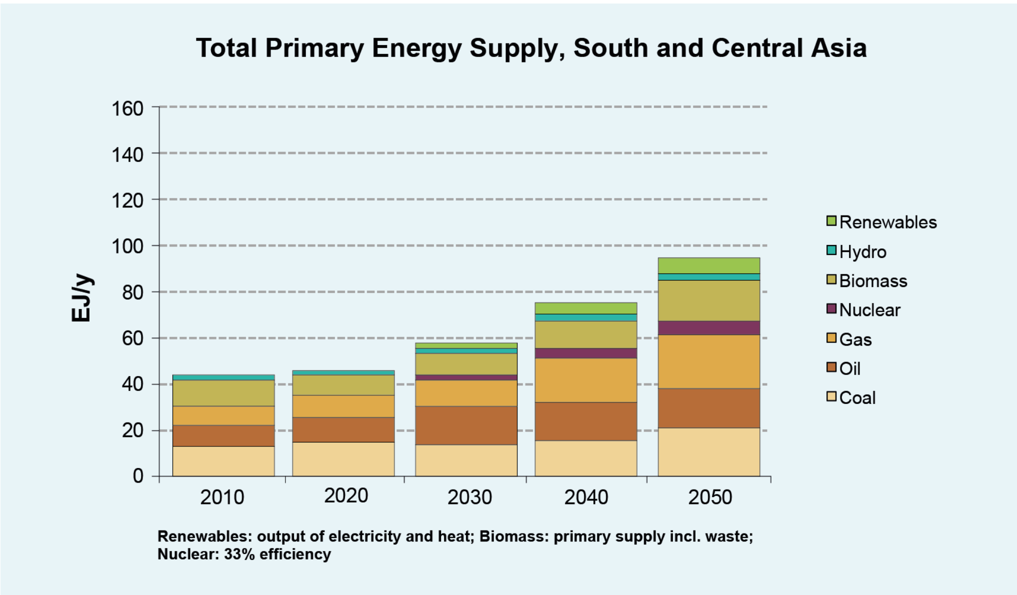
Figure 46 – Total primary energy supply (EJ/y) by fuel type: South and Central Asia

Source: World Energy Council 2013

Jazz



Symphony



Deployment of coal is a key issue in South and Central Asia, accounting for a large share in the difference of total primary energy supply between the two scenarios in 2050.

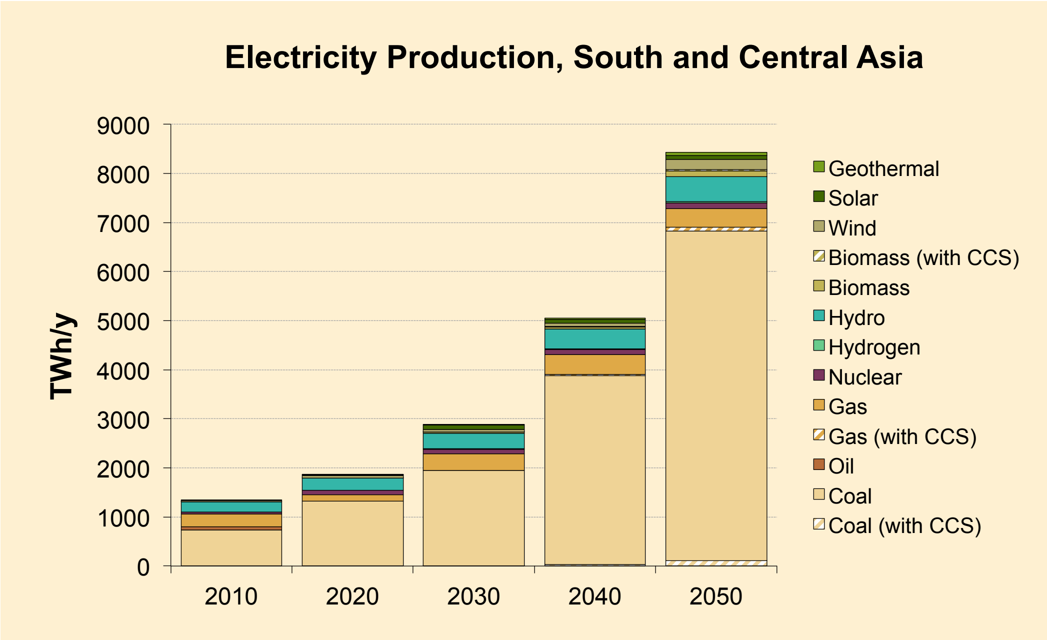
Electricity production and generating capacity by primary energy: South and Central Asia

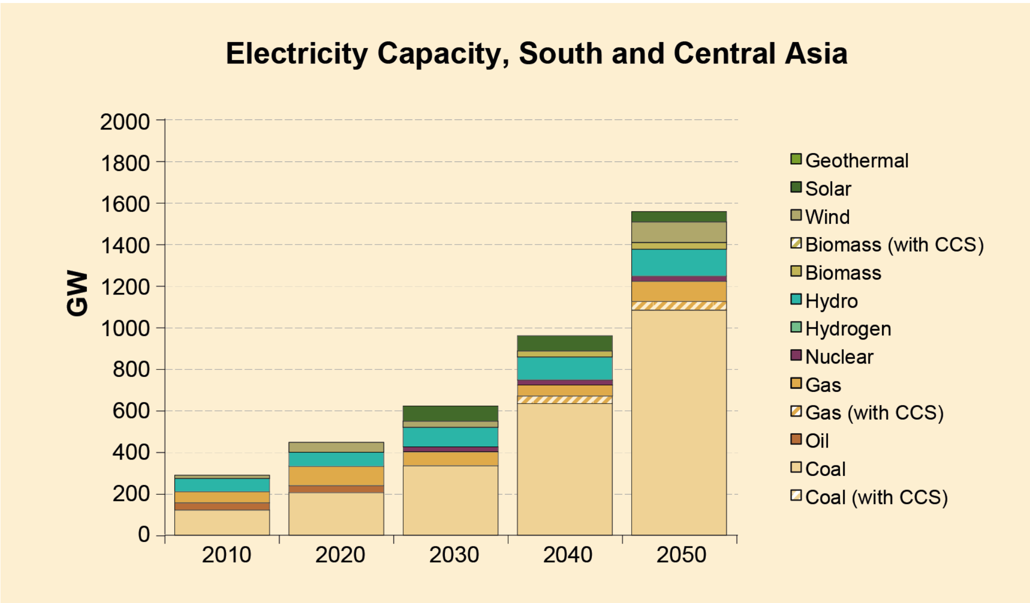
Figure 47 – Electricity production (TWh/y) and electricity generating capacity (GW) for South and Central Asia in the Jazz scenario

Source: World Energy Council (2013)

Historical data: IEA World Energy Statistics and Balances

Jazz





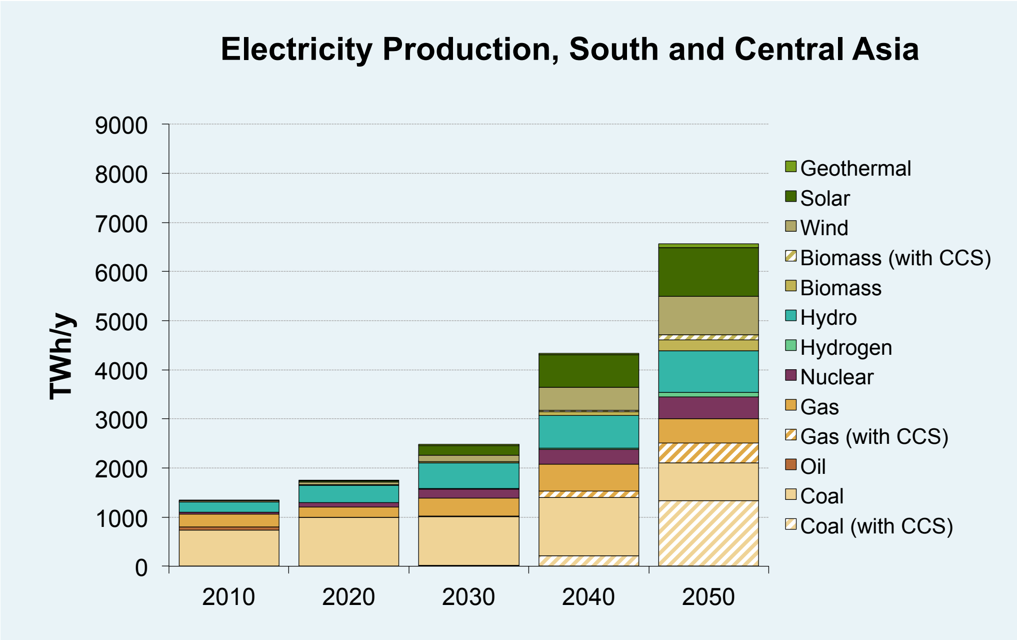
Coal-based generation dominant, with penetration of gas into the fuel mix.

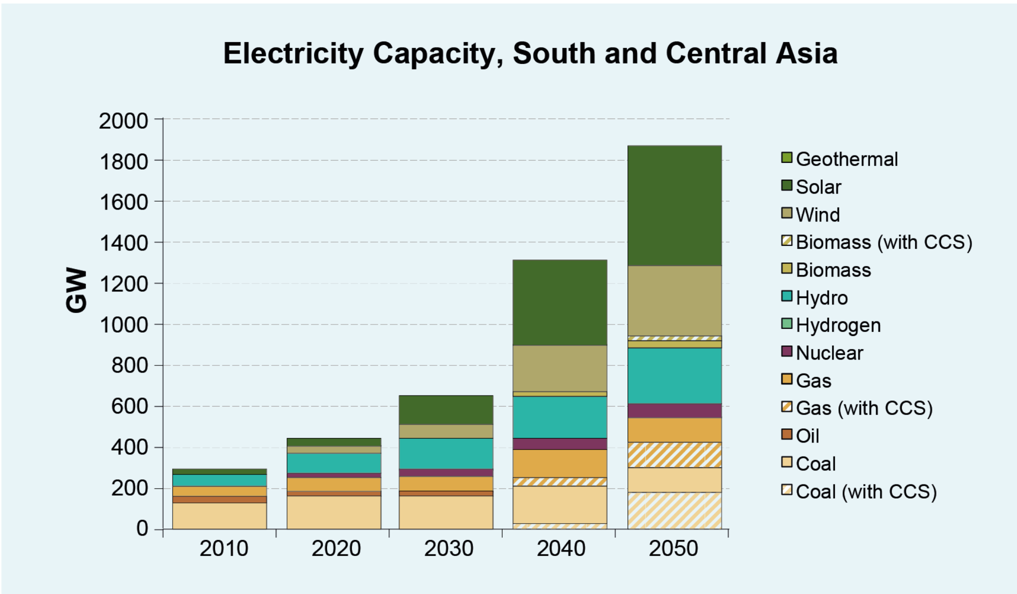
Figure 48 – Electricity production (TWh/y) and electricity generating capacity (GW) for South and Central Asia in the Symphony scenario

Source: World Energy Council (2013)

Historical data: IEA World Energy Statistics and Balances

Symphony



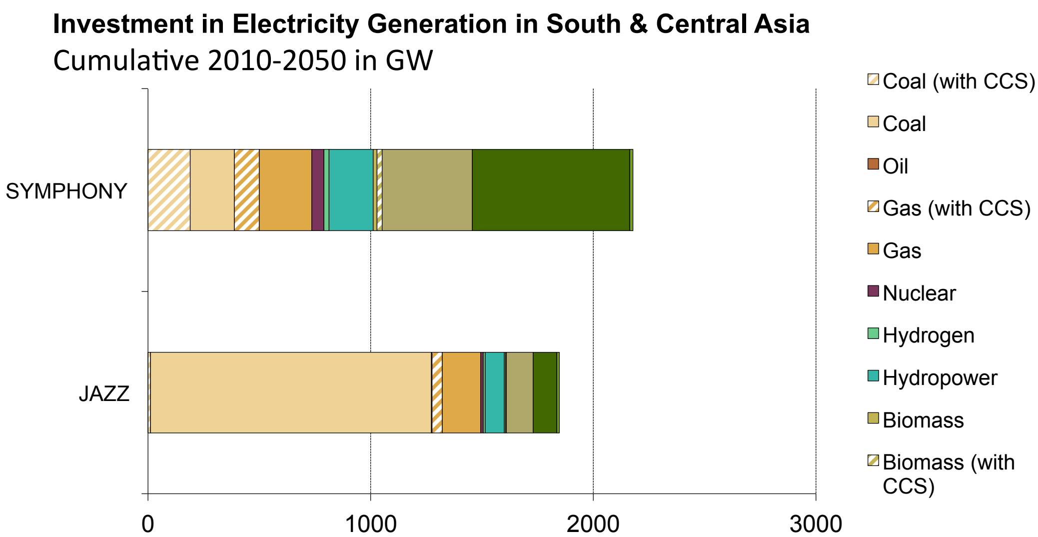


CC(U)S is adopted due to international financial support, with state investment in renewables.

Investment needs to 2050: South and Central Asia

Figure 49 – Cumulative investment needs by 2050 in South and Central Asia in electricity generation infrastructure

Source: World Energy Council (2013)



Symphony cumul. undiscounted investment: 3.5 trillion US$2010

Jazz cumul. undiscounted investment: 3.1 trillion US$2010

Jazz 2050	Symphony 2050
• Coal-based generation. • Penetration of gas into the fuel mix.	• CC(U)S is adopted due to international financial support. • State investment in renewables.

Table 21 – Cumulative investment needs by 2050 in South and Central Asia in GW in electricity generation infrastructure

Source: World Energy Council (2013)

South and Central Asia	Jazz	Symphony
Coal (with CCS)	13	190
Coal	1,261	197
Oil	3	3
Gas (with CCS)	44	110
Gas	173	235
Nuclear	13	55
Hydrogen	8	24
Hydropower	85	199
Biomass	7	17
Biomass (with CCS)	3	22
Wind	119	406
Solar	107	707
Geothermal	11	16
Total	**1,847**	**2,181**

Note: Calculation of investment needs is for power generation only.

Regional scenario stories: Southeast Asia and Pacific

Jazz scenario

Australia continues to grow as it becomes a main supplier of gas to the Asia-Pacific region (Japan, China and India). Most of the future growth in LNG is expected to come from Australia. Carbon markets in Australia and New Zealand emerge, and develop links to other carbon markets.

Symphony scenario

Australia will build fossil-fuelled power plants (gas and coal) and be subject to a carbon price under government mandates. Solar emerges as a viable option for domestic power production. It is envisioned that in this scenario, a carbon price is imposed in most countries in the East Pacific region.

Regional quantification results: Southeast Asia and Pacific

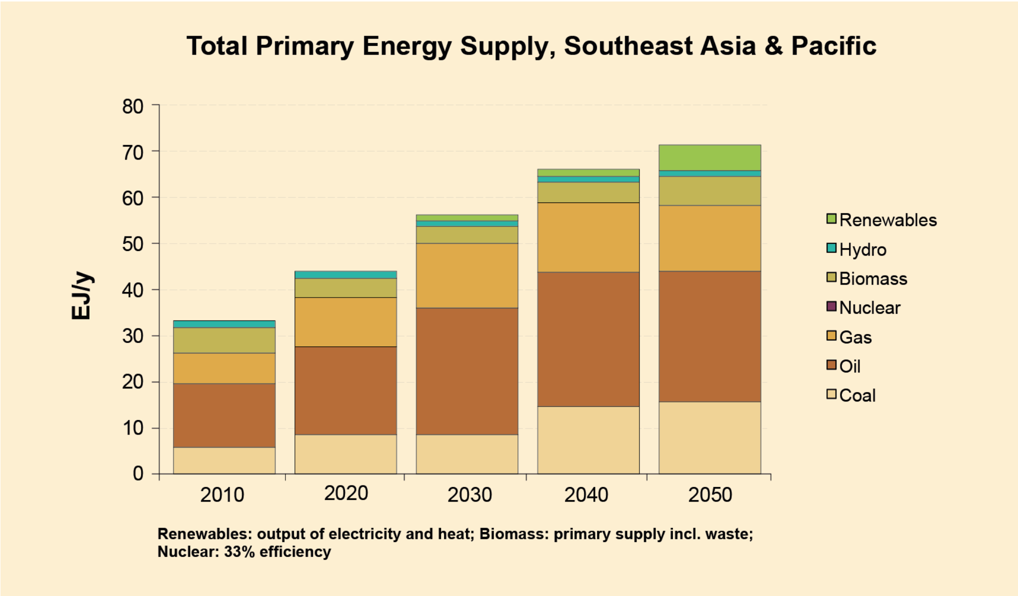
Total primary energy supply: Southeast Asia and Pacific

Total primary energy supply for this region up to 2050 is shown in the following graphs.

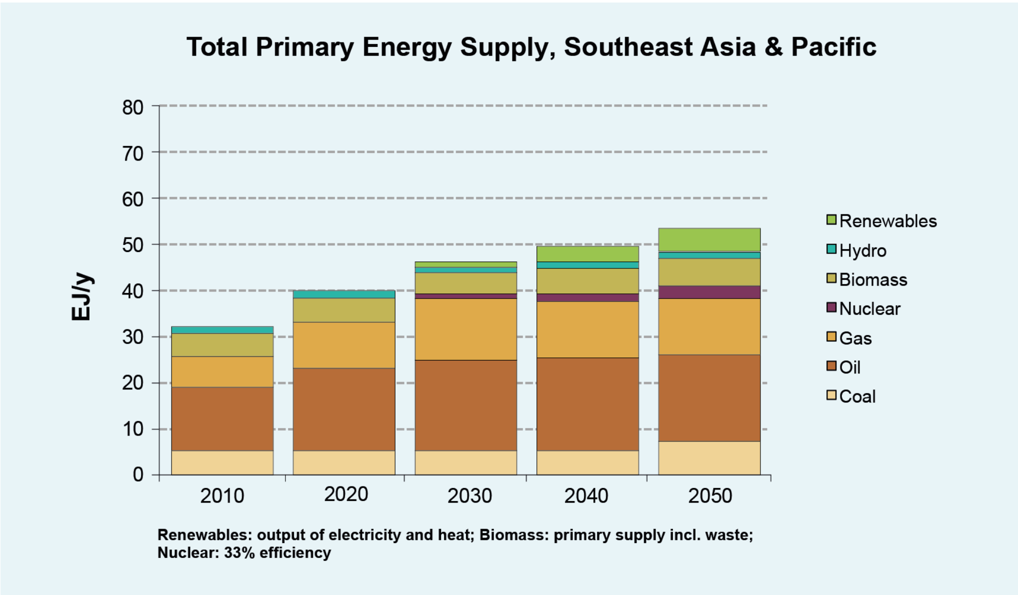
Figure 50 – Total primary energy supply (EJ/y) by fuel type: Southeast Asia and Pacific

Source: World Energy Council 2013

Jazz



Symphony



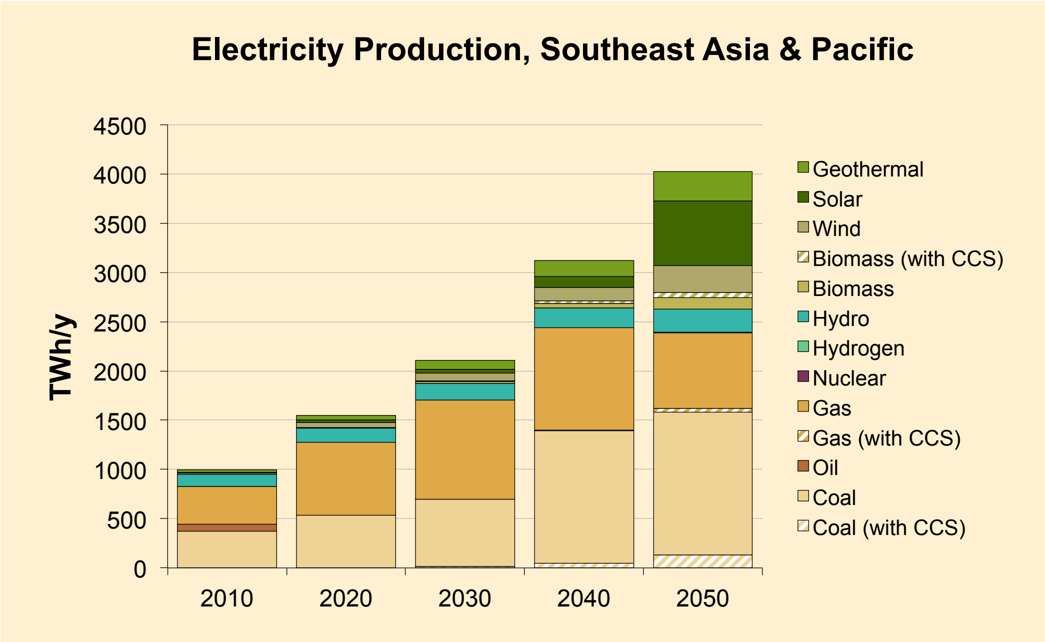
Electricity production and generating capacity by primary energy: Southeast Asia and Pacific

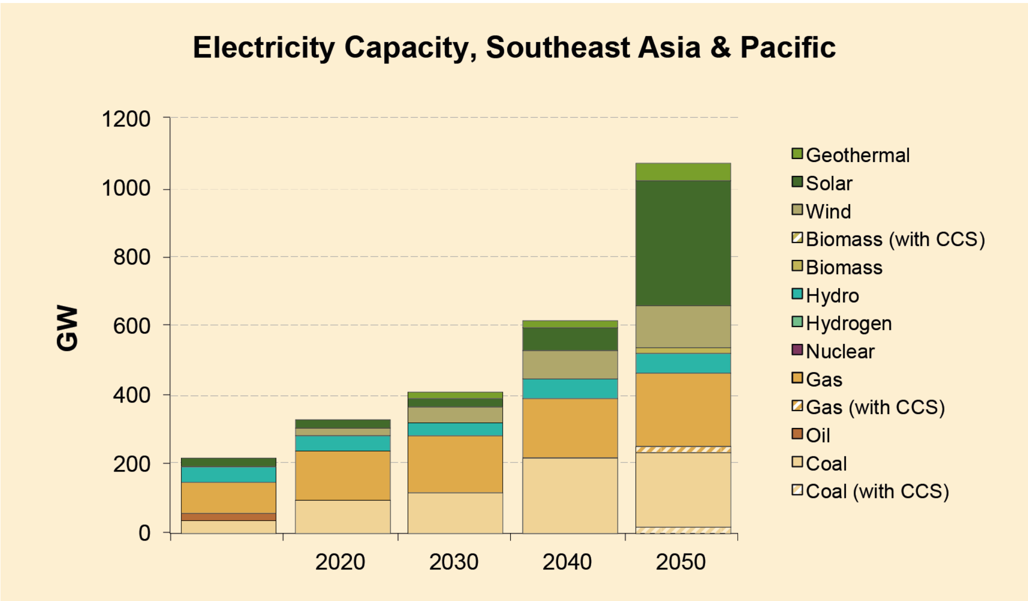
Figure 51 – Electricity production (TWh/y) and electricity generating capacity (GW) for Southeast Asia and Pacific in the Jazz scenario

Source: World Energy Council (2013)

Historical data: IEA World Energy Statistics and Balances

Jazz





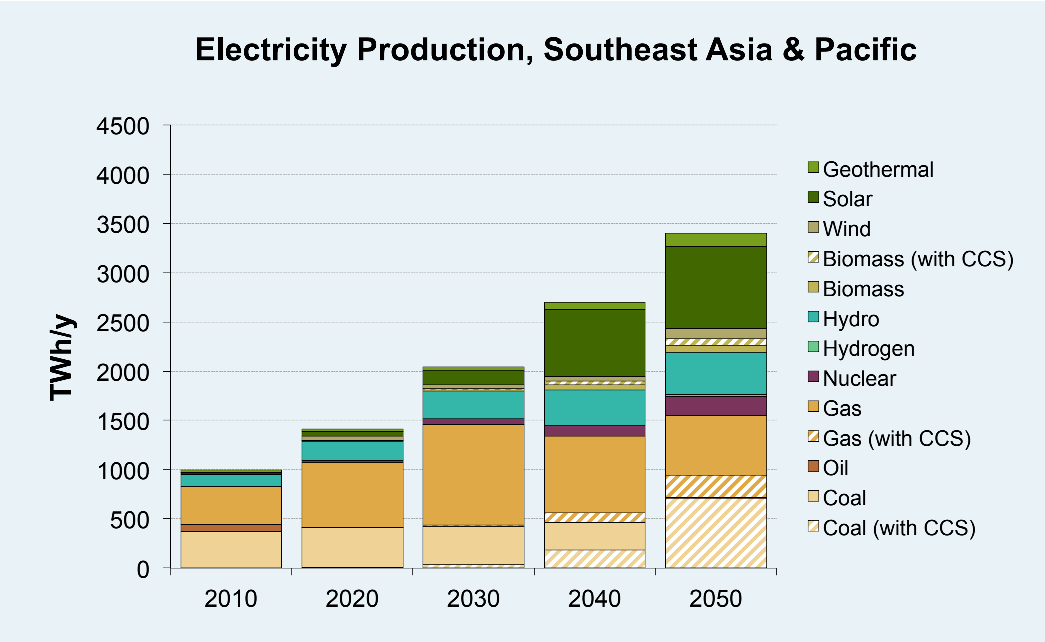
Dominance of coal in generation. Increasing gas share in the medium term. Investments in solar, wind and geothermal.

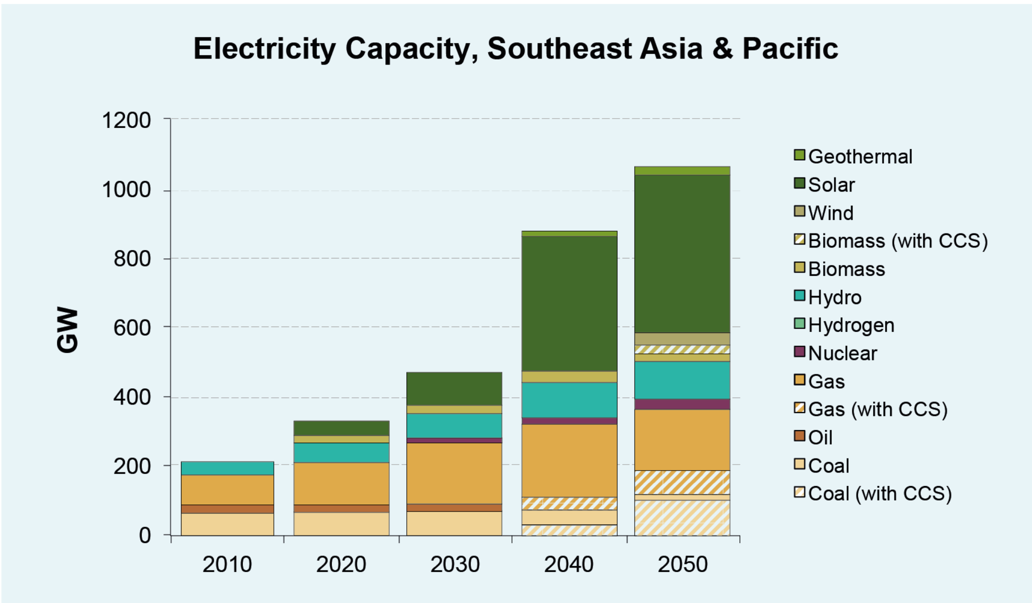
Figure 52 – Electricity production (TWh/y) and electricity generating capacity (GW) for Southeast Asia and Pacific in the Symphony scenario

Source: World Energy Council (2013)

Historical data: IEA World Energy Statistics and Balances

Symphony



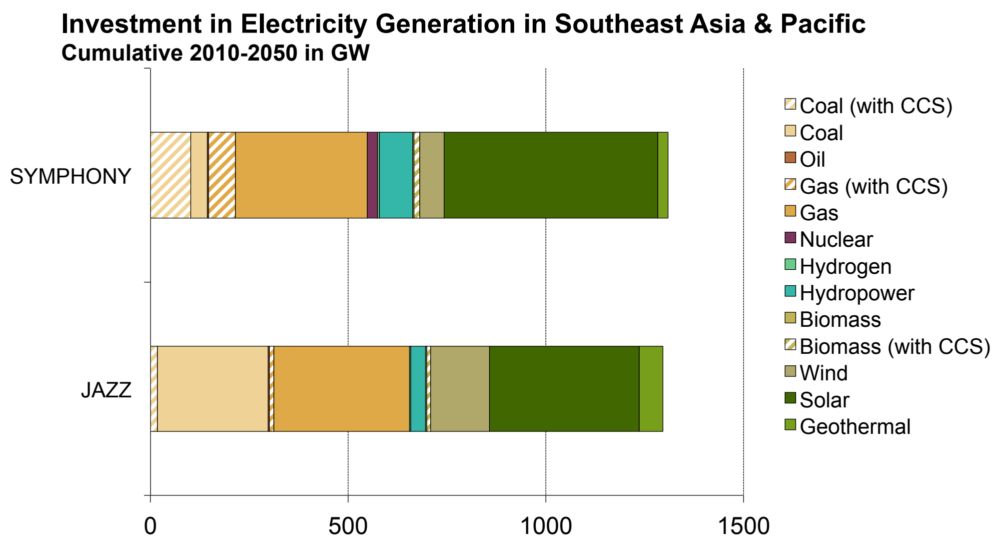


CC(U)S and renewables (solar, geothermal) displace gas from generation in 2050, and coal generation switches to CC(U)S in 2050.

Investment needs to 2050: Southeast Asia and Pacific

Figure 53 – Cumulative investment needs by 2050 in Southeast Asia and Pacific in electricity generation infrastructure

Source: World Energy Council (2013)



Symphony cumul. undiscounted investment:	**1.9**	**trillion US$2010**
Jazz cumul. undiscounted investment:	**1.8**	**trillion US$2010**

Jazz 2050	Symphony 2050
• Dominance of coal in generation. • Increasing gas share in the medium term. • Investments in solar, wind and geothermal.	• CC(U)S and renewables (solar, geothermal) displace gas from generation in 2050. • Coal generation switches to CC(U)S in 2050.

Table 22 – Cumulative investment needs by 2050 in Southeast Asia and Pacific in GW in electricity generation infrastructure

Source: World Energy Council (2013)

Southeast Asia and Pacific	Jazz	Symphony
Coal (with CCS)	17	101
Coal	280	43
Oil	3	3
Gas (with CCS)	11	68
Gas	344	334
Nuclear	0	25
Hydrogen	2	5
Hydropower	37	85
Biomass	3	4
Biomass (with CCS)	9	14
Wind	149	60
Solar	380	540
Geothermal	59	26
Total	**1,294**	**1,308**

Note: Calculation of investment needs is for power generation only

Regional scenario stories and quantification results: Europe

The energy debate in Europe will focus on the ‘Energiewende’, or energy transition, for many years to come – not only in Germany, but also in other EU28 states.

The increasing share of renewables in total electricity production also fuelled a debate about the electric system’s upgrading and ancillary cost due to increasing technical and market integration. There was also a debate about the sunken cost for renewable investments and the question of how consumers can bear the burden of that energy transition. Europe will also realise that rising energy prices are a competitive disadvantage in comparison to other regions on the world, most notably the US. This will lead to a transfer of capital, skills and productive capacity from Europe to the US.

Energy production in Europe will be dominated by the emergence of cheap coal – in the absence of a strong and binding agreement towards CO_2 prices and trading that would efficiently disincentivise the use of coal as a primary fuel for electricity generation. As a result, natural gas will be driven out of the merit order with large energy supply undertakings threatening to switch off highly efficiency but non-economic CCGT power plants.

Shale gas development in Europe is much contested out of environmental concerns, underlining the potential importance of and dependency on gas imports in the future. Shale gas is only likely to emerge in the UK, Poland and Ukraine, due to increasing NIMBY and BANANA oppositions towards hydraulic fracking and horizontal drilling in other countries of Europe. Natural gas prices in Europe are expected to remain high due to the monopoly of Russian supplies and their specific price formation (oil-indexed pricing) but it might not be so in the future when the gas market undoubtedly will change its image, and with spot prices for natural gas being below the price for natural gas procured on a long-term basis. The market dynamics are changing. For decades, long-term oil indexed natural gas contracts from Russia had been the backbone of energy security in Europe. This picture is likely to change with significant impacts on geopolitics.

Jazz scenario

Compared to other regions, Europe, including Russia, experiences low growth as the economy is service-sector based (except for Germany).

High economic growth occurs when a common EU-level economic and regulatory framework is adhered to by all EU member states. A functioning carbon market exists in this scenario, but the price of carbon remains low. Eastern Europe experiences higher growth due to increasing industrialisation.

Russia experiences lower export revenues as domestic consumption of oil and gas increases. It is still an important supplier of gas and oil.

Symphony scenario

The role of the government is consolidated centrally, with more and more national devolution to the European Commission/Parliament and less emphasis on decentralisation. Fiscal and monetary discipline is designed in Brussels and implemented by national regulators in EU member states. Energy policy is made in consultation with member states but is implemented via a central mechanism. Specific technologies are chosen for investment and supported by government subsidies.

National carbon abatement policies are slowly synchronised and brought into line with a common European carbon mitigation goal.

Eastern Europe as a region will become increasingly important as a source of gas to Europe. Relations between former Soviet Union countries will become increasingly influenced by Russian politics. Russia will seek to preserve its influence over European gas markets and will remain an important oil exporter. Government investment in social programmes will remain key to maintaining stability in the region. Unemployment and inequality continue to be problems. Russian use of nuclear will continue as it seeks to decrease consumption of gas and oil for power generation. Coal is used for power generation, but along with CC(U)S (early in 2040), which is supported by technology transfer from the EU.

Regional quantification results: Europe

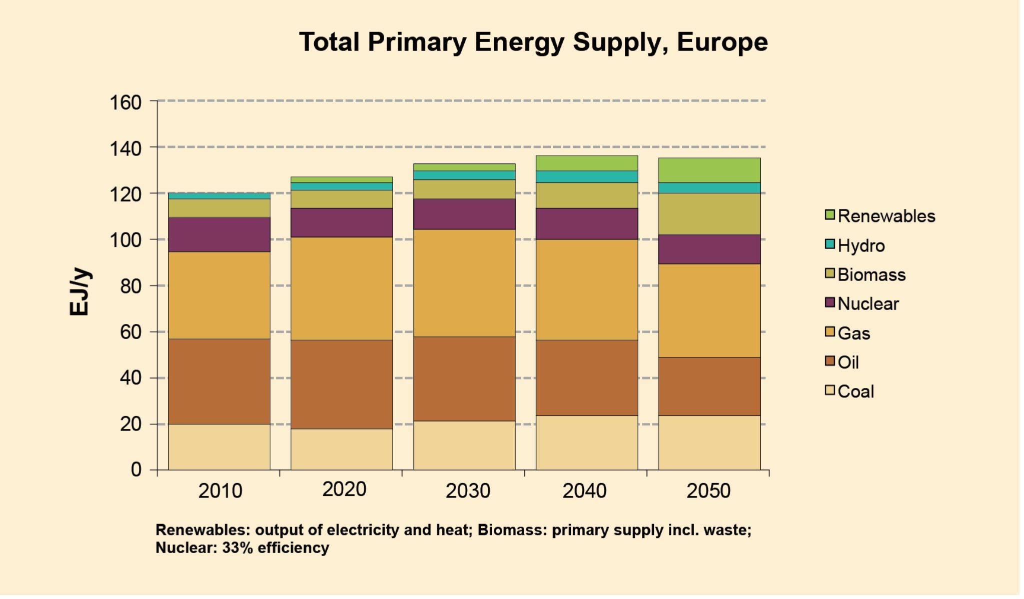
Total Primary Energy Supply: Europe

Total primary energy supply for this region up to 2050 is shown in the following graphs.

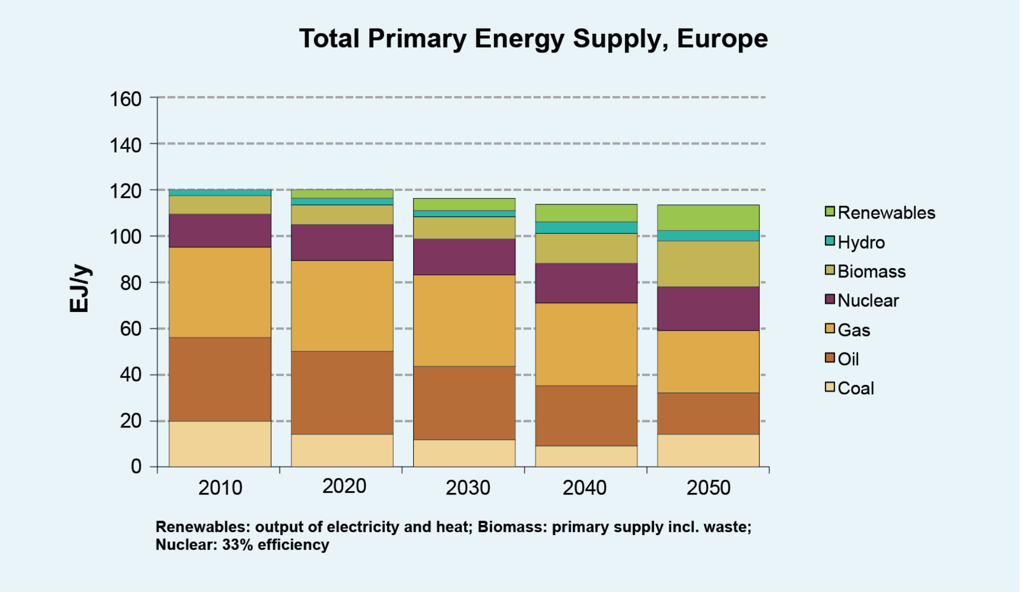
Figure 54 – Total primary energy supply (EJ/y) by fuel type: Europe

Source: World Energy Council 2013

Jazz



Symphony



In Jazz, natural gas consumption will increase up to 2030 before it descreases slightly until 2050. Overall total primary energy supply is stable from 2040 onwards. In the Symphony scenario there is a reduction in total primary energy supply, accompanied by a move to carbon-free fuels.

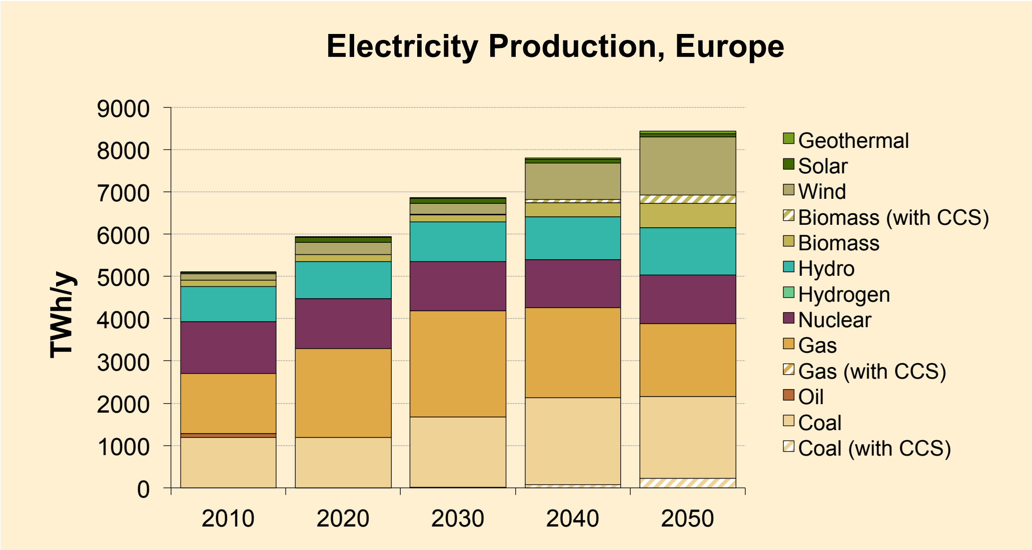
Electricity production and generating capacity by primary energy: Europe

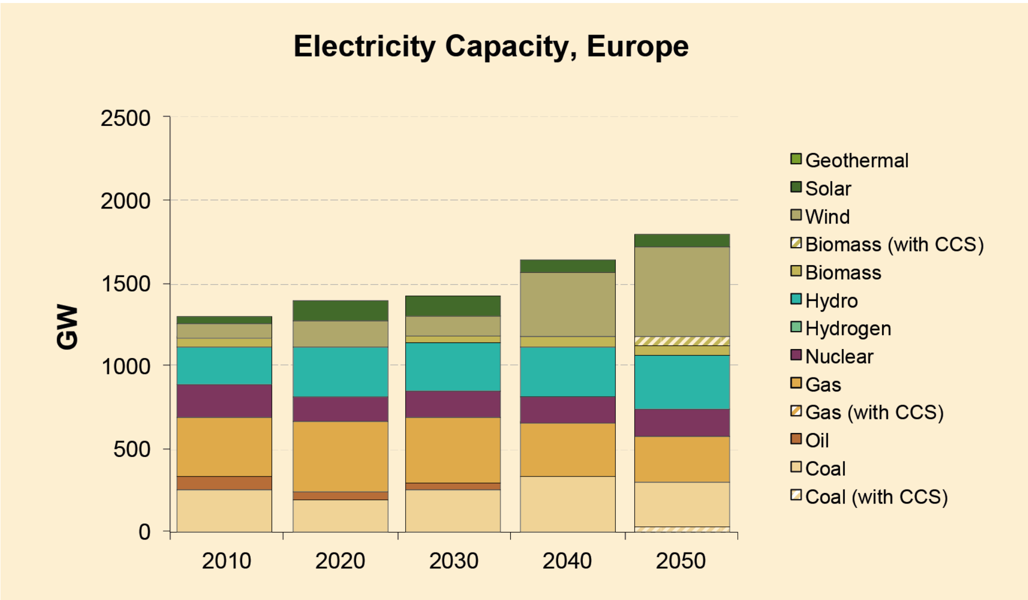
Figure 55– Electricity production (TWh/y) and electricity generating capacity (GW) for Europe in the Jazz scenario

Source: World Energy Council (2013)

Historical data: IEA World Energy Statistics and Balances

Jazz





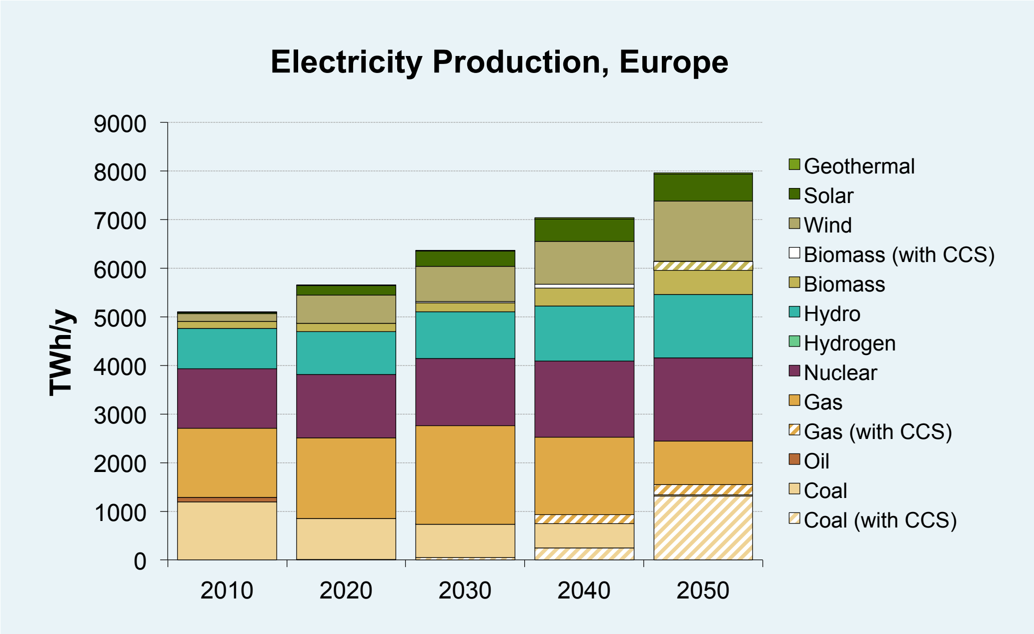
Functioning carbon market (albeit low CO_2 prices) are established. Gas investments until the medium term. High penetration of onshore wind after 2040, following investment in transmission and distribution networks and re-powering.

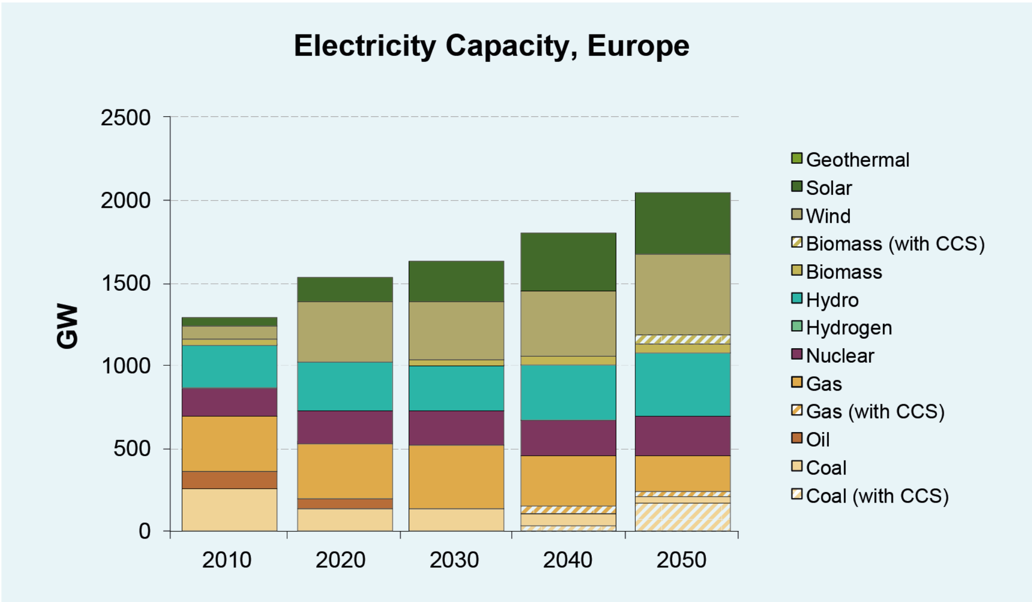
Figure 56 – Electricity production (TWh/y) and electricity generating capacity (GW) for Europe in the Symphony scenario

Source: World Energy Council (2013)

Historical data: IEA World Energy Statistics and Balances

Symphony



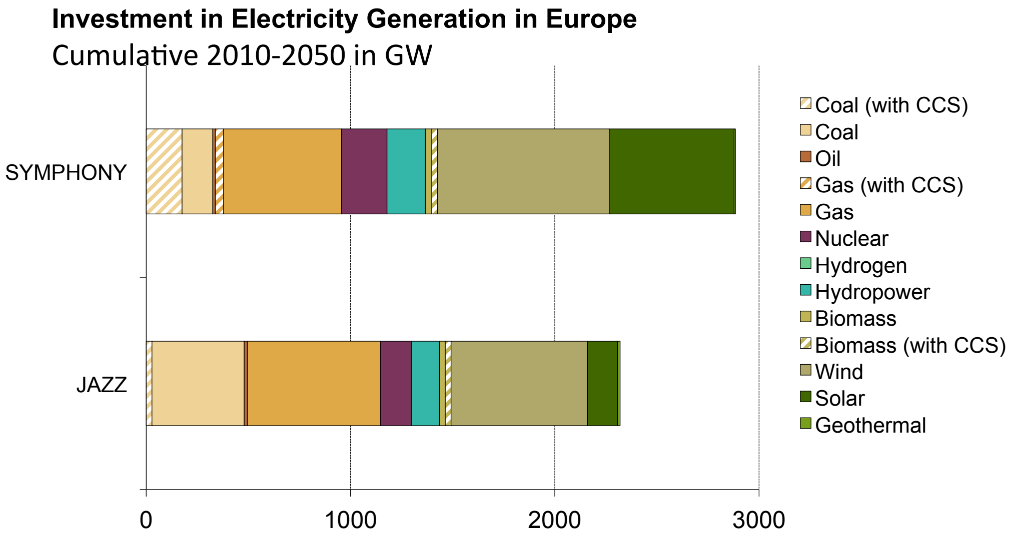


Coal electricity generation switches to CC(U)S in 2050. Nuclear, wind and solar displace gas after 2030 (strong climate policy, government support).

Investment needs to 2050: Europe

Figure 57 – Cumulative investment needs by 2050 in Europe in electricity generation infrastructure

Source: World Energy Council (2013)



Symphony cumul. undiscounted investment:	**4.4**	**trillion US$2010**
Jazz cumul. undiscounted investment:	**3.3**	**trillion US$2010**

Jazz 2050	Symphony 2050
• Functioning carbon market (albeit low CO_2 prices). • Gas investments until the medium term. • High penetration of wind after 2040.	• Coal electricity generation switches to CC(U)S in 2050. • Nuclear, wind and solar displace gas from generation after 2030 (strong climate policy, government support).

Table 23 – Cumulative investment needs by 2050 in Europe in GW in electricity generation infrastructure

Source: World Energy Council (2013)

Europe	Jazz	Symphony
Coal (with CCS)	29	176
Coal	450	149
Oil	15	15
Gas (with CCS)	0	41
Gas	654	574
Nuclear	149	224
Hydrogen	0	0
Hydropower	138	189
Biomass	30	31
Biomass (with CCS)	27	29
Wind	667	840
Solar	148	611
Geothermal	12	7
Total	**2,319**	**2,886**

Note: Calculation of investment needs is for power generation only.

Regional scenario stories: Latin America and The Caribbean

Current developments in the Latin American and The Caribbean region

The WEC's analysis has shown that global recession, energy prices, unconventionals and development of large-scale hydro systems are the major issues or concerns for leading energy experts and policymakers in the LAC region.

As far as unconventional energy resources are concerned, it is important to stress that, in some countries of LAC, the exploration of unconventional oil and gas might become economic and hence a viable option; in others, investment in hydro will become more significant (e.g. Brazil).

Venezuela is potentially a global player in oil. Gas is important in Bolivia. In total, LAC will be a region that is a net exporter of energy and, because of its endowment, is best suited to fight climate change. Renewables will play a crucial role: Argentina and Brazil are large exporters of RES-E, Uruguay is already generating most of its energy from renewables. The energy-water-food nexus will potentially be very important in the region, especially due to the conflicting interests of electricity generation and food production.

Jazz scenario

The LAC region continues to grow, based on the assumption of Brazil being an 'economic powerhouse' in the region. Agricultural production increases and the region becomes the 'bread basket' of the world. Consequently, there is a demand for agricultural machinery, water for irrigation, fertilisers, and electricity.

Manufacturing also increases due to domestic demand. Regarding the trends related to primary fuel for power generation in Brazil, a considerable increase in the use of nuclear power is foreseen, as well as an increase of gas-fired thermal power plants. For the same scenarios the hydropower installed capacity will decrease, a considerable reduction compared to the 75% of today. This power supply mix in Brazil for this time horizon is foreseen due to the exhaustion of sustainable/viable hydro potential until 2030. The option for nuclear power and gas-fired plants aims to increase the security of supply and reduction of costs for power supply expansion, since the country has huge uranium and natural gas reserves and all related technologies for use of such primary energy sources. Transport continues to depend on oil, although biofuels and EV will have a role in the late part of scenario time horizon.

Symphony scenario

LAC governments in the region push for the development of a regional energy market with gas, biofuels and electricity freely traded across borders. The development of hydropower continues and national grids are connected, leading to the emergence of a LAC-wide grid – strongly promoted by governments in the region and based on the idea of securing national self-sufficiency.. Oil and gas E&P continues, in order to support the increasing needs of domestic industry.

For the trends related to primary fuel for power generation in Brazil, we will see the same considerable increase in the use of nuclear power (in the range of 8–15% of the power supply mix, depending on the country's internal scenario), and an increase of gas-fired thermal power plants. The hydropower installed capacity will decrease, a considerable reduction compared to the 75% of today.

A power supply mix is foreseen for Brazil, due to the exhaustion of sustainable/viable hydro potential until 2030. The option for nuclear power and gas-fired plants aims to increase the security of supply and reduction of costs for power supply expansion, since the country has huge uranium and natural gas reserves and all related technologies for use of such primary energy sources.

Oil is used for transport, along with a steady increase in first-generation biofuels in the early part of the scenario period and second-generation biofuels starting to be deployed in the late part of scenario. EV will have a role in the late part of scenario. Also, in the Symphony scenario, agricultural production increases and the region consolidates its role as the 'bread basket' of the world.

Consequently, there will also be manufacturing growth due to an increased demand for agricultural machinery, water for irrigation, fertilisers, and electricity. Manufacturing also increases due to domestic demand incentives from public policies.

Regional quantification results: Latin America and The Caribbean

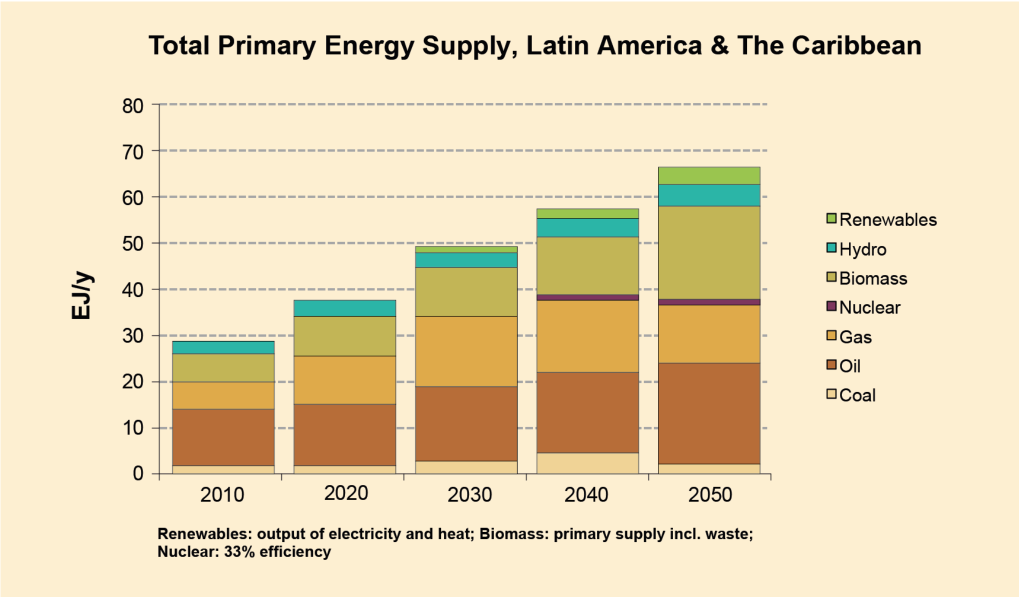
Total primary energy supply: Latin America and The Caribbean

Total primary energy supply for this region up to 2050 is shown in the following graphs.

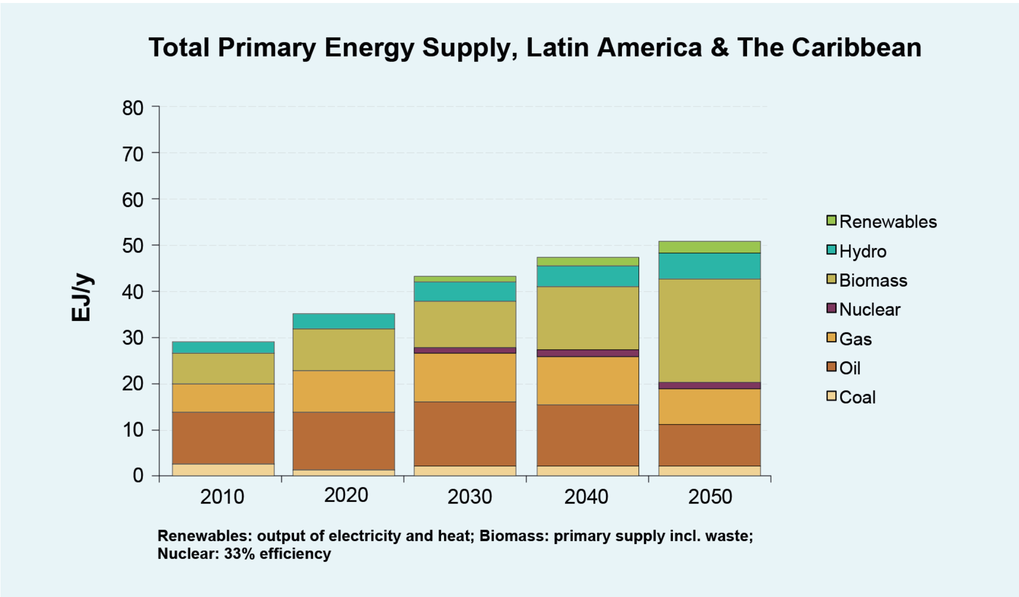
Figure 58 – Total primary energy supply (EJ/y) by fuel type: Latin America and The Caribbean

Source: World Energy Council 2013

Jazz



Symphony



Biomass will play a dominant role in Latin America and The Caribbean in both scenarios up and until 2050. The biomass share increases, especially in Symphony where it accounts for roughly 44% of the total primary energy supply, whereas in Jazz this is only 32% compared to 22% in 2010.

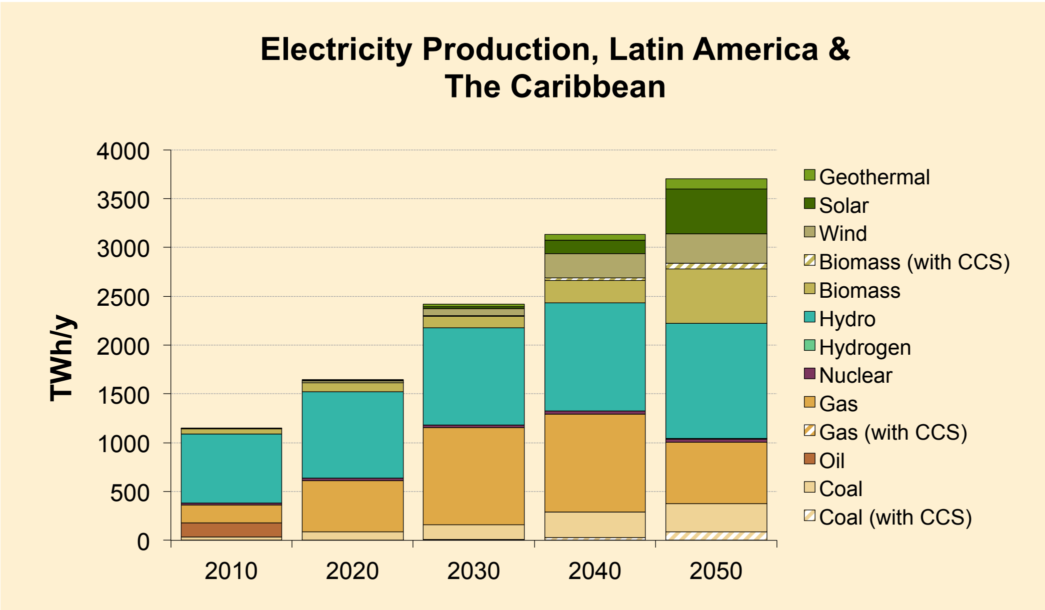
Electricity production and generating capacity by primary energy: Latin America and The Caribbean

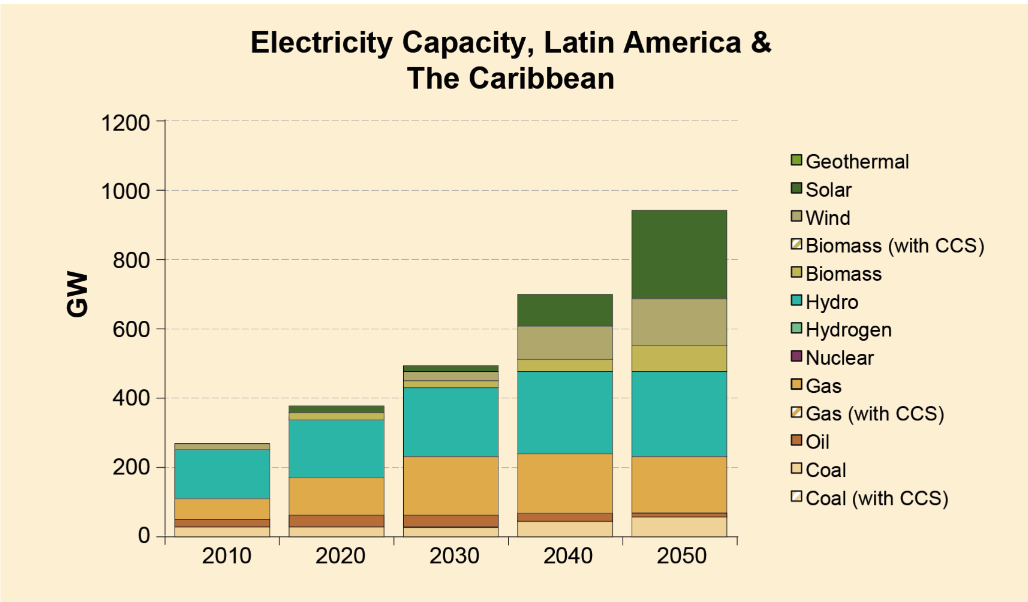
Figure 59– Electricity production (TWh/y) and electricity generating capacity (GW) for Latin America and The Caribbean in the Jazz scenario

Source: World Energy Council (2013)

Historical data: IEA World Energy Statistics and Balances

Jazz





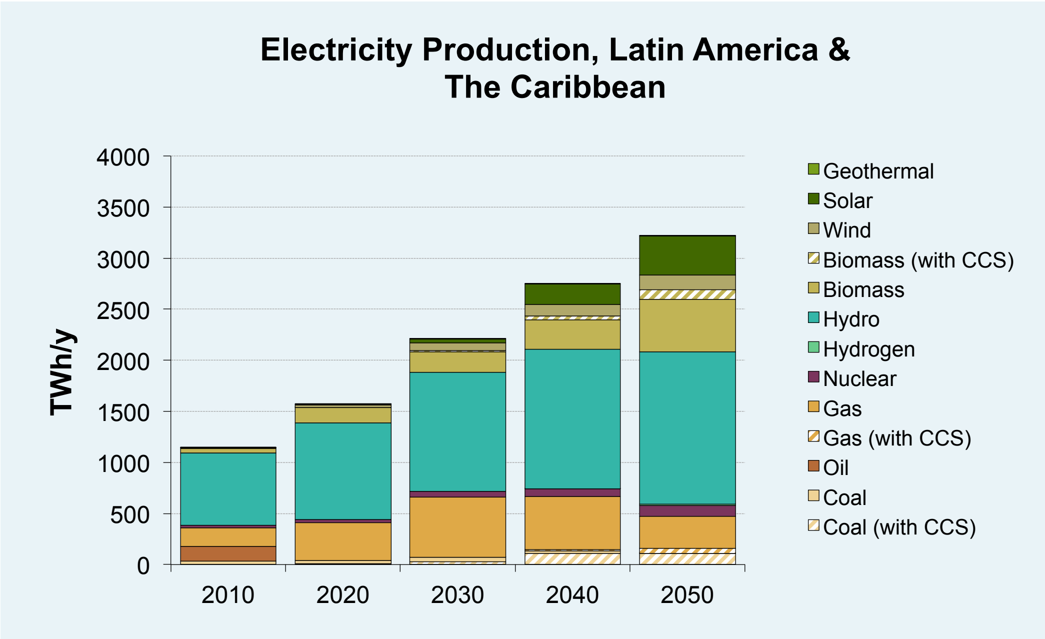
Hydro-based electricity is the dominant source. Gas emerges as a fuel for power generation (Brazil).

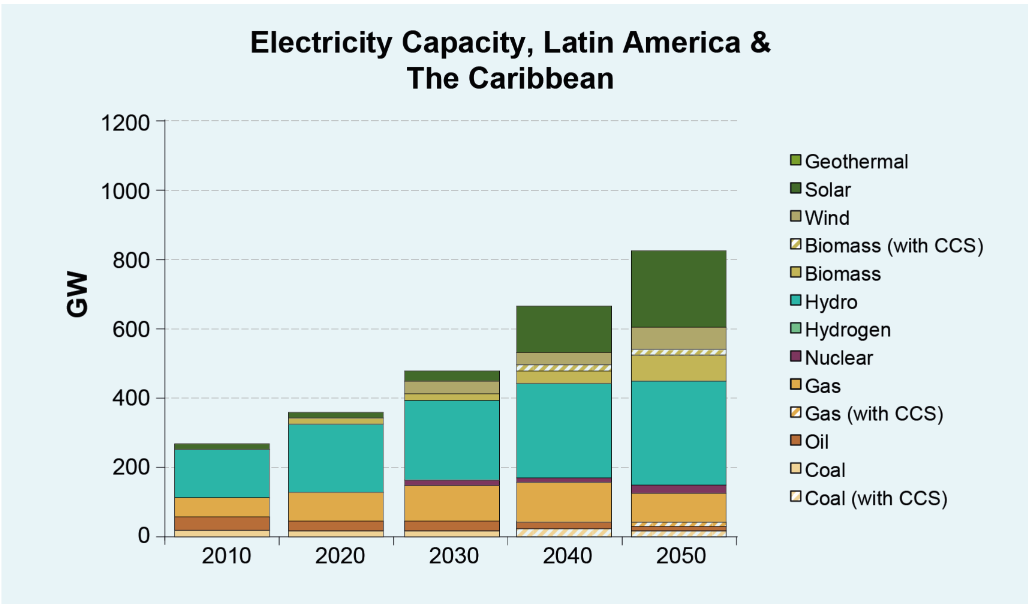
Figure 60 – Electricity production (TWh/y) and electricity generating capacity (GW) for Latin America and The Caribbean in the Symphony scenario

Source: World Energy Council (2013)

Historical data: IEA World Energy Statistics and Balances

Symphony



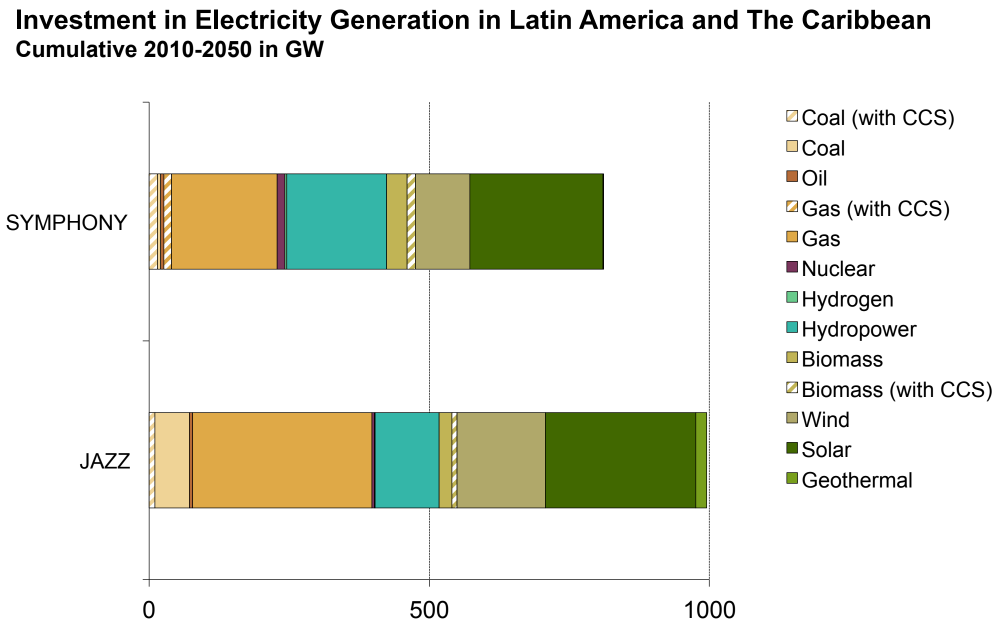


Development of hydropower facilitated by improvements in grid infrastructure (LAC-wide grid). Gas is used mainly for peak load generation.

Investment needs to 2050: Latin America and The Caribbean

Figure 61– Cumulative investment needs by 2050 in Latin America and The Caribbean in electricity generation infrastructure

Source: World Energy Council (2013)



Symphony cumul. undiscounted investment:	**1.3**	**trillion US$2010**
Jazz cumul. undiscounted investment:	**1.3**	**trillion US$2010**

Jazz 2050	Symphony 2050
• Hydro-based electricity is the dominant source. • Gas emerges as a fuel for power generation (Brazil).	• Development of hydropower facilitated by improvements in grid infrastructure (LAC-wide grid). • Gas is used mainly for peak load generation.

Table 24 – Cumulative investment needs by 2050 in Latin America and The Caribbean in GW in electricity generation infrastructure

Source: World Energy Council (2013)

Latin America and The Caribbean	Jazz	Symphony
Coal (with CCS)	11	15
Coal	62	6
Oil	5	5
Gas (with CCS)	0	14
Gas	320	189
Nuclear	4	14
Hydrogen	1	3
Hydropower	115	179
Biomass	23	37
Biomass (with CCS)	9	14
Wind	157	97
Solar	269	238
Geothermal	20	0
Total	**996**	**811**

Note: Calculation of investment needs is for power generation only.

Regional scenario stories: Middle East and North Africa (MENA)

Current developments in the MENA region

MENA as a region is unique in that it accounts for 52% of the world's proven oil reserves, and 42% of the gas reserves. Its sustainable growth depends on steady oil and gas demand, which has been influenced by global recession, as well as by the economies of China and India and increasing links between MENA and South and Central Asia. Exports from MENA into that region might increase, whereas the import dependence of countries like China and India on oil imports from Saudi Arabia will increase. The WEC anticipates that in the future, Saudi Arabia may export more oil to countries like China and India where there would be greater demand for those resources.

Looking forward the key question is how the region will develop politically, from the 'Arab Spring' into an 'Islamic Autumn'. Middle East dynamics, as geo-political issues, notably the displays of military power over the Iranian nuclear industry, are critical for the region, particularly for the states of the Gulf Cooperation Council (GCC), as their member states feel they have little influence over the issue but face huge risks in the event of conflict. Looking forward, uncertainties remain about energy prices, and global recession, in particular lower economic growth in key markets. Questions also remain as to whether subsidies energy prices are sustainable in the medium to long term. In most of the Arab world, energy prices are heavily subsidised or barely priced at cost level. Yet, energy is perceived as a cheaply available public good and its availability is taken for granted by many citizens in the MENA states.

Nuclear, CCS and unconventionals are high uncertainties that can have an impact on the region. Especially in the UAE or Saudi Arabia, acceptance is growing that nuclear energy is an effective way to diversify the potential future energy mix away from oil and gas towards other energy sources, where rapidly growing domestic power demand has eaten into the hydrocarbons available for export.

GCC member states are now implementing the region's first CCS projects, such as UAE testing the enhanced oil recovery performance which may add more value to CCS. As the WEC has stated in its World Energy Issues Monitor 2013 publication, the region could be a real 'front runner', especially given the Masdar Project in Abu Dhabi where UAE seeks to deliver the concept of a 'green city' or the DESERTEC Foundation, which aims to develop solar PV and export electricity to Europe to create a global renewable energy plan – although the future of DESERTEC remains uncertain.

Jazz scenario

The WEC anticipates economic growth to be higher in this scenario only at the national level and for some of the states in the MENA region. Saudi Arabia continuously expands its petrochemicals production. Domestic consumption of oil for power production in the region falls. Solar and nuclear capacity is added. Oil output from Iraq increases. Job creation remains an issue in the region. Stronger economic ties with sub-Saharan African countries and China and India lead to higher exports and more economic growth in that region.

Symphony scenario

The WEC anticipates that economic growth will continually rise in the region, but will be constrained by high government spending. There is a risk of regional tensions increasing. Massive investment is made in solar, and domestic consumption of oil for power generation sharply drops. The region expands domestic capability in petrochemicals and fertiliser production. North African countries, especially Libya and Egypt, adjust to political changes leading to more political stability in the region and stronger governmental involvement in the design and functioning of energy markets.

Regional quantification results: Middle East and North Africa

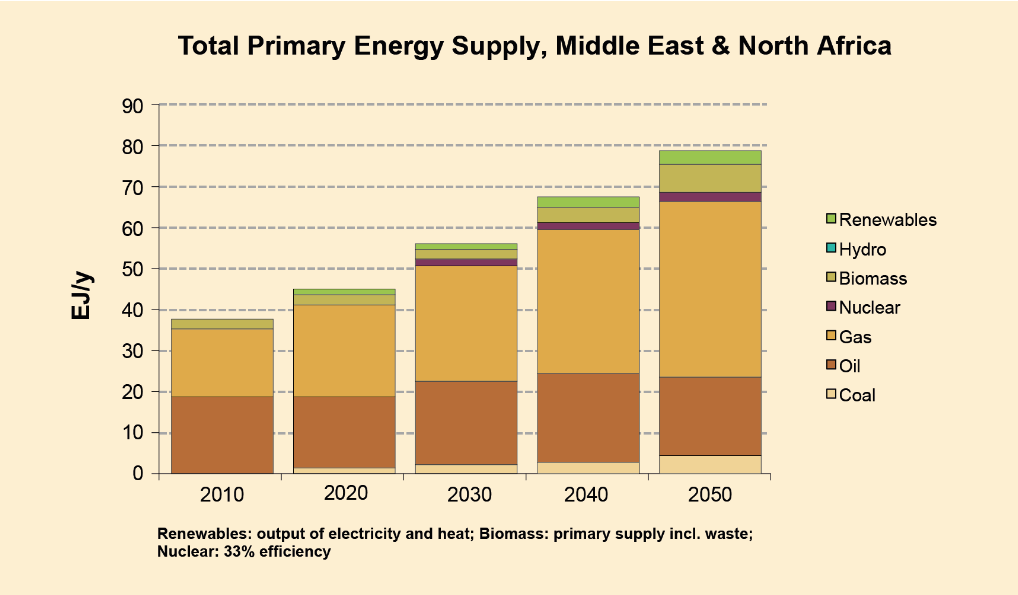
Total primary energy supply: Middle East and North Africa

Total primary energy supply for this region up to 2050 is shown in the following graphs.

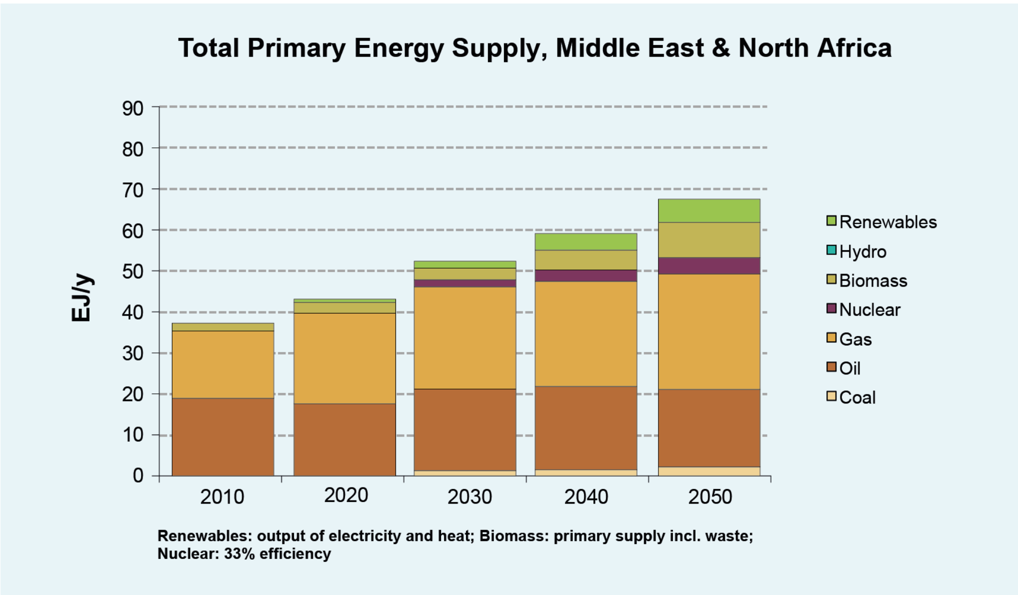
Figure 62 – Total primary energy supply (EJ/y) by fuel type: Middle East and North Africa

Source: World Energy Council 2013

Jazz



Symphony



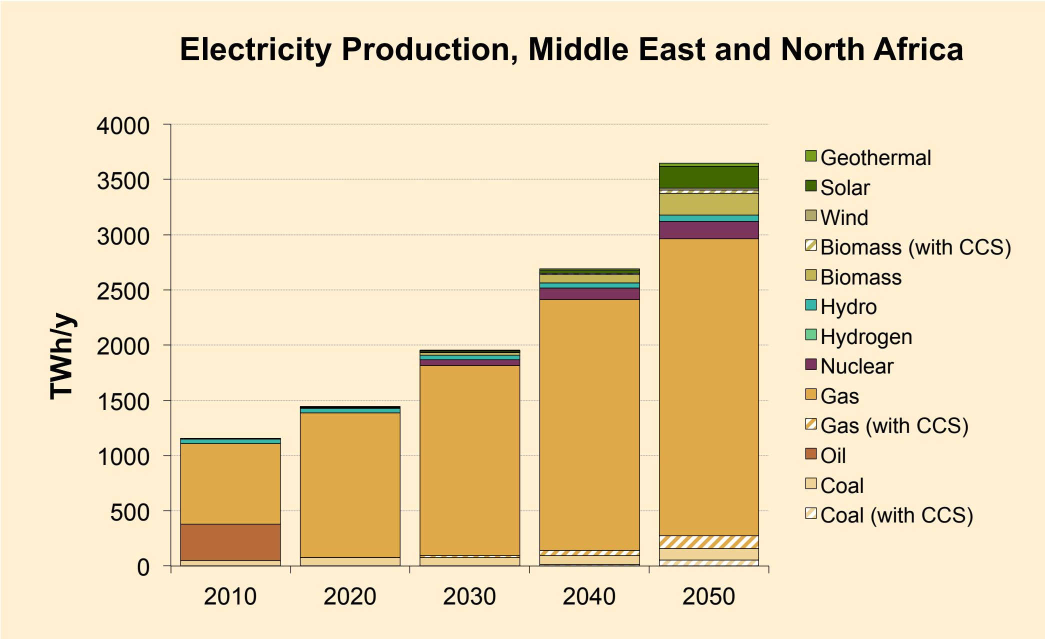
Electricity production and generating capacity by primary energy: Middle East and North Africa

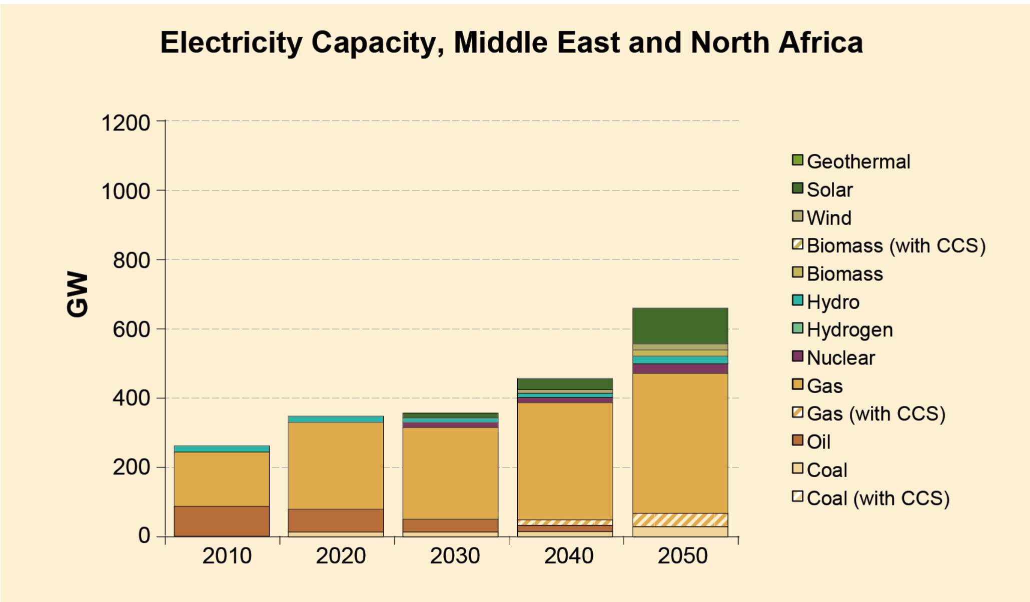
Figure 63– Electricity production (TWh/y) and electricity generating capacity (GW) for Middle East and North Africa in the Jazz scenario

Source: World Energy Council (2013)

Historical data: IEA World Energy Statistics and Balances

Jazz





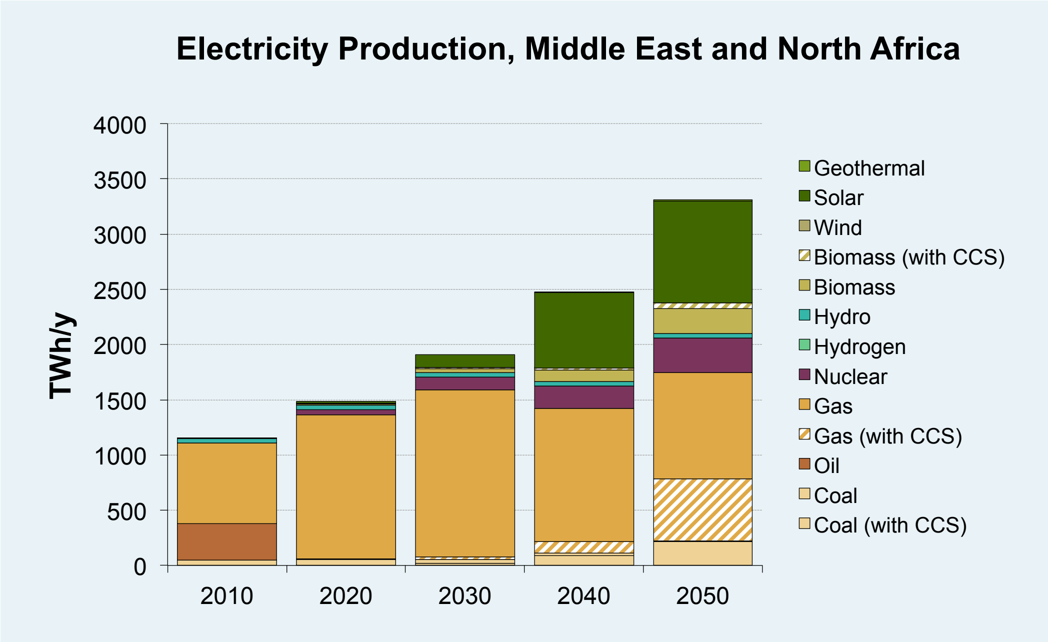
Gas is the main choice for power generation. Oil-generated electricity drops sharply. Solar and nuclear capacity is added.

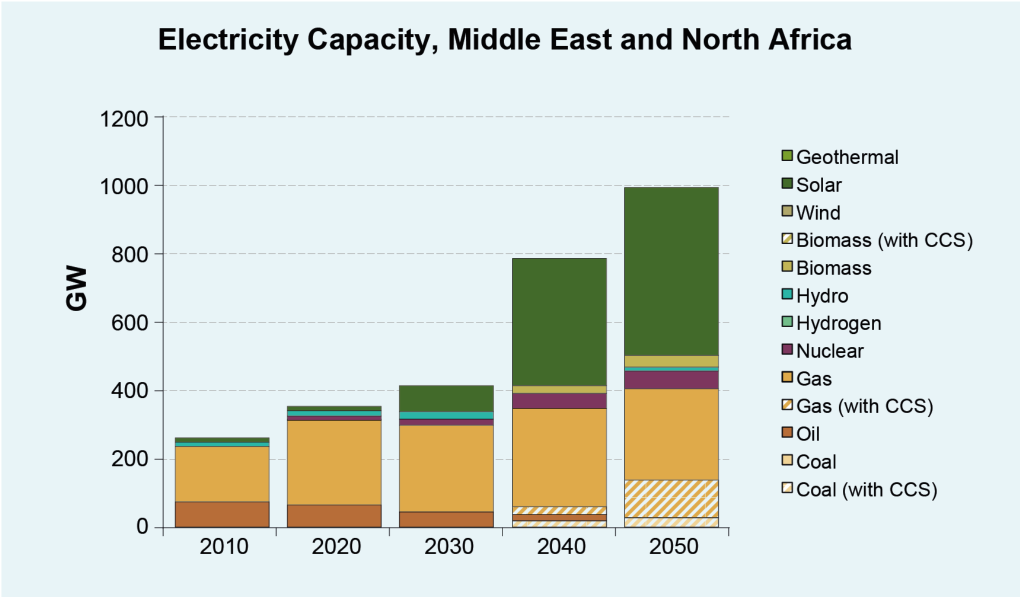
Figure 64 – Electricity production (TWh/y) and electricity generating capacity (GW) for Middle East and North Africa in the Symphony scenario

Source: World Energy Council (2013)

Historical data: IEA World Energy Statistics and Balances

Symphony



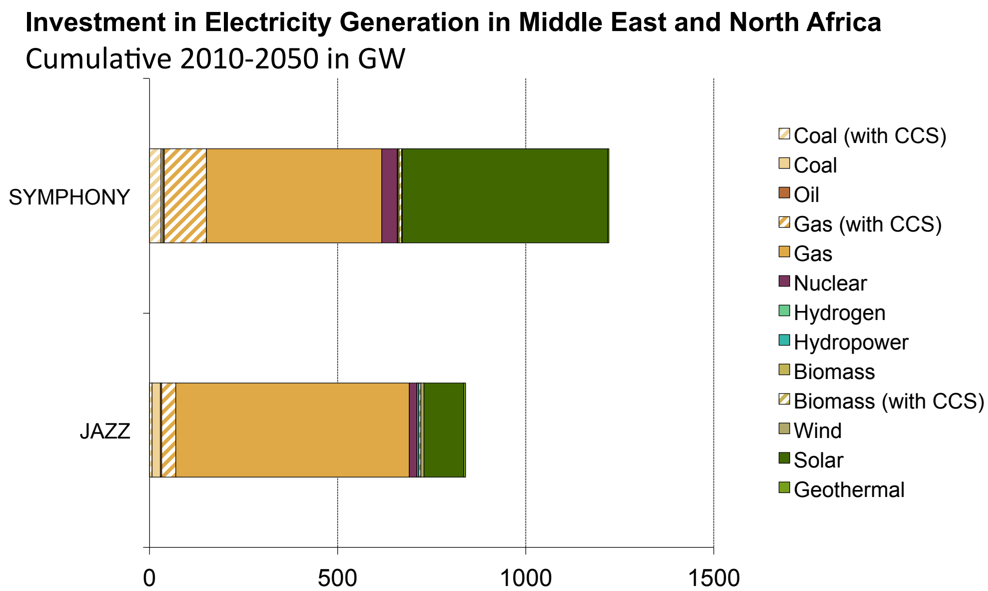


Gas remains the main choice for power generation. Large investments in solar. Nuclear electricity is led by the government.

Investment needs to 2050: Middle East and North Africa

Figure 65 – Cumulative investment needs by 2050 in Middle East and North Africa in electricity generation infrastructure

Source: World Energy Council (2013)



Symphony cumul. undiscounted investment:	**1.4**	**trillion US$2010**
Jazz cumul. undiscounted investment:	**0.7**	**trillion US$2010**

Jazz 2050	Symphony 2050
• Gas is the main choice for power generation. • Oil-generated electricity drops sharply. • Solar and nuclear capacity is added.	• Gas remains the main choice for power generation. • Large investments in solar. • Nuclear electricity is led by the government.

Table 25 – Cumulative investment needs by 2050 in Middle East and North Africa in GW in electricity generation infrastructure

Source: World Energy Council (2013)

Middle East and North Africa	Jazz	Symphony
Coal (with CCS)	6	30
Coal	22	5
Oil	4	4
Gas (with CCS)	38	112
Gas	620	466
Nuclear	21	41
Hydrogen	0	0
Hydropower	5	1
Biomass	0	3
Biomass (with CCS)	4	7
Wind	8	2
Solar	107	546
Geothermal	4	3
Total	**839**	**1,220**

Note: Calculation of investment needs is for power generation only.

Regional scenario stories: North America

North America is undoubtedly the region in the world where, due to the shale gas revolution, spill-over effects will have an impact on global energy dynamics, not only in Europe, but worldwide. With its massive shift from coal to natural gas, the US has made it possible to be on target to achieve their goal of CO_2 reduction in line with the Copenhagen Accord, although the US government has not set a climate change policy. The demand for energy, electricity and gasoline has dropped, in part due to the recession and also due to significant efficiency gains in automobiles, building, and appliances.

The WEC anticipates that the US will soon become a natural gas exporter. Unconventional gas development in the US has been successful, providing natural gas at far lower prices for domestic consumption than other regional markets around the globe. Thus, the US will become more self-sufficient due to shale gas development and domestic petroleum production. In Canada, hydropower business remains significant. Canada is likely to become an energy exporter to the US which makes more US resources available for the global markets. Mexico has also shifted to natural gas to replace ageing fuel-oil electricity generation as well as to satisfy the continuous growing energy demand.

The WEC anticipates nuclear to play a lesser role in North America. It is likely that the US will see a significant reduction of nuclear power plants without replacement thanks to the availability to cheap shale gas. As far as coal-fired generation is concerned, it is unlikely that any new-build infrastructure will be without CCS. CCS in North America is also more in line with CC(U)S, where CCS is used in EOR.

Jazz scenario

There is a re-emergence of industry on the back of cheap gas leading to re-industrialisation and a manufacturing revolution": As some manufacturing shifts back to the US in the early part of the scenario, job creation occurs which leads to a higher economic growth rate. Heavy transport moves into gas with the emergence of flex engines (which can burn both diesel and gas at a 20:80 ratio).

Canada continues to develop the extraction of oil from oil sands and begins to target export markets outside North America. Overall, the consumption of oil gradually drops, primarily due to the changes in freight transport. A carbon market is launched in California, and other US states begin to adopt similar state-level mechanisms.

Energy demand in Mexico is growing. Mexico is hence characterised by a need in investment infrastructure, the need to set incentives for energy efficiency, increasing demand for fuel in transport, and increasing consumption (or ‘energy hunger’).

Symphony scenario

The production of oil and gas in North America is lower in this scenario. Canadian development of unconventional fossil fuels (oil sands) is constrained as developing countries seek to wean themselves off carbon-intensive fuels and move towards cleaner-burning fuels. Due to low-cost domestic oil production, a cap and trade system is expected to emerge in North America with the strong support of national governments. The situation in Mexico can be characterised by greater emphasis on increasing energy efficiency where the government takes measures to incentivise a reduction of energy consumption in building through regulation, information and financial schemes.

Regional quantification results: North America

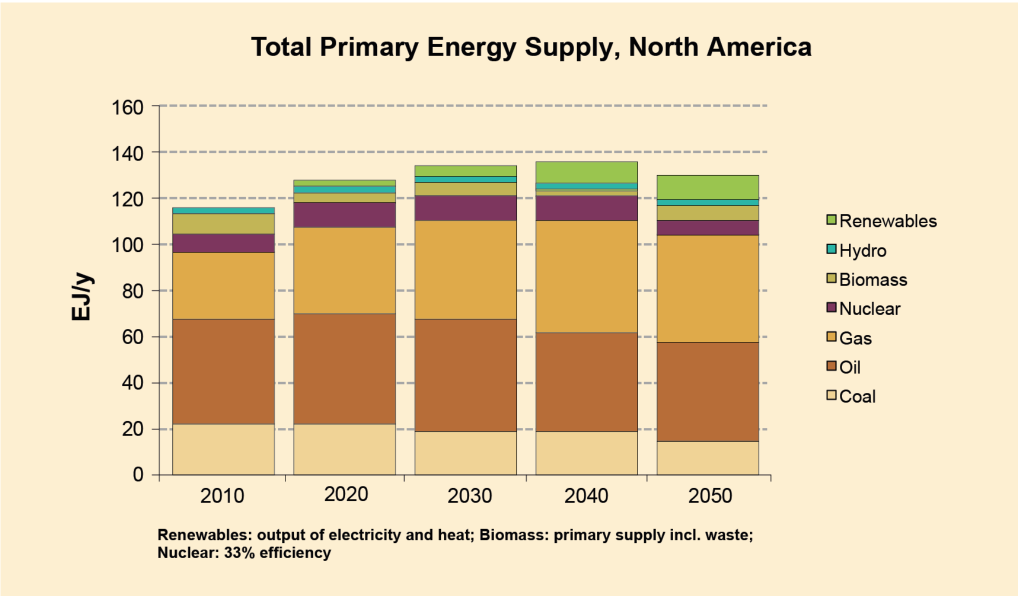
Total primary energy supply: North America

Total primary energy supply for this region up to 2050 is shown in the following graphs.

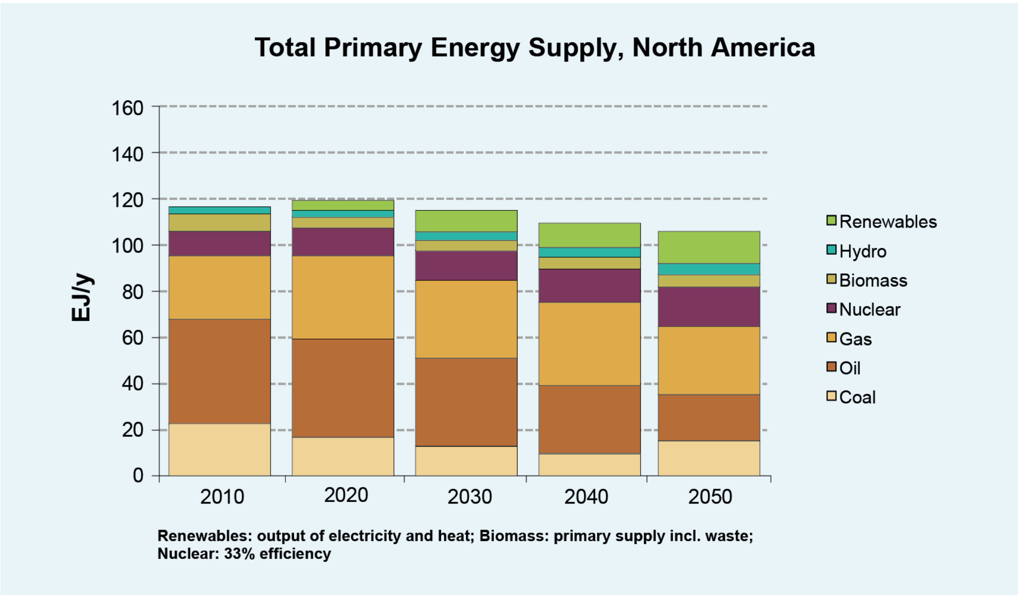
Figure 66 – Total primary energy supply (EJ/y) by fuel type: North America

Source: World Energy Council 2013

Jazz



Symphony



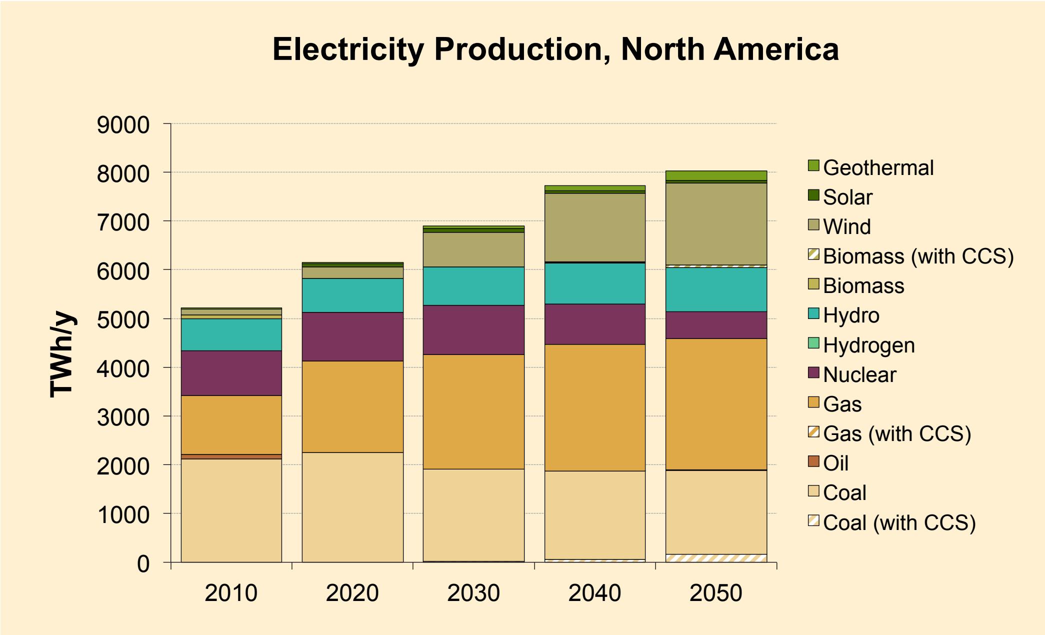
Electricity production and generating capacity by primary energy: North America

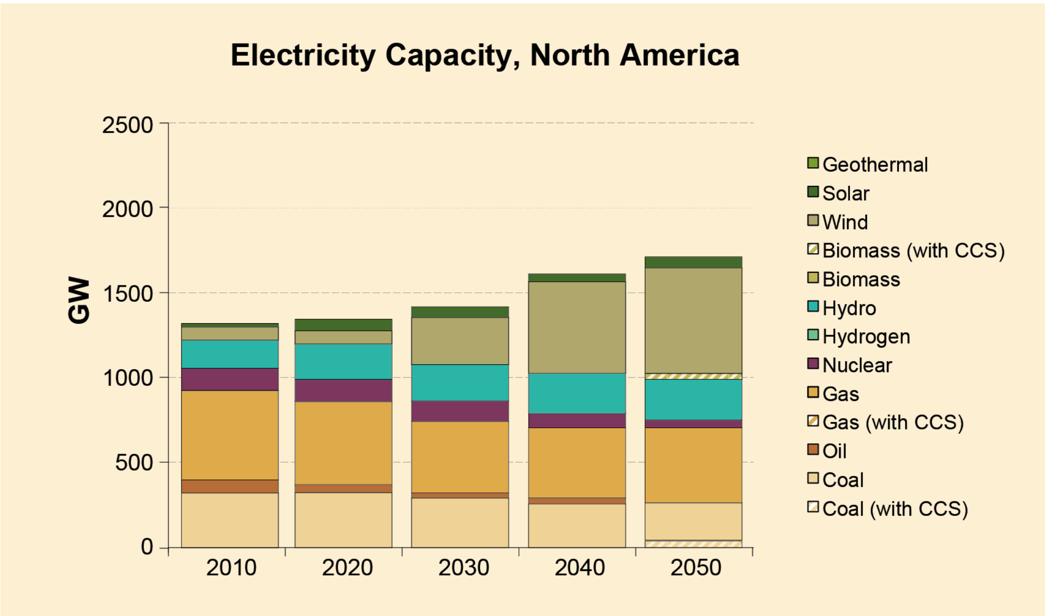
Figure 67– Electricity production (TWh/y) and electricity generating capacity (GW) for North America in the Jazz scenario

Source: World Energy Council (2013)

Historical data: IEA World Energy Statistics and Balances

Jazz





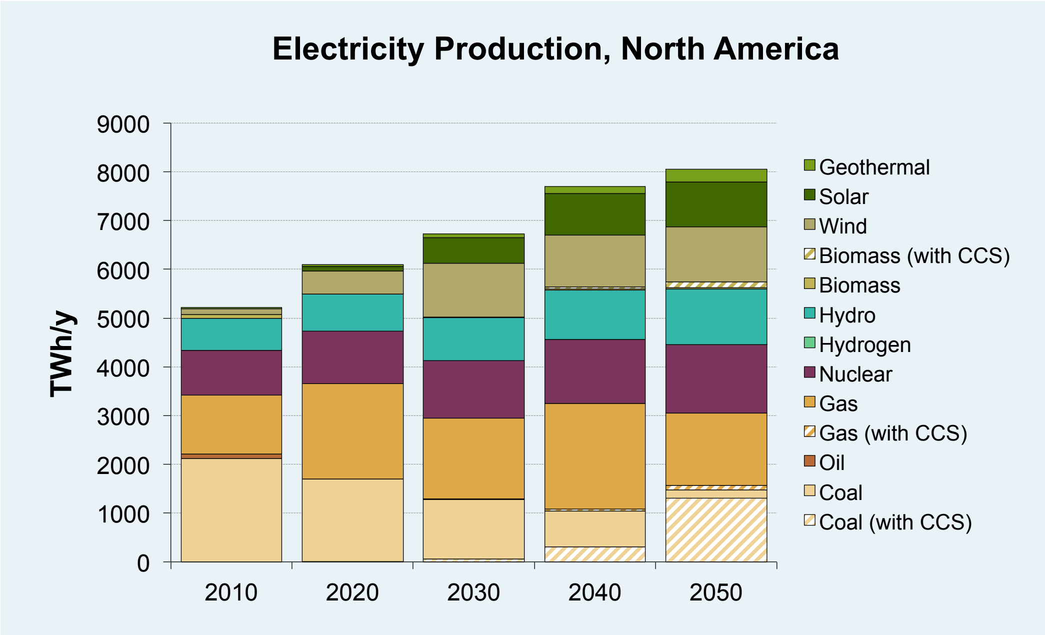
Share of gas in power generation increases at the expense of coal (and nuclear). Wind generation displaces fossil fuels from 2040.

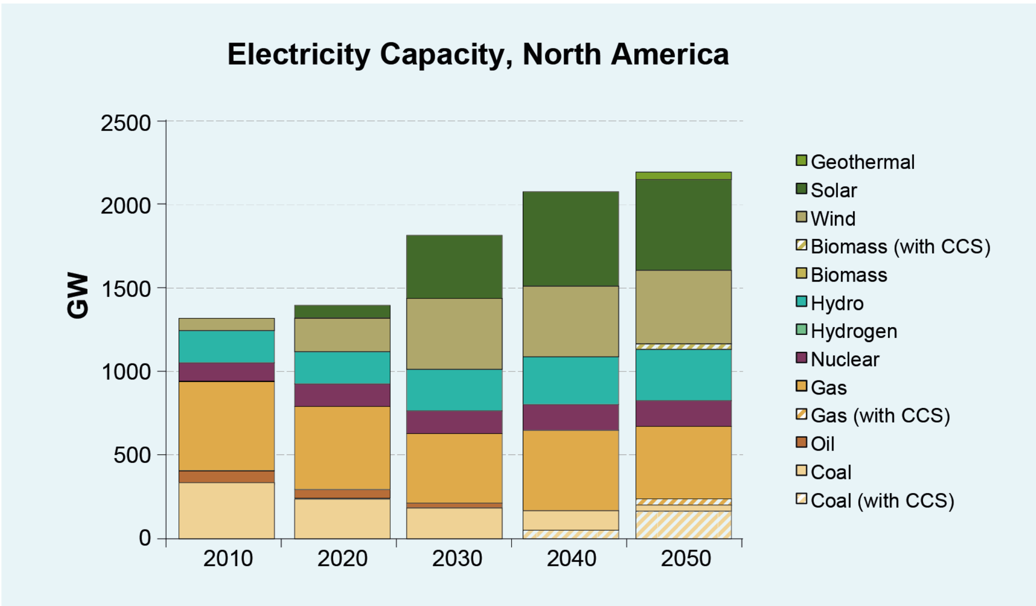
Figure 68 – Electricity production (TWh/y) and electricity generating capacity (GW) for North America in the Symphony scenario

Source: World Energy Council (2013)

Historical data: IEA World Energy Statistics and Balances

Symphony



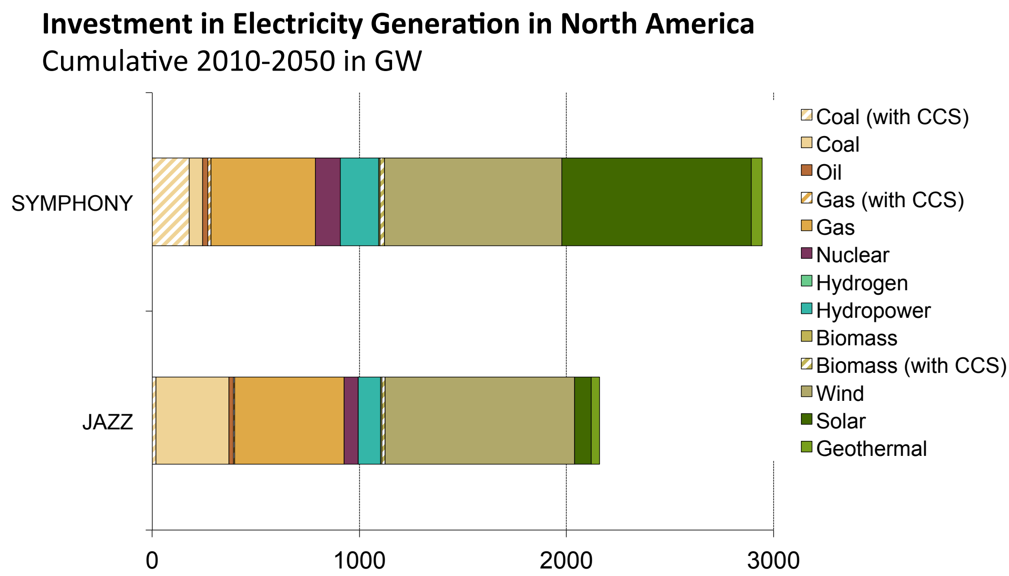


Gas share drops in 2050 at the expense of renewables and CC(U)S generation (IGCC). Nuclear investments to replace retirements.

Investment needs to 2050: North America

Figure 69 – Cumulative investment needs by 2050 in North America in electricity generation infrastructure

Source: World Energy Council (2013)



Symphony cumul. undiscounted investment:	**4.5**	**trillion US$2010**
Jazz cumul. undiscounted investment:	**2.8**	**trillion US$2010**

Jazz 2050	Symphony 2050
• Share of gas in power generation increases at the expense of coal. • Wind generation displaces fossil fuels from 2040.	• Gas share drops in 2050 at the expense of renewables and CC(U)S generation (IGCC). • Nuclear investments to replace retirements.

Table 26 – Cumulative investment needs by 2050 in North America in GW in electricity generation infrastructure

Source: World Energy Council (2013)

North America	Jazz	Symphony
Coal (with CCS)	19	179
Coal	350	64
Oil	24	24
Gas (with CCS)	4	17
Gas	531	504
Nuclear	66	120
Hydrogen	0	0
Hydropower	108	183
Biomass	8	8
Biomass (with CCS)	15	22
Wind	913	854
Solar	82	917
Geothermal	38	52
Total	**2,158**	**2,944**

Note: Calculation of investment needs is for power generation only.

Regional scenario stories: Sub-Saharan Africa

The global recession has affected sub-Saharan Africa heavily, economic growth and energy poverty and access issues remain major concerns in that part of the world. The region is faced with an ever-growing need for energy. Electricity demand has grown, and energy security has tightened as the result of the lack of required investment and increasing power shortages across the continent. The economic cooperation with China and India has intensified as more exploration activities in a number of countries, particularly in Southern, West and Central Africa have positive outcomes, unveiling the huge potential of hydrocarbon prospects and new potential markets. In contrast, climate change issues have been considered a lower priority on the overall agenda.

Large-scale hydro and regional interconnection are the issues that are highly uncertain at present and have seen significant changes recently. Looking forward, their impact remains uncertain, too. In fact, in 2012, the top critical uncertainties, keeping energy leaders awake at night, were trade barriers and terrorism, issues that strongly affected the sustainable development of the African economy.

Large-scale hydro is considered to be the most inexpensive, efficient and affordable form of renewable energy, with a large potential yet to develop in Africa (only 7% of the potential is developed – the lowest rate of the world's regions). For large hydro to be effective in this part of the world, the creation of regional markets is needed, together with more investment in cross-border transmission infrastructure. The WEC anticipates that huge gas reserves and new discoveries, further development and prospects of LNG markets, and cross-border pipelines will change the energy landscape up to 2050 significantly.

Jazz scenario

The region experiences fast growth due to a natural resources boom. Gas production increases in East Africa (Tanzania, Mozambique, Uganda). Investment increases with further FDI flowing in to the region.

Symphony scenario

The region does not realise its growth potential due to high regulatory uncertainty in the early part of the scenario. East Africa undergoes economic development, due to a boom in oil E&P. South Africa continues to grow, but its growth is not the same as in the Jazz scenario.

Regional quantification results: Sub-Saharan Africa

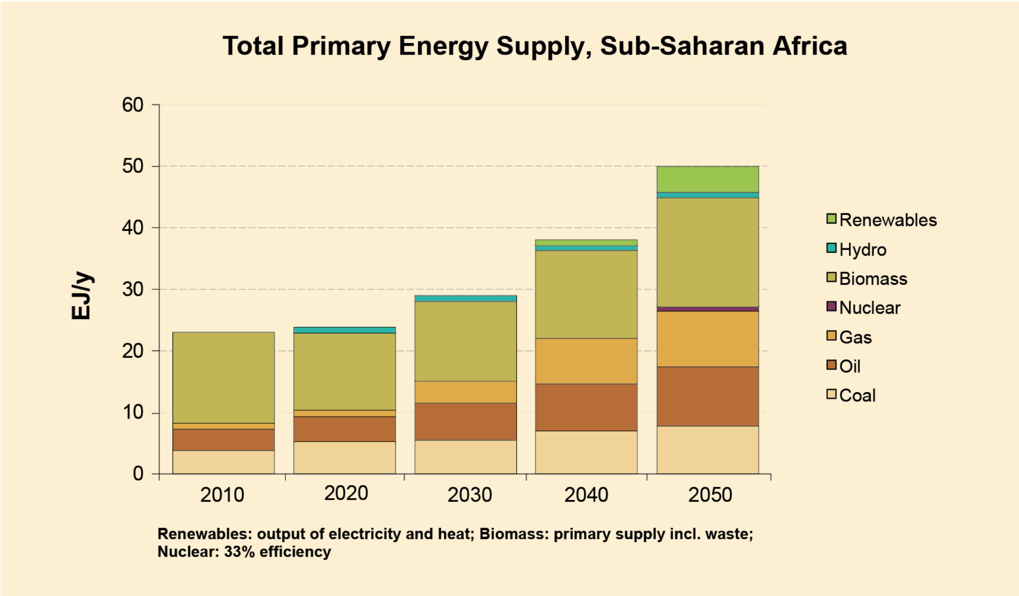
Total Primary Energy Supply: Sub-Saharan Africa

Total primary energy supply for this region up to 2050 is shown in the following graphs.

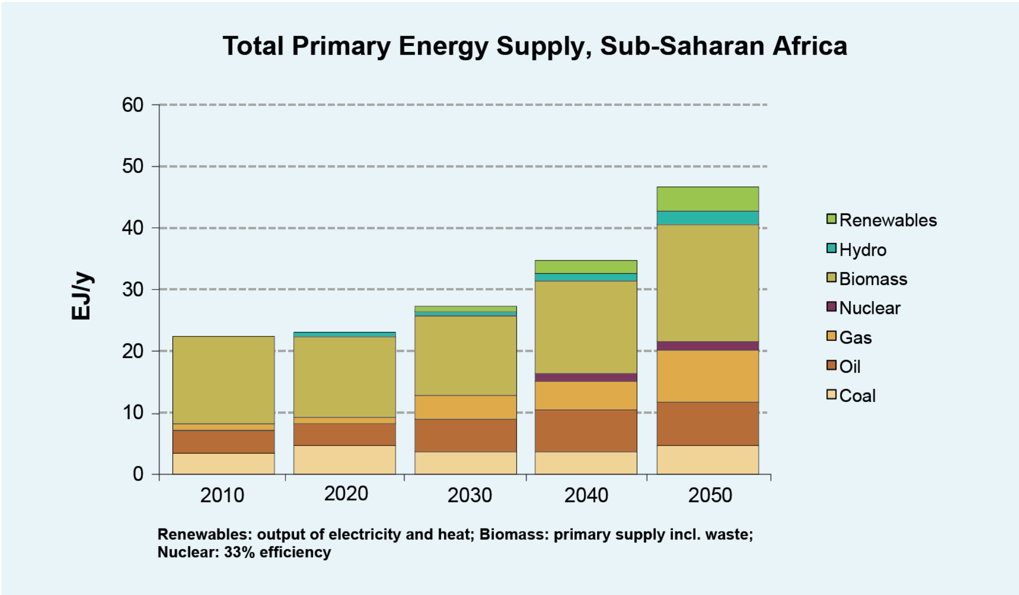
Figure 70 – Total primary energy supply (EJ/y) by fuel type: Sub-Saharan Africa

Source: World Energy Council 2013

Jazz



Symphony



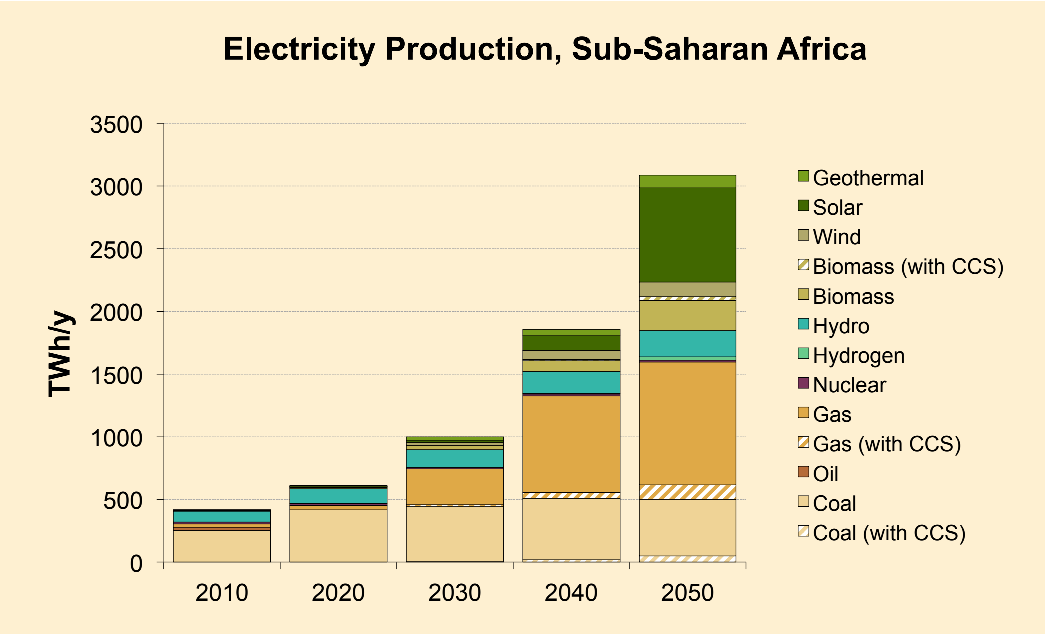
Electricity production and generating capacity by primary energy: Sub-Saharan Africa

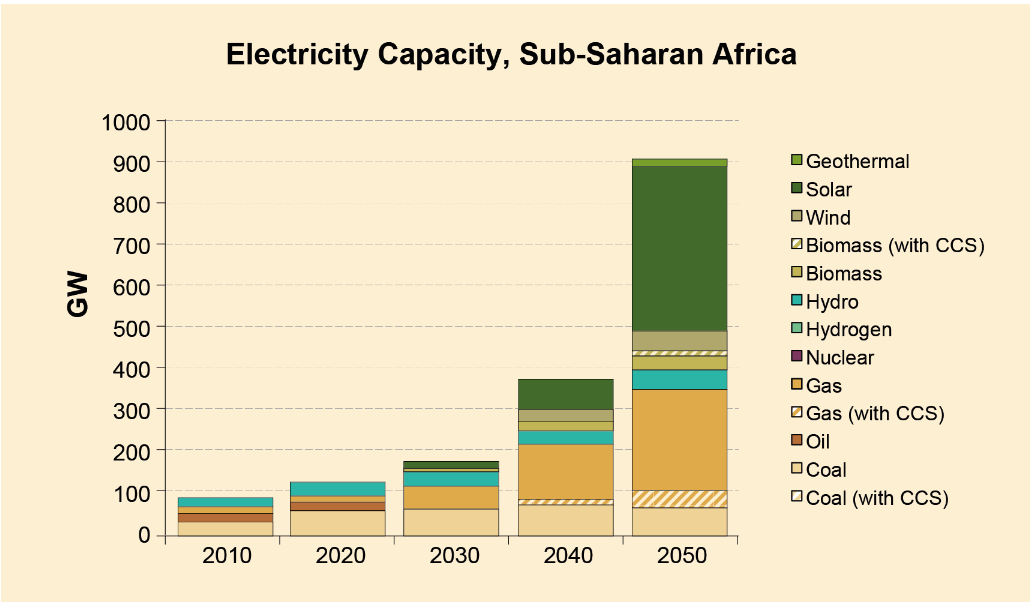
Figure 71 – Electricity production (TWh/y) and electricity generating capacity (GW) for sub-Saharan Africa in the Jazz scenario

Source: World Energy Council (2013)

Historical data: IEA World Energy Statistics and Balances

Jazz





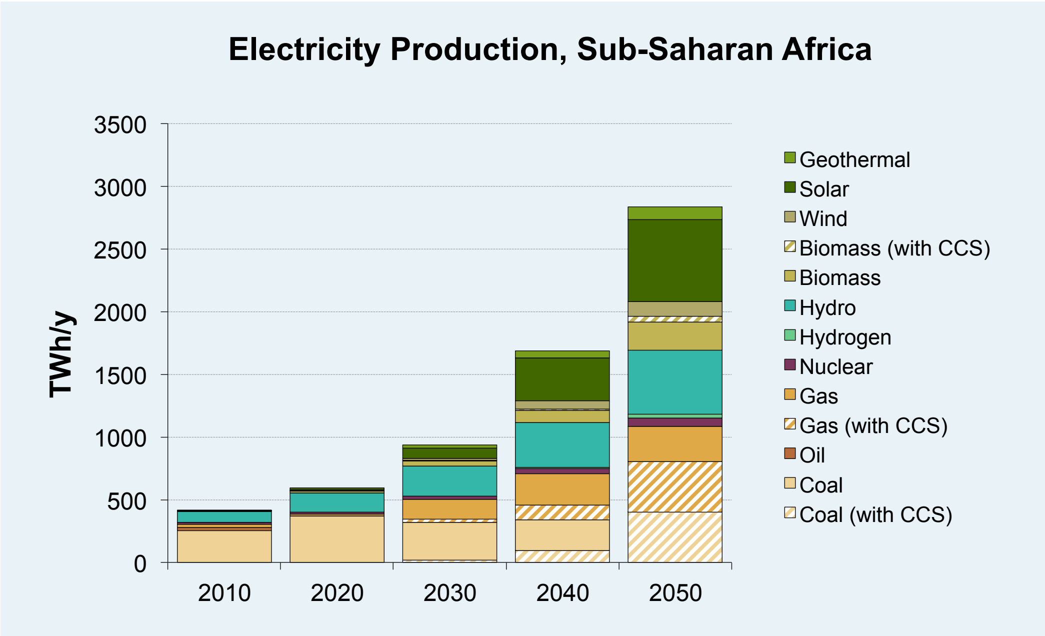
Gas boom in electricity generation. Investments in solar PV (mainly decentralised, some centralised).

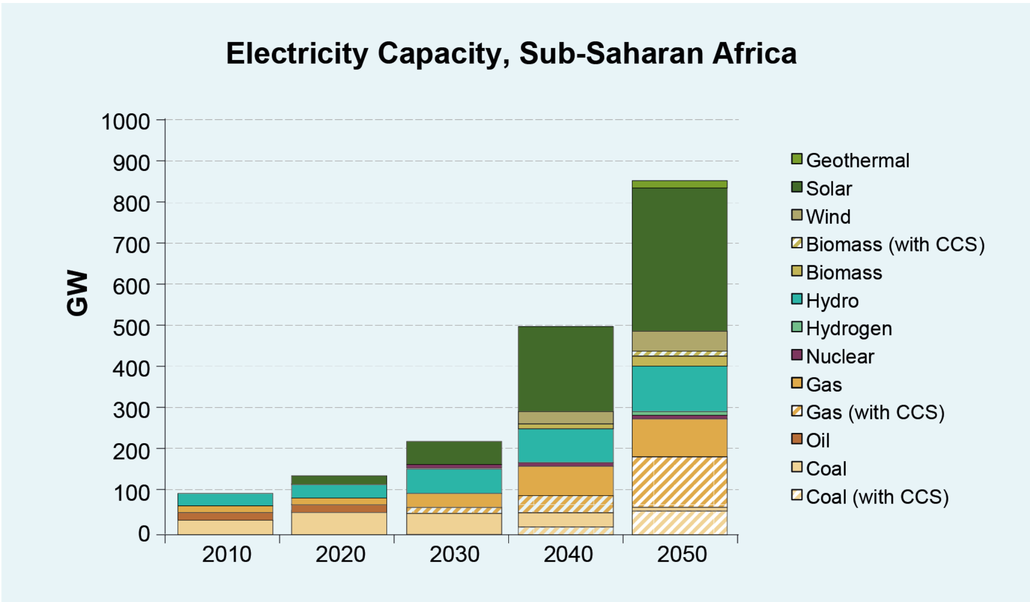
Figure 72 – Electricity production (TWh/y) and electricity generating capacity (GW) for sub-Saharan Africa in the Symphony scenario

Source: World Energy Council (2013)

Historical data: IEA World Energy Statistics and Balances

Symphony



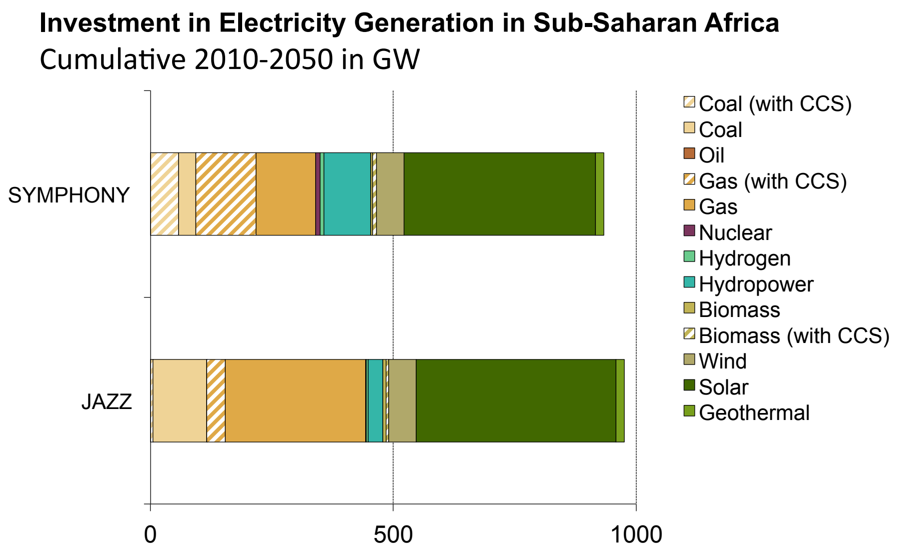


Diversity in electricity production after 2040. Further development of hydropower as it is exploited even more by governments in sub-Saharan Africa. CC(U)S increases (due to leapfrogging).

Investment needs to 2050: Sub-Saharan Africa

Figure 73 – Cumulative investment needs by 2050 in sub-Saharan Africa in electricity generation infrastructure

Source: World Energy Council (2013)



Symphony cumul. undiscounted investment:	**1.4**	**trillion US$2010**
Jazz cumul. undiscounted investment:	**1.2**	**trillion US$2010**

Jazz 2050	Symphony 2050
• Gas boom in the electricity generation. • Investments in solar PV (decentralised).	• Diversity in electricity production after 2040. • Hydropower is starting to being exploited by the government. • CC(U)S increases (leapfrogging).

Table 27 – Cumulative investment needs by 2050 in sub-Saharan Africa in GW in electricity generation infrastructure

Source: World Energy Council (2013)

Sub-Saharan Africa	Jazz	Symphony
Coal (with CCS)	5	57
Coal	110	36
Oil	0	0
Gas (with CCS)	38	124
Gas	289	123
Nuclear	2	9
Hydrogen	3	9
Hydropower	30	96
Biomass	7	4
Biomass (with CCS)	4	7
Wind	58	57
Solar	411	394
Geothermal	17	17
Total	**974**	**933**

Note: Calculation of investment needs is for power generation only.

Comparison of key scenario developments across regions

The WEC has also carried out a cross-region analysis.

Key differences in the regional quantification for the Jazz and Symphony scenarios are shown for:

- Fuel mix in total primary energy supply in 2050 by region.
- Fuel mix in electricity production in 2050 by region.
- Fuel mix in total final consumption in 2050 by region.
- Cumulative global investment needs in 2050 by region (power generation only).

These differences are presented in Figures 74 to 76 and Table 28, together with a brief interpretation for both the Jazz and Symphony scenarios.

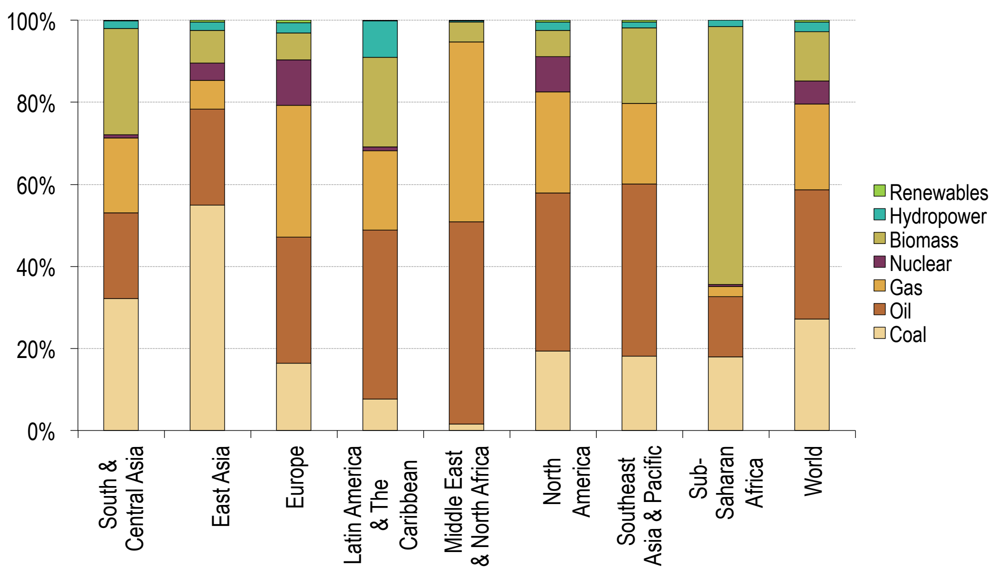
Fuel mix in total primary energy supply in 2050 by region

Figure 74 – Total primary energy supply mix by regions in 2010 and in 2050

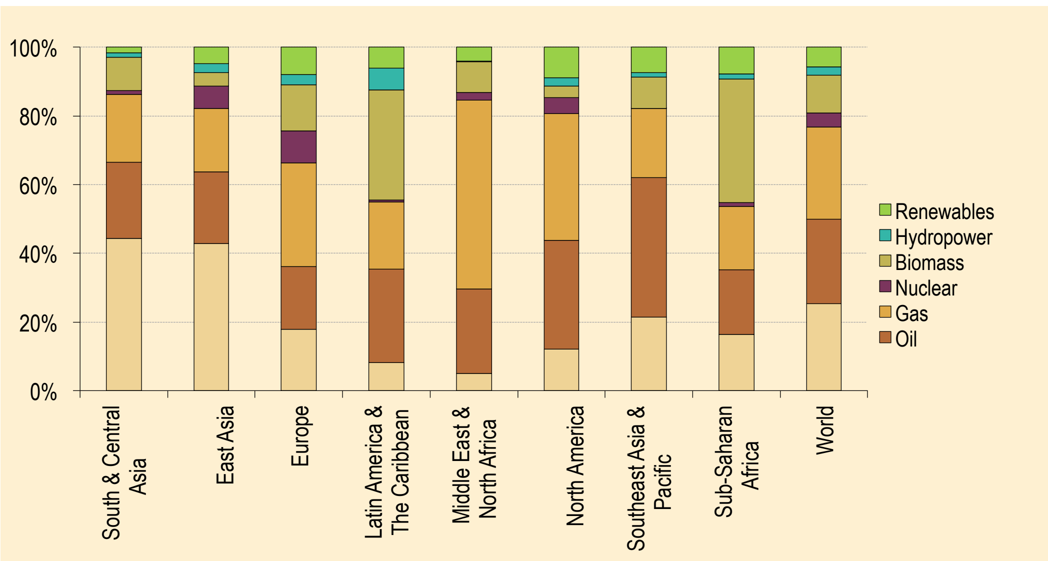
Source: World Energy Council (2013)

Historical data: IEA World Energy Statistics and Balances

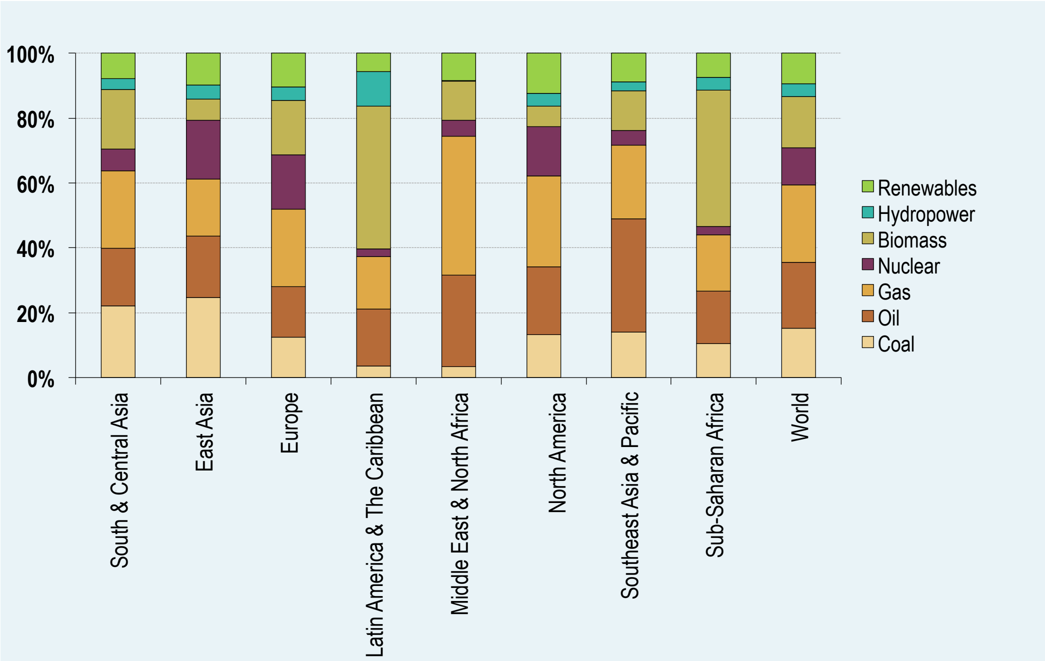
2010



Jazz



Symphony



Jazz 2050	Symphony 2050
• Surge of supply. • Upstream liberalisation. • Coal remains dominant in some regions.	• Climate change concerns. • Increased shares of renewables. • Reduced dependence on fossil fuels.

Total primary energy supply mix by regions in 2010 and 2050

Table 28 – Total Primary energy supply mix by regions in 2010 and 2050

Source: World Energy Council (2013)

2010 %Shares in TPES	Coal	Oil	Gas	Nuclear	Biomass	Hydro-power	Renewables
South and Central Asia	32.2%	20.9%	18.2%	0.8%	26.0%	1.8%	0.2%
East Asia	55.0%	23.4%	7.0%	4.2%	7.8%	2.1%	0.4%
Europe	16.4%	30.8%	32.1%	11.0%	6.5%	2.5%	0.7%
Latin America and The Caribbean	7.7%	41.1%	19.4%	0.8%	21.9%	8.9%	0.1%
Middle East and North Africa	1.5%	49.4%	43.8%	0.0%	4.7%	0.3%	0.2%
North America	19.3%	38.6%	24.6%	8.6%	6.4%	2.0%	0.5%
Southeast Asia and Pacific	18.1%	41.9%	19.8%	0.0%	18.4%	1.4%	0.4%
Sub-Saharan Africa	18.0%	14.6%	2.5%	0.6%	62.9%	1.4%	0.0%
World	**27.2%**	**31.5%**	**20.9%**	**5.5%**	**12.1%**	**2.3%**	**0.4%**

2050 Jazz Scenario %Shares in TPES	Coal	Oil	Gas	Nuclear	Biomass	Hydropower	Renewables
South and Central Asia	44.3%	22.3%	19.6%	1.2%	9.6%	1.3%	1.6%
East Asia	42.8%	20.9%	18.5%	6.5%	3.9%	2.7%	4.7%
Europe	17.9%	18.3%	30.2%	9.3%	13.5%	3.0%	7.9%
Latin America and The Caribbean	8.1%	27.2%	19.5%	0.5%	32.1%	6.4%	6.1%
Middle East and North Africa	5.0%	24.7%	54.9%	2.2%	9.0%	0.3%	4.0%
North America	12.1%	31.7%	36.9%	4.7%	3.3%	2.5%	8.9%
Southeast Asia and Pacific	21.3%	40.8%	20.0%	0.0%	9.2%	1.2%	7.5%
Sub-Saharan Africa	16.3%	19.0%	18.4%	1.0%	36.0%	1.5%	7.8%
World	**25.4%**	**24.6%**	**26.7%**	**4.2%**	**11.0%**	**2.4%**	**5.8%**

2050 Symphony Scenario %Shares in TPES	Coal	Oil	Gas	Nuclear	Biomass	Hydropower	Renewables
South and Central Asia	22.0%	17.8%	24.0%	6.7%	18.4%	3.2%	7.9%
East Asia	24.7%	18.8%	17.6%	18.1%	6.6%	4.3%	9.8%
Europe	12.5%	15.5%	24.0%	16.7%	16.8%	4.1%	10.4%
Latin America and The Caribbean	3.6%	17.6%	16.0%	2.5%	44.0%	10.6%	5.6%
Middle East and North Africa	3.5%	28.0%	42.8%	5.0%	12.1%	0.2%	8.4%
North America	13.3%	20.8%	28.1%	15.2%	6.3%	3.9%	12.4%
Southeast Asia and Pacific	14.0%	35.1%	22.6%	4.7%	12.1%	2.9%	8.8%
Sub-Saharan Africa	10.4%	16.1%	17.5%	2.6%	41.9%	3.9%	7.5%
World	**15.3%**	**20.3%**	**23.8%**	**11.4%**	**15.9%**	**4.0%**	**9.4%**

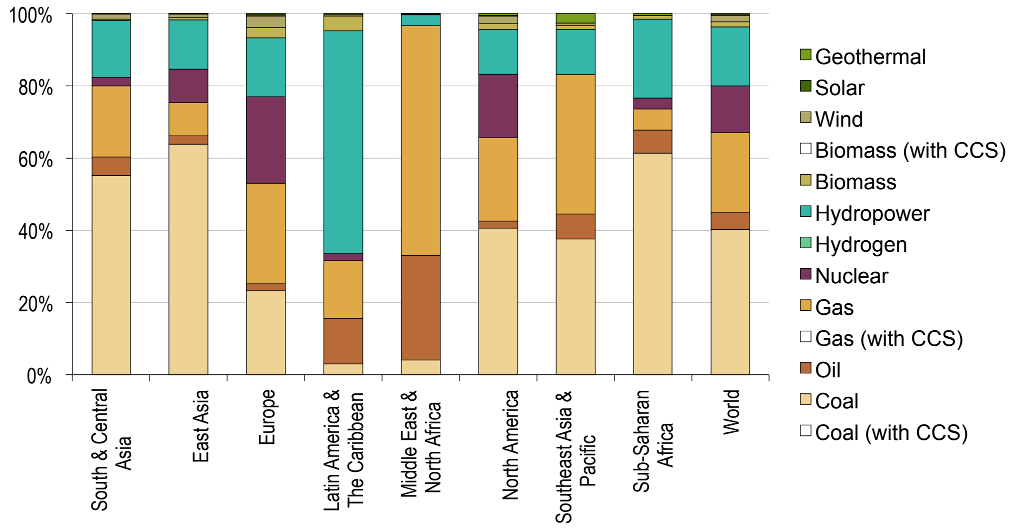
Fuel mix in electricity production by region in 2010 and 2050

Figure 75 – Electricity production fuel mix by region in 2010 and 2050

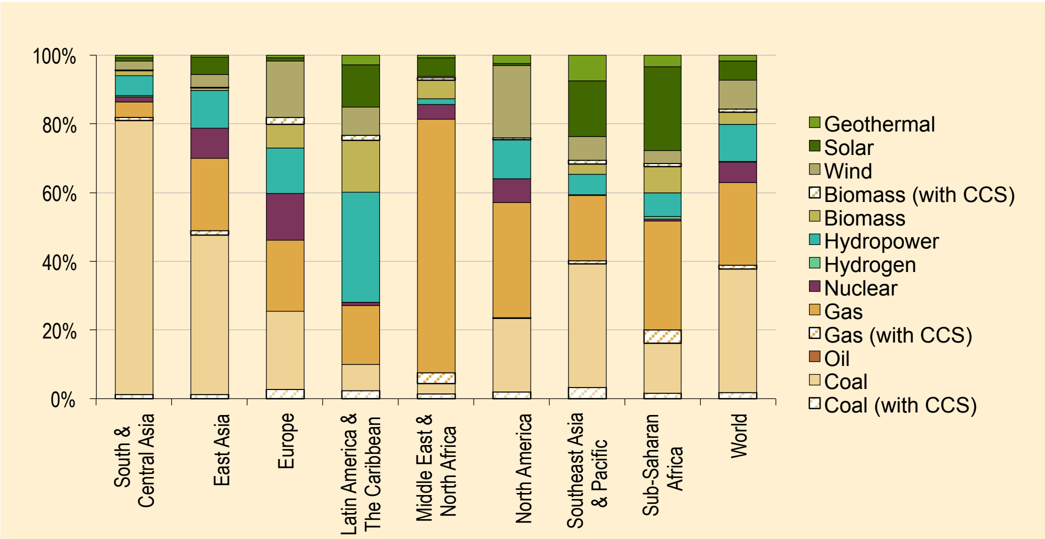
Source: World Energy Council (2013)

Historical data: IEA World Energy Statistics and Balances

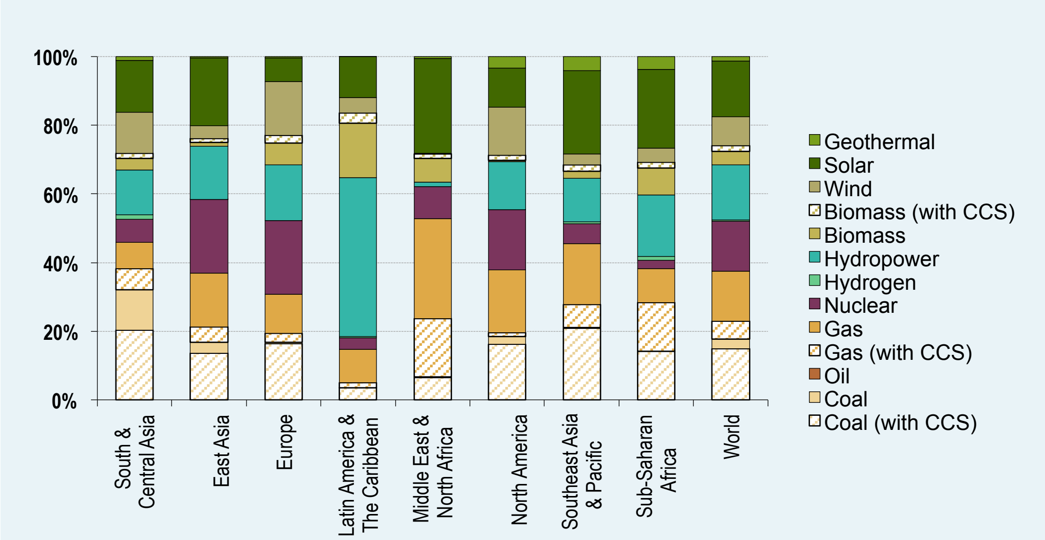
2010



Jazz



Symphony



Jazz 2050: Fuel choice is based on market competition	Symphony 2050: Fuel choice is led by governments
• Different patterns of production among regions. • Investments on flexible projects with short construction times. • Gas is preferred in OECD countries. • Coal is the main source for China and India. • Wind penetrates mainly in the OECD markets. • Solar emerges only in markets where it is competitive. • Hydro and nuclear are not favoured by market competition. • Dependence on fossil fuel generation (60% globally).	• More uniform generation mix across regions. • Focused investments on projects towards sustainability. • Coal-fired generation switches to CSS in all regions. • Gas share drops at the expense of renewable capacity. • Solar and wind enter in all regions. • Government support on capital-intensive projects (hydro, nuclear). • Increased diversification of production in all regions.

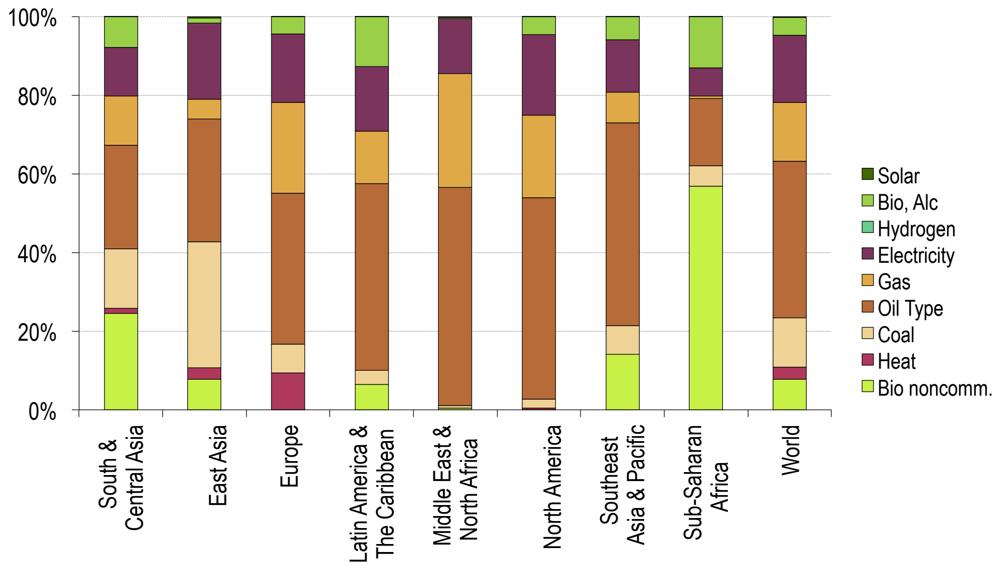
Fuel mix in total final consumption in 2050

Figure 76 – Total final consumption (including non-energy use) mix by regions in 2010 and in 2050

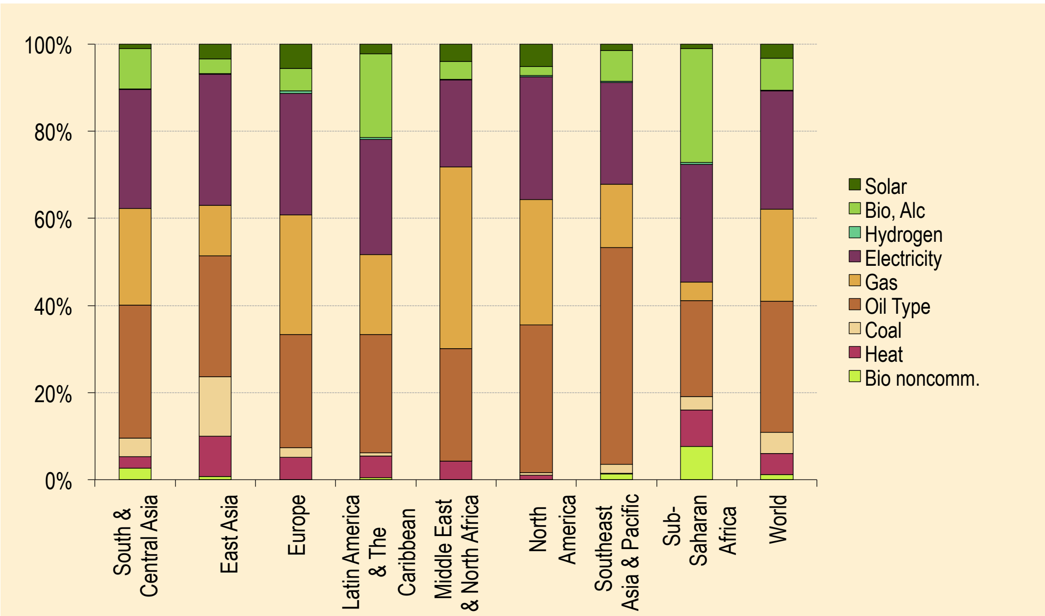
Source: World Energy Council (2013)

Historical data: IEA World Energy Statistics and Balances

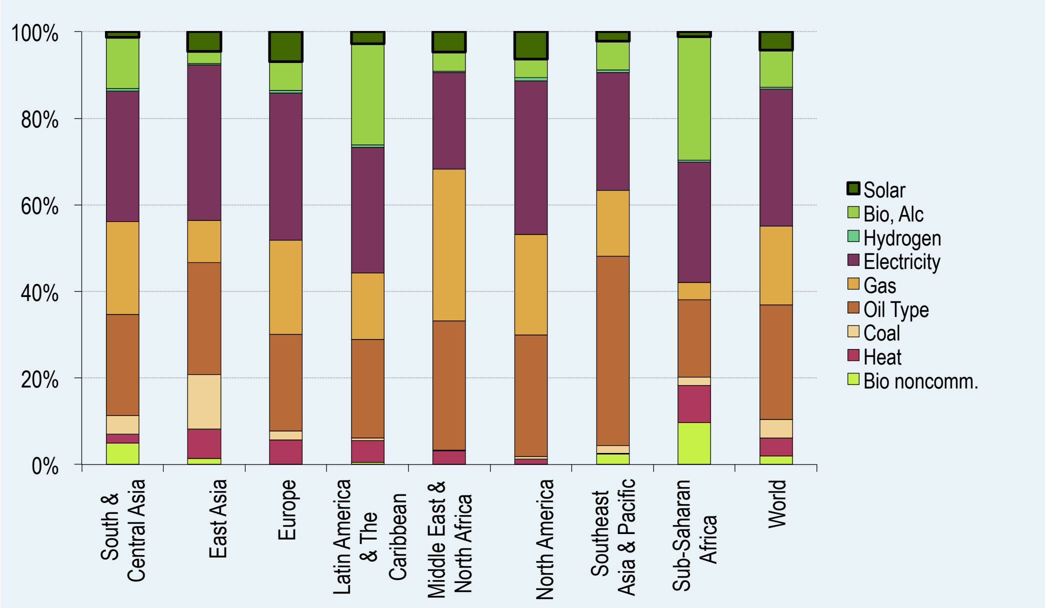
2010



Jazz



Symphony



Jazz 2050	Symphony 2050
• Efficiency due to high prices. • Efficient buildings in OECD countries. • Industry becomes efficient in non-OECD countries.	• Increased energy efficiency. • Building codes in non-OECD countries. • Industry moves away from fossil fuels to reduce emissions.

Assessing cumulative investment needs across regions

The WEC has comprehensively assessed the cumulative investment needs across the different regions of this scenario study. The results are presented for:

- Cumulative discounted investment in electricity generation as a percentage of 2010 GDP.
- Cumulative discounted investment to incremental electricity production ($2010/MWh).
- Cumulative discounted investment in electricity generation to cumulative discounted GDP 2010–2050.
- Undiscounted cumulative investment in electricity generation in trillion US$2010.
- Cumulative discounted investment in electricity generation in billion US$2010.

Results are presented in Figures 77 to 81.

Figure 77 – Cumulative discounted investment in electricity generation as % of 2010 GDP

Source: World Energy Council (2013)

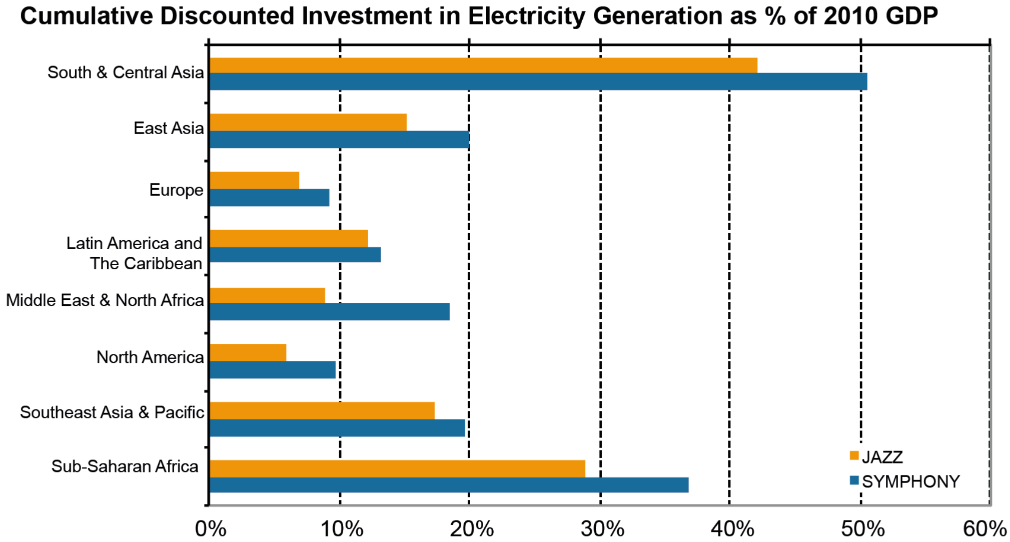


Figure 78 – Cumulative discounted investment to incremental electricity production ($2010/MWh)

Source: World Energy Council (2013)

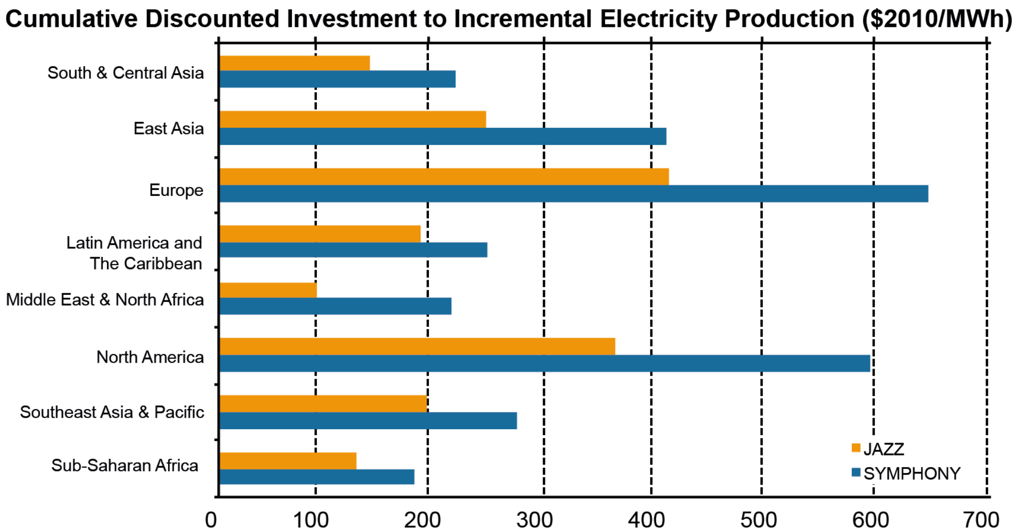


Figure 79 – Cumulative discounted investment in electricity generation as % of cumulative discounted GDP 2010 – 2050

Source: World Energy Council (2013)

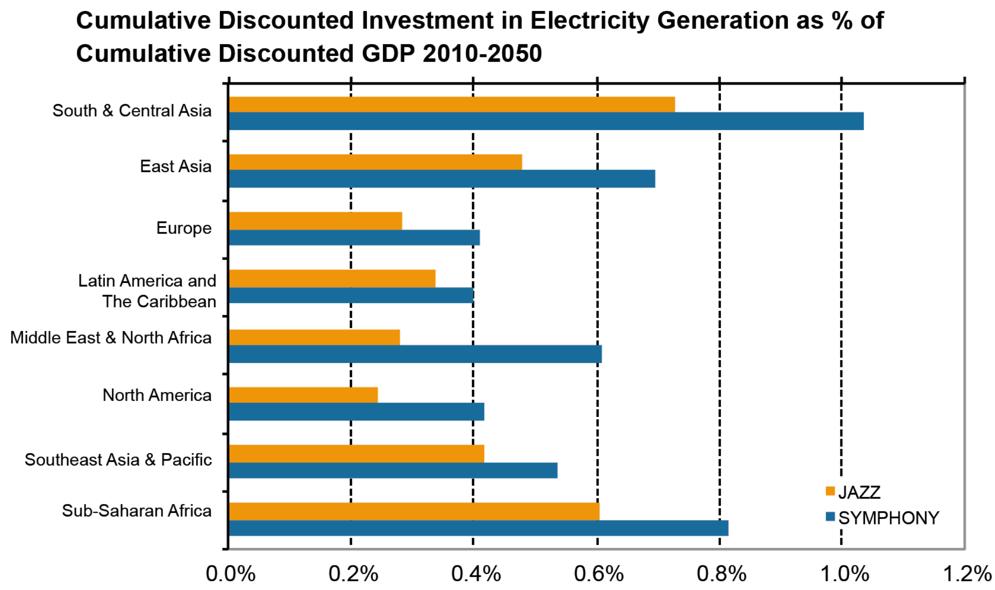


Figure 80 – Undiscounted cumulative investment in electricity generation in trillion US$2010

Source: World Energy Council (2013)

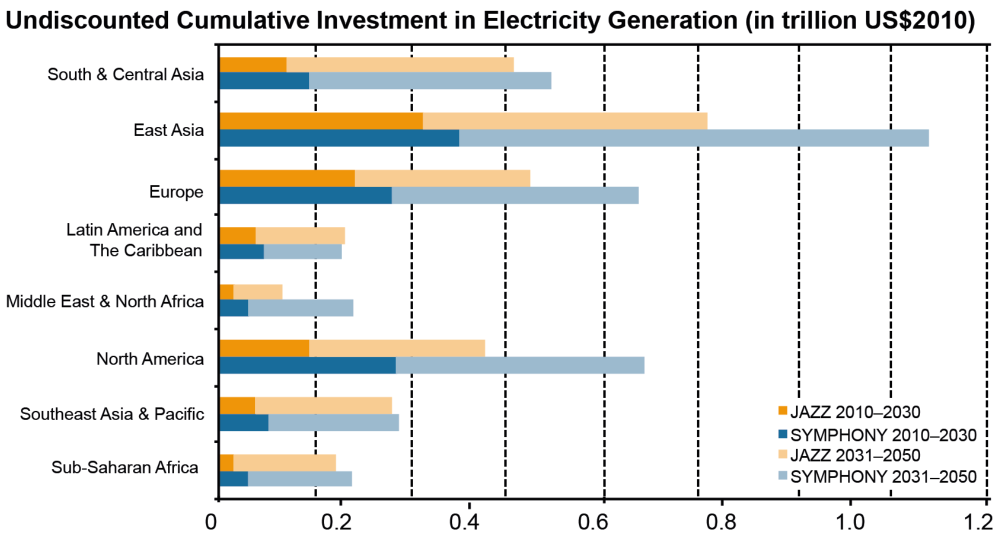
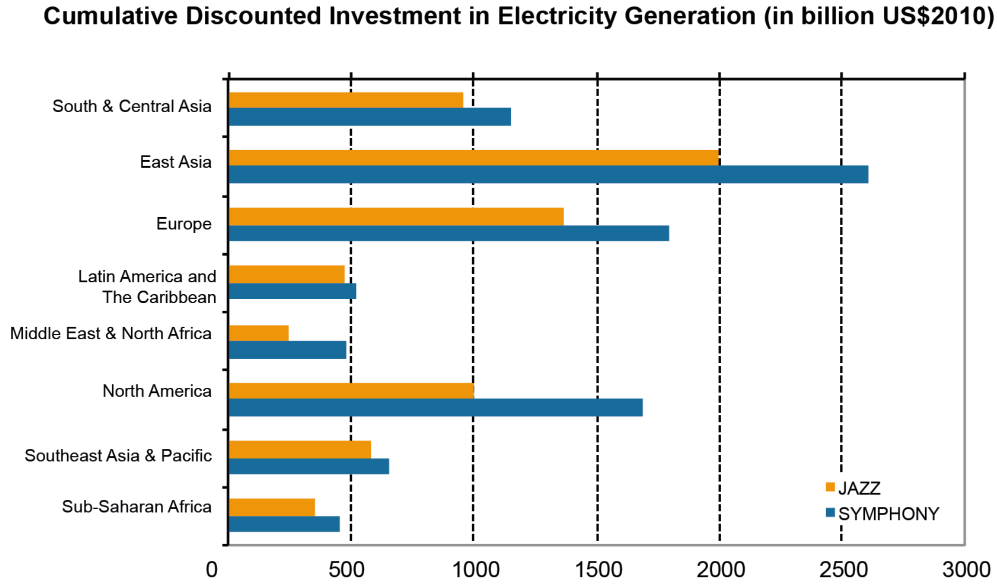


Figure 81 – Cumulative discounted investment in electricity generation in billion US$2010

Source: World Energy Council (2013)



7. The WEC's World Energy Scenarios to 2050 and the energy trilemma

Using trilemma indicators to assess each of the scenarios

In order to assess the wider societal, economic and environmental implications of how the energy landscape might develop until 2050, the WEC has established a link between its work on the global energy scenarios and its work based on the energy trilemma triad.

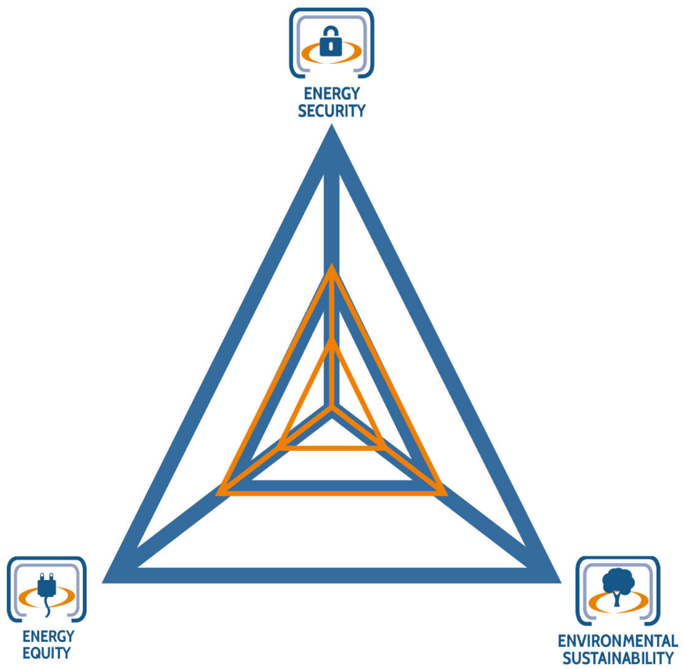
The WEC's definition of energy sustainability is based on three core dimensions:

- **Energy security:** For both net energy importers and exporters this refers to the effective management of primary energy supply from domestic and external sources, the reliability of energy infrastructure, and the ability of participating energy companies to meet current and future demand. For countries that are net energy exporters, this also relates to an ability to maintain revenues from external sales markets.
- **Energy equity:** The accessibility and affordability of energy supply across the population.
- **Environmental sustainability:** The achievement of the supply and demand-side of energy efficiencies and the development of energy supply from renewable and other low-carbon sources.

The development of stable, affordable, and environmentally-sound energy systems defies simple solutions. These three goals constitute a 'trilemma', entailing complex interwoven links between public and private governments and regulators, economic and social factors, national resources, environmental concerns, and individual behaviours.

Figure 82 – WEC World Energy Trilemma

Source: World Energy Council (2013)



The WEC's work has examined the three dimensions of the trilemma. Each scenario can equally be evaluated, based on key metrics. There is a difference between the WEC's work on the energy trilemma in the past and the scenarios. While the WEC's work has looked at the trilemma on an ex-post basis (by using historic data and assessing past energy policies), scenarios are by nature forward-looking. Therefore, a direct comparison of the findings is not possible. Quantifying the energy trilemma as proposed in the following section can help to shed light on some key aspects of how the energy landscape is developing up and until 2050 – looking forward, not backwards.

Trilemma indicators in theory and practice

The following metrics can, in theory, be considered within both scenarios, Jazz and Symphony, to clarify the complexity, and at the same time highlight the trade-offs, in dealing with the energy trilemma:

1. Energy security

- Share of imports
- Diversity of supply
- Diversity of demand (markets for export and range for home market)
- Reserve capacity (electricity)
- R/P ratios.

2. Energy Equity (access and affordability)

- Marginal generation cost
- Marginal cost of petrol/diesel

- Costs vs. GDP
- Investment required
- Access (number connected).

3. Environmental sustainability

- CO_2 emissions
- Competition for land (biofuels)
- Water use (unconventional oil and gas, large hydro)
- Clear air, clear water, soil.

In practice, the WEC has derived a number of energy trilemma indicators based on the results of its scenario quantifications, and on the fundamentals of: (i) robustness; (ii) data availability; and (iii) interpretability/significance and ease-of-use.

Such metrics could be as follows:

- Energy security:
  - Share of net imports in primary energy supply (%)
  - Diversity of primary energy supply (Simpson Index).
- Energy equity:
  - Income in terms of GDP per capita
  - Energy access data: population without access in electricity (in millions)
  - GDP/capita vs. TPES/GDP
  - Final energy and electricity per capita (GJ) (excluding non-energy uses).
- Environmental sustainability:
  - CO_2 intensity of primary energy (tCO_2/PJ)
  - CO_2 emissions and CC(U)S
  - Depletion of resources (natural gas and oil).

The WEC has used these indicators to evaluate each scenario based on all three dimensions of the energy trilemma. The first indicative results from this evaluation can be found in the following subsections.

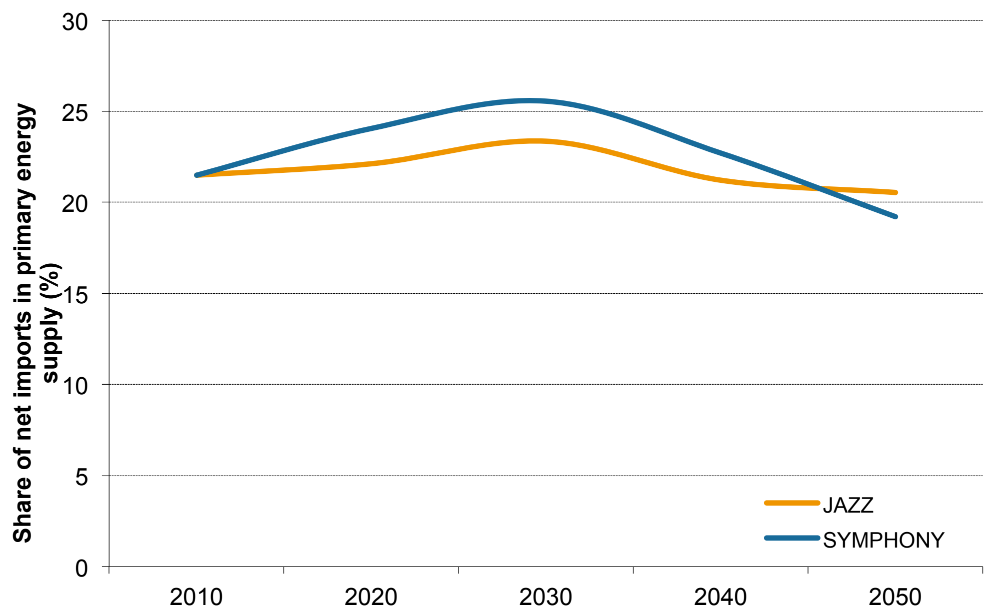
These trilemma measures for Jazz and Symphony are still being developed and will be refined in the future. It is important to point out though that the WEC global energy model does not contain a land-use model. Therefore, it is not possible to derive a statement about competition for land (e.g. for biofuels). Also, the model does not contain a water use module, although the link between water and energy usage is relevance e.g. in the context of the development of unconventional oil and gas. To assess this, water usage coefficients would be needed for all or each production technology included in the model. These are extensions to the existing model that can be looked at in the future.

Trilemma indictors for Jazz and Symphony: Results

Energy security

Figure 83 – Share of net imports in primary energy supply (%)

Source: WEC/PSI projections (2013)

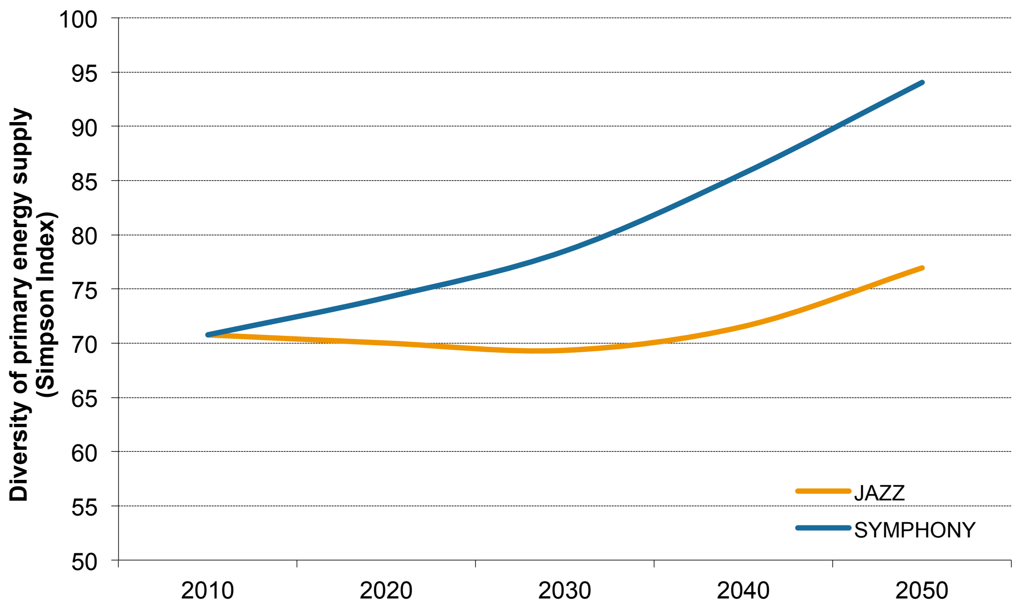


Jazz	Symphony
• Fewer trade barriers, globalised economy. • Trade disputes arise. • Domestic unconventional fossil resources. • Net energy import 2010–2050: +70%. • Gas import peaks in 2030.	• Security of supply; more local content and solutions. • Domestic nuclear energy and renewables. • WTO support. • Net energy import 2010-–2050 increase: +40%, oil import peaks in 2030.

Assessment: Similar import dependence in Jazz and Symphony – stable over time.

Figure 84 – Diversity of primary energy supply (Simpson Index)

Source: WEC/PSI projections (2013)



Jazz	Symphony
• Renewables join gradually. • Fossil energy stays.	• Energy security. • Renewables - a significant share. • Additional risk/issues by additional energy types. • Higher overall energy security of supply due to diversified energy sources.

Assessment: Symphony – primary energy is more diversified.

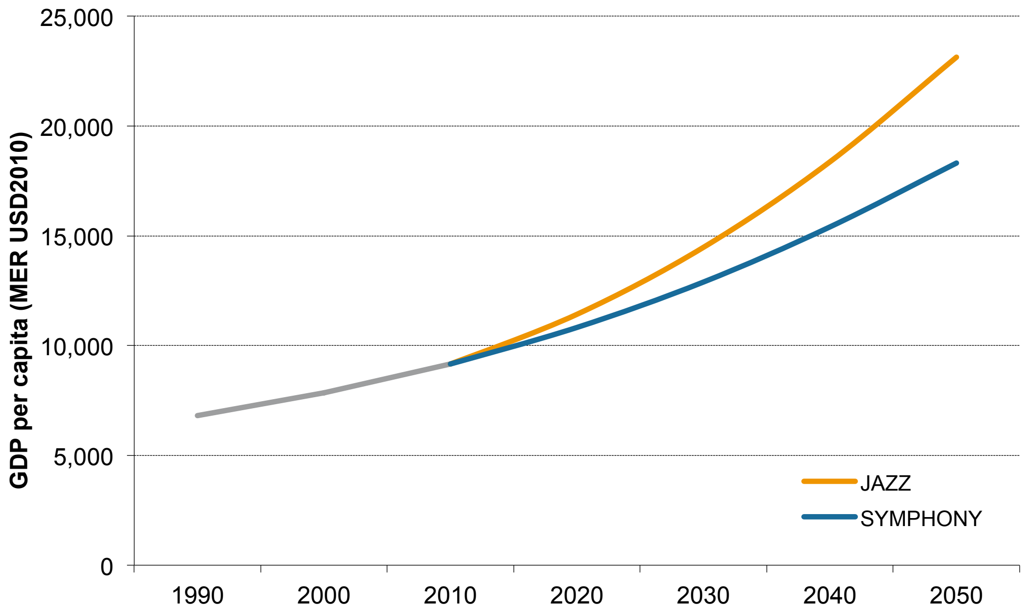
The Simpson Index measures the diversity of TPES relative to an even distribution. The formal definition of the Index is:

$$\text{Simpson} = \frac{\text{Prob. of choosing twice the same type, with types having equal share}}{\text{Prob. of choosing twice the same type}}$$

Energy equity

Figure 85 – Income (GDP per capita)

Source: World Energy Council (2013)



Jazz	Symphony
• High and increasing wealth in the developed and transitional world. • Rich–poor gap widens. • Quality over quantity: large GDP growth, slow population growth.	• Wealth in the developing world improves. • Wealth disparity is smaller in the developed world. • Lower GDP growth, faster population growth.

Assessment: Symphony has a lower GDP per capita ratio (but may have smaller rich–poor wealth gap).

Table 29 – Population without access to electricity (in millions)

Source: World Energy Council (2013)

	1970	1980	1990	2000	2010
South & Central Asia	595	695	775	822	471
East Asia	565	576	455	47	22
Latin America & The Caribbean	129	130	108	55	29
Middle East & North Africa	90	94	94	29	20
Southeast Asia & Pacific	229	256	266	193	135
Sub-Saharan Africa	269	340	433	515	589
World	**1,877**	**2,091**	**2,131**	**1,662**	**1,267**

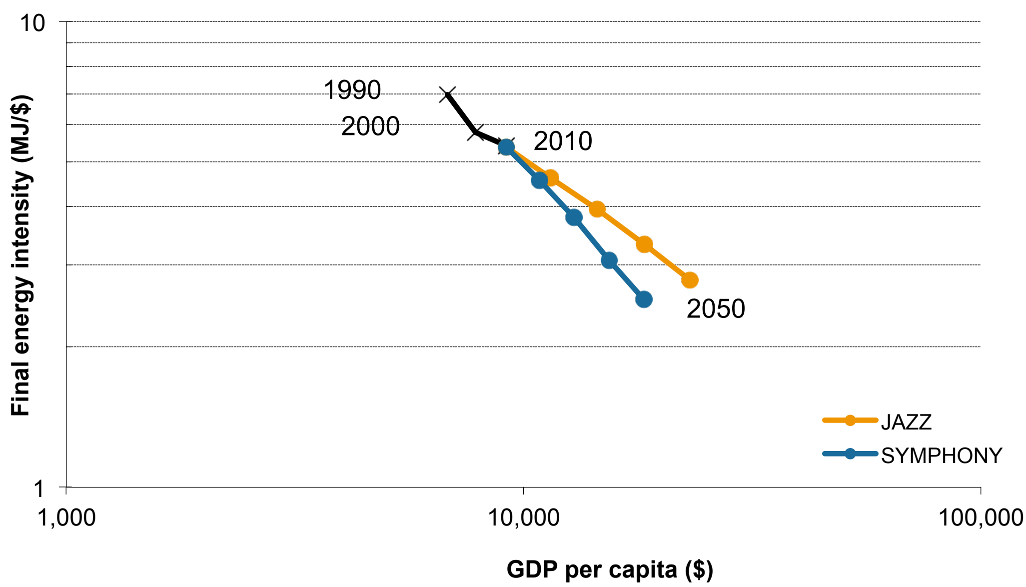
	Jazz				Symphony			
	2020	**2030**	**2040**	**2050**	**2020**	**2030**	**2040**	**2050**
South & Central Asia	341	226	124	45	380	264	181	102
East Asia	1	0	0	0	3	0	0	0
Latin America & The Caribbean	5	1	0	0	7	3	1	1
Middle East & North Africa	4	1	0	0	6	2	1	0
Southeast Asia & Pacific	90	49	21	8	106	74	44	26
Sub-Saharan Africa	570	455	341	266	596	542	433	401
World	**1,012**	**733**	**486**	**319**	**1,098**	**885**	**660**	**530**

Jazz	Symphony
• Reduction in the number of people without access to electricity from 1.267bn in 2010 to 319m in 2050 (globally): -75%.	• Reduction in the number of people without access to electricity from 1.267bn in 2010 to 530m in 2050 (globally): -38%.
• Energy access will increase; infrastructure investment lagging due to lack of available funds. • Increasing consumption level. • Industry: energy growth comparable to GDP growth. • Residential/commercial/transport sectors: efficiency measures when cost-effective.	• Energy access for the poor, but may be generally on a limited level. • Consumption levels are lower. • Industry: energy growth is moderate. • Residential/commercial: higher energy savings and more efficient equipment and insulation in use.

Assessment: Jazz is better in ensuring access to electricity due to Symphony's lack of government funding and conflicting spending priorities and budget constraints.

Figure 86 – GDP/capita vs. TPES/GDP

Source: World Energy Council (2013)



Jazz	Symphony
• Higher GDP/capita vs. TPES/GDP ratio.	• Lower GDP/capita vs. TPES/GDP ratio.

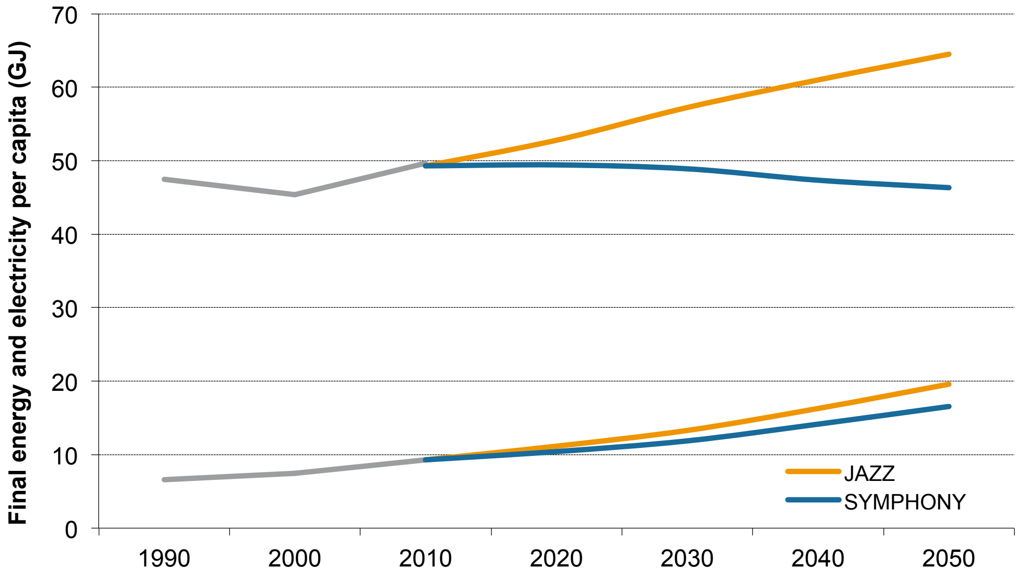
Assessment: Symphony is more efficient in terms of primary -energy for a given income.

Note: This indicator also incorporates elements of efficiency and fuel mix. Thus, a low value does not necessarily mean lower energy equity if the system is more efficient and contains more renewables (this applies partly to final energy per capita as well, but with TPES we have the added issue of the accounting of renewable electricity generation).

Figure 87 – Final energy and electricity per capita (GJ) (excluding non-energy uses)

Source: World Energy Council (2013); WEC/PSI projections; IEA, UN (historical data)

Historical data: IEA World Energy Statistics and Balances



Jazz	Symphony
• Fast growth of GDP, more CO_2 emissions, high final energy/electricity per capita. • Efficiency measures (cost-effective). • Slow growth of population.	• Slow growth of GDP, less CO_2 emissions, low final energy/electricity per capita. • Efficiency measures (policy induced). • Fast growth of population.

Assessment: Both scenarios continue to decouple GDP from CO_2.

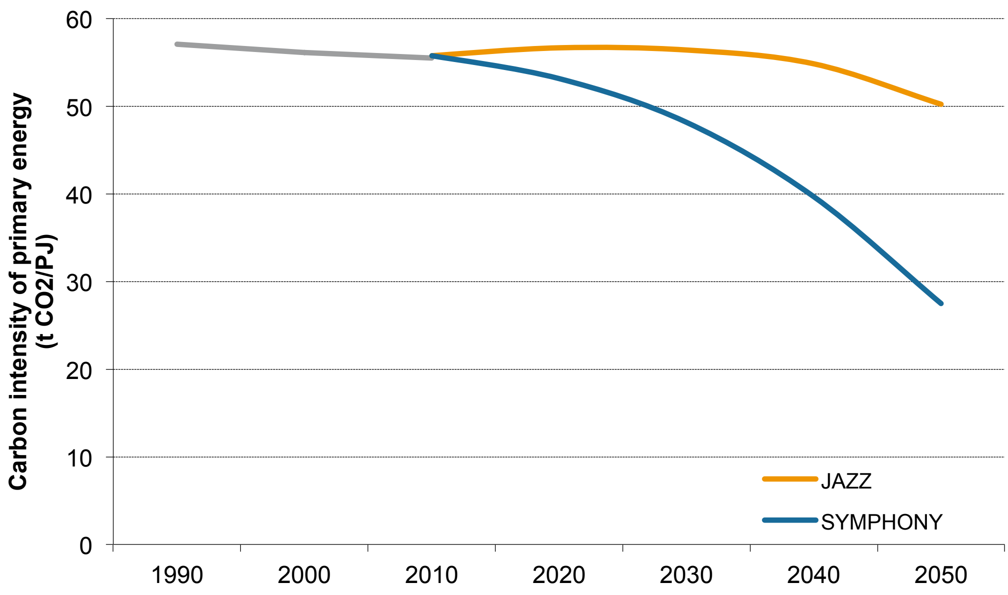
Notes: Final energy includes coal use in coke ovens, blast furnaces and gas works and also non-commercial biomass.

Environmental sustainability

Figure 88 – CO_2 intensity of primary energy (t CO_2/PJ)

Source: WEC/PSI projections (2013); IEA (historical data)

Historical data: IEA CO_2 Emissions from Fuel Combustion Statistics; IEA World Energy Statistics and Balances



Jazz	Symphony
• Delayed CO_2 market. • Unconventional fossil resources are more exploited. • Increased energy demand. • Cost-effective efficiency.	• Environmentally aware citizen. • Early CO_2 measures. • Early incentives for renewables. • CC(U)S (social and environmental issues). • Less energy demand, high efficiency.

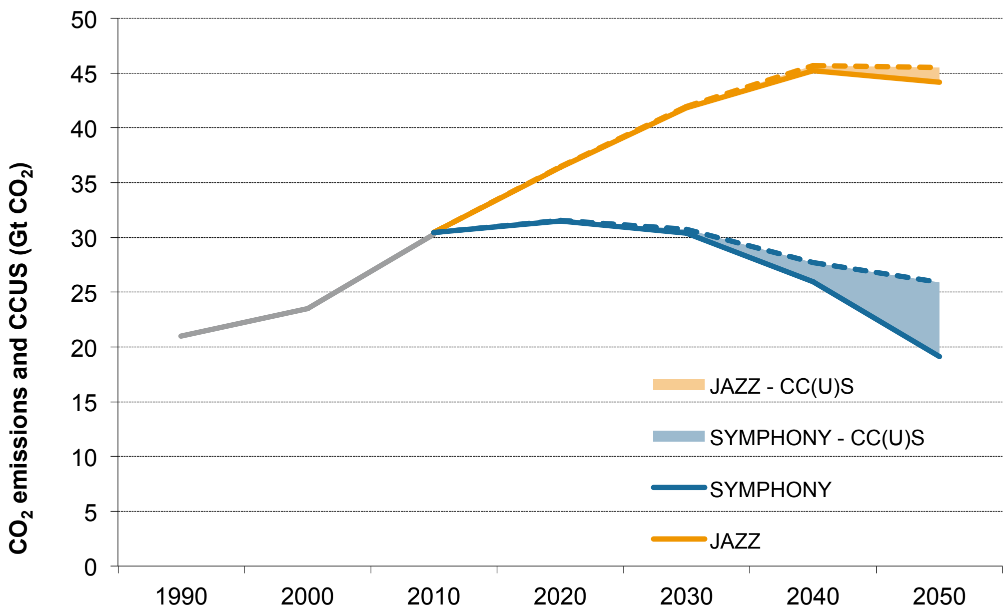
Assessment: Symphony: CO_2-intensity breaks historical trend.

In the WEC/PSI projections, the primary energy content of renewable electricity (hydro, wind, solar PV, solar thermal, geothermal power) is calculated as equal to generation; primary energy amounts for geothermal and solar heating represent thermal energy. Primary energy content of biomass is the energy content (lower heating value) of the biomass. In comparison, the sources used for the historical data apply a slightly different methodology (accounting for the small difference in 2010).

Figure 89 – CO_2 emissions and CC(U)S

Source: WEC/PSI projections (2013); IEA (historical data)

Historical data: IEA CO_2 Emissions from Fuel Combustion Statistics

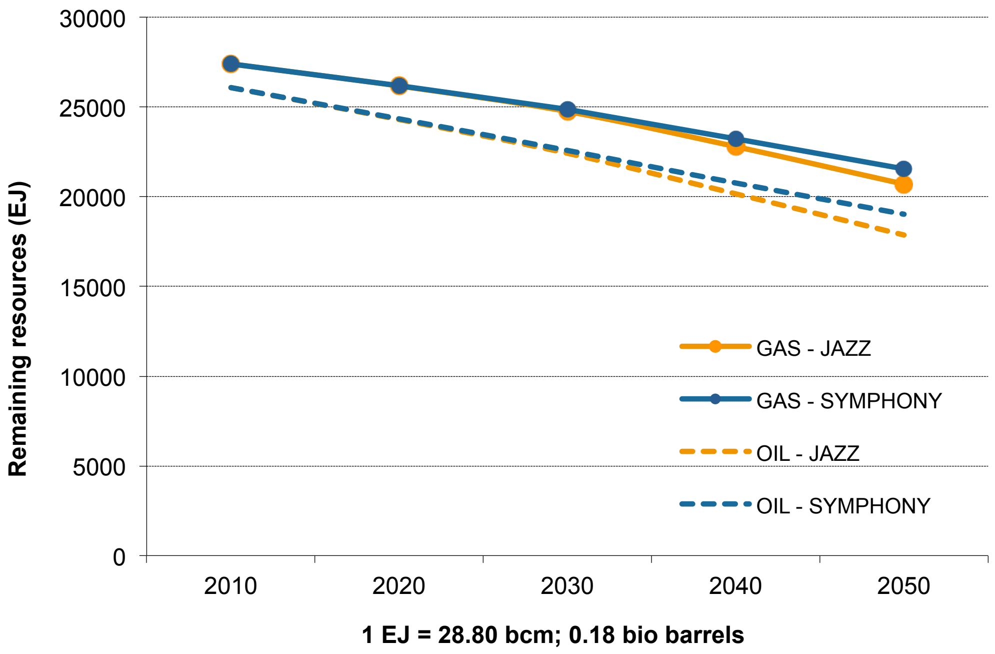


Jazz	Symphony
• Fast growth of GDP and more CO_2 emissions. • CC(U)S reduces CO_2 emissions, but only after 2030.	• Slow growth of GDP and less CO_2 emissions. • The reduction in CO_2 emissions due to CC(U)S and less CO_2 being produced is higher in Symphony than it is in Jazz.

Assessment: CC(U)S is more effective in Symphony than in Jazz

Figure 90 – Depletion of resources

Source: WEC/PSI projections (2013); BGR (2010 data)



Jazz	Symphony
• Oil and gas depletion is higher in Jazz.	• Oil and gas depletion is lower in Symphony.

Assessment: Oil and gas depletion is higher in Jazz than it is in Symphony – i.e. Symphony performs better than Jazz in this case.

Assessment of Jazz vs. Symphony based on the trilemma metrics

Energy security

As far as energy security is concerned, dependence over time is much the same in Jazz and Symphony, although there are fewer trade barriers in the Jazz scenario in a truly globalised economy. Trade disputes may arise and the net energy import increases by about 70% from 2010 to 2050. Natural gas import peaks in 2030 in Jazz. In the Symphony scenario, security of supply is higher, there is more local content and solutions, and an emphasis on domestic nuclear energy and renewables. There is support for the WTO. In Symphony, net energy imports increase by about 40% from 2010 to 2050, and oil import peaks in 2030.

Diversity of primary energy supply is higher in Symphony than it is in Jazz. In the Jazz scenario, renewables join gradually and fossil energy stays for the whole duration of the time period under consideration. In the Symphony scenario, energy security is higher, renewables have a significant share and consequently there are additional risks and /issues introduced by the additional energy types. However, in the Symphony scenario, energy security of supply is higher due to diversified energy sources.

Symphony makes use of a wider diversity of energy resource types, and has government-promoted investment in infrastructure. In Jazz there is higher energy production, greater trading and diversity of international fossil energy suppliers.

Energy equity

In terms of energy equity, Symphony has a lower GDP per capita ratio (but may have a smaller rich–-poor wealth gap). In the Symphony scenario, wealth in the developing world improves and the wealth disparity is smaller in the developed world. As a consequence, there is lower GDP growth and faster population growth in Symphony. In the Jazz scenario, there is high and increasing wealth in the developed and developing countries. Consequently, the gap between rich and poor widens, in line with large GDP growth, with slow population growth.

As far as energy access is concerned, Jazz is better in ensuring access to electricity due to a lack of government funding, conflicting spending priorities and budget constraints in Symphony. In the Jazz scenario, the overall global number of people without access to electricity will be reduced from 1.267 billion in 2010 to 319 million in 2050 (a decrease of about 75%).

Energy access will increase. There is a lag in infrastructure investment though as energy consumption levels increase. Energy growth is comparable to GDP growth for industrial demand. In the residential, commercial and transport sectors, efficiency measures are undertaking when they are cost-effective.

In the Symphony scenario, the global number of people without access to electricity will be reduced from 1.267 billion in 2010 to 530 million in 2050 (a decrease of about 38%). In Symphony, governments place emphasis on energy access for the poor, but generally to a limited level due to constraints in government spending and different spending priorities. Overall consumption levels for energy are lower and energy growth in the industrial sector is moderate. In the residential and commercial sectors, there are higher energy savings as more efficient equipment and insulation is in use.

The ratio of GDP/capita vs. TPES/GDP indicates energy efficiency (in terms of energy use) in relation to income. Jazz has a higher GDP/capita vs. TPES/GDP ratio. This rate is lower in Symphony. Consequently, Symphony is more efficient in terms of primary energy for a given income.

In terms of final energy and electricity per capita (GJ) (excluding non-energy uses), both scenarios continue to decouple GDP from CO_2. In the Jazz scenario, this is due to a wide range of factors, such as:

- Fast growth of GDP, leading to more CO_2 emissions.
- High final energy/electricity per capita ratio.
- Efficiency measures being implemented (when cost-effective).
- Slow growth of population.
- Stagnation of CO_2-intensity between 2000 and 2010 because TPES/GDP is constant.

Whereas in the Symphony scenario, the following is the case:

- Slow growth of GDP, and less CO_2 emissions.
- Low final energy/electricity per capita ratio.
- Efficiency measures are being introduced due to a political mandate/induced by the government.
- Fast growth of population, from 2000 to 2010 the population increased +13%, consequently, tCO_2/y: +29%.

It can therefore be concluded that, on average and across all dimensions considered, energy equity progresses better in Jazz. More people are able to afford energy because the global market leads to higher GDP growth. Energy equity is less in Symphony because there are inevitably interventions restricting GDP growth. In the Symphony scenario, funds directed into low-carbon initiatives would actually start diverting funds from other government priorities such as healthcare. Financial resources are not limitless, and governments have to set spending priorities. Wise choice of policies as identified in the WEC World Energy Trilemma Report could avoid this drop, as countries strive to score well on the WEC's trilemma index.

Environmental sustainability

As far as environmental sustainability is concerned, in Symphony, CO_2-intensity breaks the historical trend if equal to the CO_2 intensity of primary energy (tCO_2/PJ). In the Symphony scenario, citizens are more environmentally aware, CO_2 measures are implemented at the early stages of the scenario time periods and governments create incentives for renewables sooner, rather than later. CC(U)S is being implemented and overall energy demand is lower, whereas energy efficiency is higher.

Broadly speaking, CC(U)S as a technology is more effective in Symphony than in Jazz. In Symphony, GDP grows at a slower rate than it does in Jazz and hence there are less CO_2 emissions. The reduction in CO_2 emissions is higher in Symphony than it is in Jazz. In Jazz, GDP grows faster and there are more CO_2 emissions. CC(U)S comes in at the second half of the scenarios period, i.e. post-2030. CC(U)S reduces the increase in CO_2 emissions only after 2030.

In terms of the depletion of resources, oil and gas depletion is higher in Jazz, than it is in Symphony.

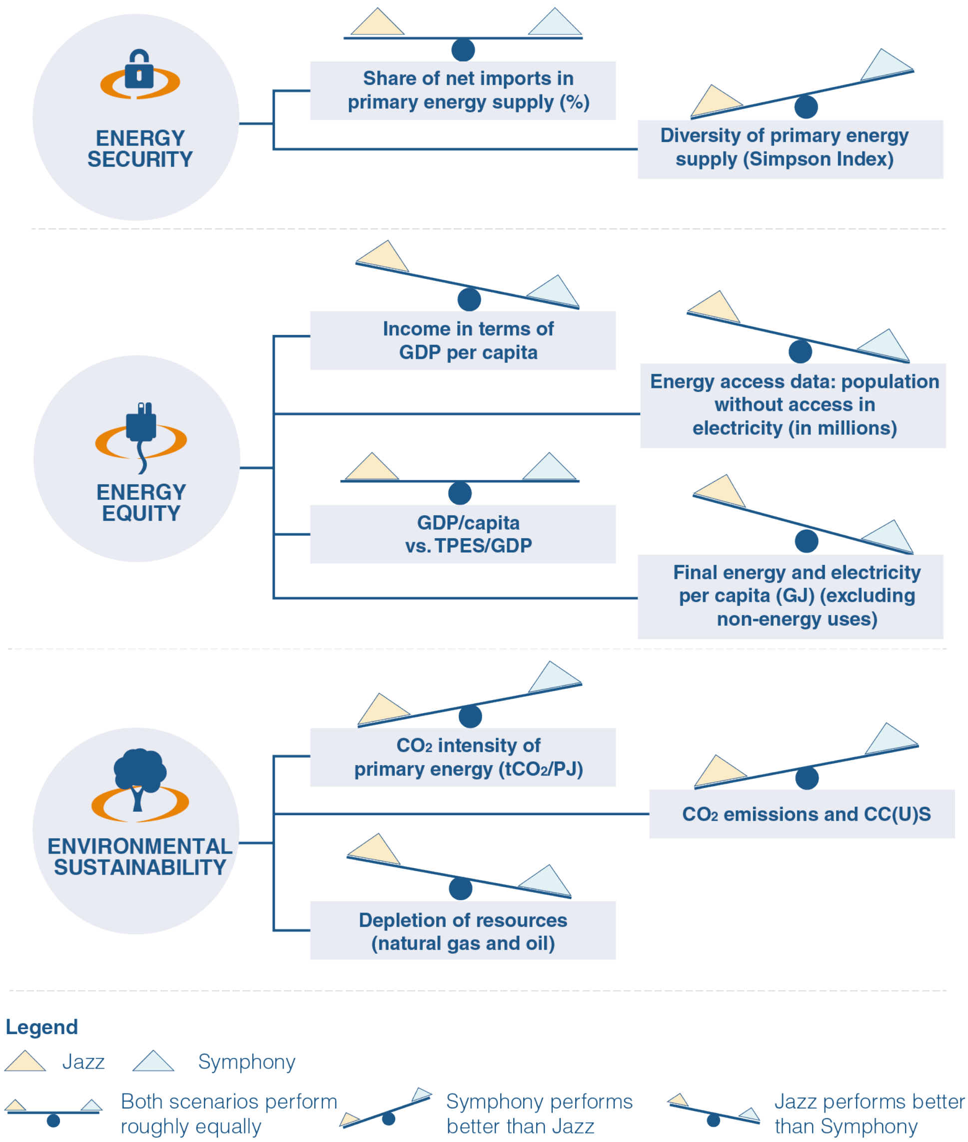
In summary, Symphony scores well on environmental sustainability, particularly CO_2 emission reduction, with emissions dropping after 2020. In Symphony, externalities are more effectively internalised. This is primarily because countries adopt a range of mechanisms to meet treaty obligations on CO_2. Higher carbon prices would achieve higher emission reduction. In Symphony the market instrument emission trading is assumed as the leading mechanism for meeting CO_2 emission obligations in the second part of the scenario period.

Jazz does not do so well with emissions not dropping until after 2040. A lot of the difference relates to a slower development of a global price of carbon. Jazz performance improves markedly if a bottom-up carbon market develops early in the scenario, but the higher GDP growth still means higher emissions. Jazz therefore puts more emphasis on adaptation, rather than mitigation as in Symphony, as markets can adapt quicker than state governments.

‘Neither scenario relies on a “magic wand” to radically change the future. Rather, both scenarios are exploratory and show the multiplicity of possible choices regarding the energy trilemma.’

Figure 91 – Assessment: Jazz vs. Symphony

Source: World Energy Council (2013)



What Jazz and Symphony can offer

Many key messages arise from the Jazz and Symphony scenarios. One of these is that more international cooperation, including internationally harmonised politics and trust in market mechanisms, is essential for achieving environmental goals, energy security and energy equity.

Jazz and Symphony can therefore contribute towards enhancing the debate on how these goals can best be achieved, taking into account a wide range of policy options. The WEC's World Energy Scenarios to 2050 therefore help to initiate this much-needed debate on how collaboration among all relevant stakeholders in the energy field can effectively be implemented.

Summary

More international cooperation, including internationally harmonised politics and trust in market mechanisms, are the key elements for environmental goals, energy security and energy equity.

8. Conclusions

Global scenarios

The WEC has built two scenarios which comprehensively describe the world in 2050. They are the consumer-driven Jazz scenario, which focuses on energy access, affordability and quality of supply, and the voter-driven Symphony scenario, which focuses on environmental sustainability and energy security.

These scenarios are designed to help a range of stakeholders address the energy trilemma of achieving environmental sustainability, energy security, and energy equity. The scenarios are meant to challenge us, but still remain achievable. We do not intend one scenario to be better than the other. There will be things that succeed in both scenarios, and there will be failures as well. As a result, there will certainly be winners and losers within each scenario. The findings of these scenarios will allow us to make progress on all three aspects of the energy trilemma.

Energy trilemma

Balancing the Energy Trilemma means making choices.

Energy equity

The Jazz scenario is better on energy equity, with higher GDP growth and a 75% reduction in the 1.267 billion people without access to electricity. CO_2 emissions in Jazz do not begin to drop until late in the scenario period. The Symphony scenario addresses environmental sustainability at the expense of GDP growth and access to energy. CO_2 levels will drop from 2020, but at the expense of GDP growth and energy access with almost twice as many people left without access to energy as in Jazz.

In the Symphony scenario, governments commit to a global market by 2020, and then work to cut red tape and ensure it is efficient and achieves its objectives. This will mean nations making concessions for the global good. In the Jazz scenario, international negotiations fail, and regions, countries, states and municipalities take their own sustainable development pathways.

Energy security

Both Jazz and Symphony address energy security. Symphony makes use of a wider diversity of energy resources, and has government investment in energy supply infrastructures. In Jazz there is higher energy production and a greater trading and diversity of international suppliers.

Up to 2050, the reality will lie somewhere between the Jazz and Symphony scenarios in terms of energy supply, energy demand increases, CO_2 emissions and GDP growth.

Energy sustainability

In this complex setting, all three entities – governments, markets and industry – play a crucial role in delivering a sustainable energy supply for the greater benefit of all. Jazz and Symphony are only two possible scenarios, and other futures are possible.

Energy system complexity

The energy equation grows ever more complex, day by day. This complexity is not going to diminish by 2050. Working towards ensuring a sustainable energy mix is therefore a major challenge for the 21st century. Energy system complexity increases – there are substantial system integration costs due to increased network expansion costs in both transmission and distribution systems, especially in Symphony where a large proportion of renewables is involved.

There is no global solution to the energy supply issue; reaching a solution involves solving each of the individual parts to reach the global goal of sustainable, affordable and secure energy supply for all. Critical uncertainties remain, especially regarding CC(U)S, solar and the future development of energy storage technologies that are scalable in economic terms (i.e. potential synergies, cost savings potential, economies of scale, and so on). In this complex trilemma, governments play a crucial role in determining and establishing frameworks for markets to function. Industries and markets need to provide efficient solutions.

Energy mix in 2050

The WEC's World Energy Scenarios to 2050 show that, in 2050, fossil fuels will still play a crucial role for transport and power generation.

- Coal is going to play an important role in the long run, especially in the Jazz scenario – in particular for power generation in China and India, the two most rapidly growing demand centres up to 2050. The WEC sees some potential for CTL projects in Jazz and increasing challenges around CC(U)S. CC(U)S is only going to happen if economically feasible (e.g. in the context of EOR) or in Symphony where stipulated by governments.
- Natural gas, especially from unconventional sources, will play an increasing role and gain more importance in the energy share. An example is the transport sector where heavy transport will depend on fossil fuels for decades to come. The WEC also expects a significant rise in shale gas, e.g. in the US , China and Australia. Shale gas in China will be very significant up to 2050. The cost of Australian and other LNG projects will have an impact on the shift to gas in Asia. The WEC believes that natural gas will play an increasing role as a transition energy source towards a low-carbon world in both scenarios, but more so in Jazz where the global gas market will develop and encourage exploration and development of new gas projects.
- Oil will continue to remain dominant for transport. But an increase in importance of unconventional energy sources – in particular oil sands, and oil shale is expected in Jazz. And, in Symphony, there will be a bigger move to biofuels and so less demand for oil.
- Nuclear energy is not a game-changer – its impact will also be limited because of restrictions in economics. Nuclear remains a matter of energy security in those countries that have it. In addition, the WEC expects some new build e.g. in France, Finland, the Middle East, India and China due to increasing electricity

demand. In developed countries, the WEC expects the public resistance to nuclear to remain. Nuclear in Symphony will attract government support but no renaissance of nuclear energy is expected.

- The analysis shows the great economic potential of hydro electricity generation, especially in SSA and LAC. There is growing public resistance to large hydro infrastructure projects. There is also resistance from the developed world to large-scale projects such as the Inga Dam or the exploitation of the Amazon Basin. A careful assessment of the overall benefits vs. the negative impact (on the environment and local population) of new hydro projects need to be carefully assessed by governments. Therefore, large hydro plays more of a role in Symphony.
- The WEC anticipates a large increase in the share of renewables, especially in the Symphony scenario – mainly in solar PV, wind and hydro. Solar has a high potential, including facilitating rural electrification projects (decentralised solar PV, off-grid solutions). In Symphony, the growth of solar to 14% is rapid and on course to exceed hydro not long after 2050. Wind will also become an important source of electricity generation in China and India, where potential sites have already been identified.
- Solar technologies, in particular solar PV, will take off, promoted by FITs for electricity, subsidies and net pricing in Europe, and tumbling solar technology prices. The technologies make major inroads, used in India, Africa and other countries to bring power to rural and off-grid communities. Subsidies are needed for solar to be economical and to create an incentive for investment. Subsidies for solar are higher in Symphony than they are in Jazz, which leads to a higher trajectory of uptake of solar PV in Symphony.
- Transmission and distribution issues where physical constraints might have an impact on how much renewable electricity energy systems can cope with, especially in Symphony where a larger proportion of renewables are involved than in Jazz. In some developed countries (such as Germany and Italy), there is already an overcapacity of renewables in the system and hence stranded assets (‘dead capital’) is already a reality. This has negative side effects for consumers who have to bear the cost via higher electricity tariffs. Also, there might be physical limitations of the renewable share in the electricity mix due to transmission and distribution network restrictions. There is a PV future, with 40% PV in the electricity mix as required by some other organisations’ scenarios.

Energy efficiency and energy savings

The World Energy Scenarios to 2050 highlight that energy efficiency and energy conservation are absolutely crucial in dealing with demand outstripping supply, as both require a change in the mindset of consumers and have cost implications across industries. Capital is required to finance energy-efficiency measures in terms of an initial investment before it can pay off. In Jazz, energy-efficiency measures are left to market forces, promoted by good information, labelling and the introduction of MEPS. In Symphony, governments will subsidise and regulate energy efficiency and achieve a higher level of energy intensity improvement than in Jazz.

In both the Jazz and Symphony scenarios, electric mobility comes later than originally expected. Policymakers need to undertake even greater effort to promote the share of renewables in electricity production which is not increasing enough to ensure environmental sustainability in the lead up to 2050 and beyond.

The WEC therefore believes that demand-side management and measures to increase electricity consumption awareness (which in turn help to reduce overall electricity consumption levels) will be crucial moving forward to 2050. This includes technical measures (smart grids, smart meters) as well as behavioural aspects (changes in consumer behaviour). Smart grids need smart rules and smart markets to work. These demand-side developments are also a key to managing the intermittency of renewable electricity supply.

CO_2 emissions and CC(U)S

Current signals indicate that the global economy is not on track to meet the 450ppm target for emissions. The WEC's World Energy Scenarios to 2050 indicate that large reductions in CO_2 are possible when governments are proactive and industry players and markets are given the right incentives to provide suitable technological solutions to achieve this.

CO_2 emissions will increase in both scenarios in the first half of the scenario period. In the Symphony scenario, where, by assumption, greater emphasis is placed on climate change mitigation and adaptation, a turning point will be reached by 2020.

The WEC's World Energy Scenarios to 2050 underline that a reduction of greenhouse gas emissions is possible in the second half of the scenario period with global agreements and the implementation of cost-efficient measures like emissions trading within a cap and trade system (assumed in Symphony).

In Symphony – where we pass through the Doha gateway and countries agree to the implementation of a global carbon market with cost-efficient instruments like emissions trading within a cap-and-trade system – emissions begin to drop from 2020 onwards. To achieve the 450ppm target, higher carbon prices than we envisage in this scenario would be needed to make emissions drop sooner.

In the Jazz scenario, the turning point is only reached by 2040. They will drop sooner if national and regional carbon markets coalesce and grow, accelerating the externalisation of the cost of carbon.

As far as the total amount of CO_2 emissions are concerned, both scenarios differ substantially. In the Jazz scenario, CO_2 emissions will be more than 44 billion tonnes per annum in 2050 which is 45% higher than in 2010. In the Symphony scenario, CO_2 emissions reach 19 billion tonnes per annum which is nearly 40% lower than in 2010.

CC(U)S is a suitable technology (in addition to renewable electricity generation) to reduce CO_2 emissions. Given a CO_2 price signal, CC(U)S can play an important role after 2030 as a cost-efficient CO_2 mitigation option. Such a price for CO_2 has to be high enough to create the right signals to provide an adequate incentive for CO_2 reduction. Issues remain such as technical feasibility at a large scale, public resistance and the upfront infrastructure cost. These are addressed more in Symphony, where CC(U)S and solar contribute equally to the decarbonisation of energy systems by 2050.

For politicians, clear and stable legislative frameworks are needed for markets to develop and for industry to provide solutions to rising global energy needs. Customers face a choice between cheap and more expensive energy and less impact on the environment. This underlines that a holistic, long-term view of the energy sector is needed to address these energy trilemma issues up to 2050 and beyond.

CC(U)S will be most important in China and India, especially in Symphony, but early demonstration and deployment is likely to be in the US and/or Europe.

Market design and markets structures

The WEC firmly believes that energy policy should ensure that energy and carbon markets deliver investments, promote regional integration and provide benefits to consumers.

In Symphony, an agreed 2030 decarbonisation target could provide the right signals to investors and encourage investment in different technologies. Governments should be aware that promoting new technologies through subsidies such as FITs can also lead to ‘energy market bubbles’.

In the Jazz scenario, governments facilitate the growth of national and regional markets by cutting the red tape, and through the promotion of regional integration and greater cooperation. This will lead to better market integration and the creation of regional markets with greater benefits for all consumers.

Evolution of the global transport sector to 2050

In its 2011 report World Energy Scenarios: Global Transport Scenarios 2050, the WEC stated that, over the next four decades, the global transportation sector will face unprecedented challenges related to demographics, urbanisation, pressure to minimise and dislocate emissions outside urban centres, congestion of ageing transport infrastructure and growth in fuel demand. This trend can also be observed in this scenario exercise. Total fuel demand in all transport modes will increase; demand will be driven mainly by trucks, buses, trains, ships, and airplanes.

Transport sector fuel mix will remain heavily dependent on gasoline, diesel, fuel oil and jet fuel, as they will constitute the bulk of transport market fuels. Biofuels will also help to satisfy the demand for transport fuel and their use will increase, but to a lesser extent than previously assumed. Other fuels, including electricity, hydrogen, and natural gas will increase. In these scenarios the WEC has amended its view on EV penetration rates. The WEC now believes that the global impact of EV will be lower than anticipated. This is due to: (i) high battery cost; (ii) requirements for infrastructure investments; and (iii) lack of smart grids to use EV as an effective storage. Also, there is missing customer awareness and a lack of technical solutions that are scalable in economic terms (i.e. in terms of potential synergies, cost-savings potential, and economies of scale).

The World Energy Scenarios to 2050 also show significant regional differences, with shale gas being a driver for natural-gas-fuelled transport in North America, biofuels with a significant contribution in Latin America, and electric mobility having a particularly strong push in Asia/China where the growth of megacities is most dramatic.

In the Jazz symphony, assumptions from the WEC's previous Freeway transportation scenario have been incorporated.[16] Freeway envisages a world where market forces prevail to create a climate for open global competition, higher levels of privatisation, deregulation, and liberalisation. It also stimulates the role of the private sector, entrepreneurs and global companies so that they emerge as central players in a new international trading environment without trade barriers. There is high growth in air traffic and freight, road freight shifts to gas-diesel in some regions and there is increasing car ownership. Fuel demand rises from 100 to 175 EJ/y with over 90% from fossil fuels.

In the Symphony scenario, the WEC has incorporated the assumption made in its earlier Tollway scenario.[17] Tollway is best described as a regulated world where governments and prominent politicians decide to put common interests at the forefront and intervene in markets. In such an environment, the more fragmented and differentiated global economy suffers weak cooperation on free-market mechanisms, which results in more trade restrictions. The world as a whole has witnessed increasing international cooperation on climate-change issues. There is lower growth in air traffic, mandates for biofuels, a smaller increase in car ownership and increased hybrids and EVs. Fuel demand levels off at 120EJ/y with one-sixth from biofuels, electricity and hydrogen.

Global vs. regional energy issues

Regional priorities differ

Priorities in terms of the energy trilemma are different in various regions of the world. Climate change is not the main issue in the most regions of the world, but economic development and improvement of air quality are. Europe is a notable exception.

In China, 300 million people have come out of poverty since the end of the Cultural Revolution – mainly due to providing access to energy at affordable costs. Such a development can continue in future. There are 1,200 coal-fired power stations under construction worldwide. In India priorities are about making cheap energy available to all citizens.

Shale gas becomes more important, especially in the US and potentially in China and other countries such as Australia. Shale gas will be of minor importance in Europe. The US is keeping the competitive advantage from the shale gas boom for the purpose of re-industrialisation.

The importance of gas is going to increase in Japan and China for different reasons. In Japan, one of the reasons is a possible replacement of nuclear power plants; in China the reason is improvement of the air quality. In Europe the production of power on the basis of gas is not competitive in most cases.

In developing countries, there is a hierarchy of energy needs, whereby access comes first, followed by security and affordability, with environmental issues last. In developed countries, where security of supply is high, environmental concerns are higher on the priority list. The WEC finds that energy and environmental policies need to be carefully calibrated in order to avoid market distortions.

16 WEC, 2011: Global Transport Scenarios 2050
17 WEC, 2011: Global Transport Scenarios 2050

The WEC feels that providing energy access to those 1.267 billion people who lack it is a key priority and therefore it fully supports and works with the UN's Sustainable Energy for All initiative to achieve this. Jazz is more effective in improving access than Symphony,

In practice, regional differences remain and there is no 'one-size-fits-all' to regional energy needs. The challenge will be to promote energy access and economic activity, hence prosperity, and decoupling emissions levels in order to minimise the negative externalities and the impact on the environment.

Regional developments up to 2050

East Asia

In the Jazz scenario, electricity generation is dominated by supercritical coal generation with some penetration of natural gas-fired generation from 2030 onwards. In the Symphony scenario, coal generation in this region switches to IGCC with CC(U)S in 2050, and the nuclear share increases mainly due to governmental initiatives. State investment is made in renewable energy. The total investment needed to meet energy demand in 2050 in this region will be between $5.14 trillion in the Jazz scenario and $7.4 trillion in the Symphony scenario (US$2010) (investment in power generation only).

South and Central Asia

In the Jazz scenario, electricity generation is mainly dominated by coal-based generation, with some penetration of gas into the fuel mix by 2050. In the Symphony scenario, CC(U)S is adopted with international financial support. State investment in renewables will play a prominent role by 2050. The total investment needed to meet energy demand in 2050 in this region will be between $3.1 trillion in the Jazz scenario and $3.5 trillion in the Symphony scenario (US$2010) (investment in power generation only).

Southeast Asia and Pacific

In the Jazz scenario, the dominance of coal in generation will remain. There is an increasing share of natural gas-fired generation in the medium term. Investments in solar, wind and geothermal take place. In the Symphony scenario, CC(U)S and renewables (solar, geothermal) displace gas from generation in 2050. Coal generation switches to CC(U)S in 2050. The total investment needed to meet energy demand in 2050 in this region will be $1.8 trillion in the Jazz scenario and $1.9 trillion the Symphony scenario (US$2010) (investment in power generation only).

Europe

In the Jazz scenario, a functioning carbon market (albeit low CO_2 prices) will be created and investments in gas-fired generation will be postponed until the medium term. There is a high penetration of wind after 2040. In the Symphony scenario, coal electricity generation switches to CC(U)S by 2050 and nuclear, wind and solar displace gas from generation after 2030 due to strong climate policy and governmental support. The total investment needed to meet energy demand in 2050 in this region will be between $3.3 trillion in the Jazz scenario and $4.4 trillion in the Symphony scenario (US$2010) (investment in power generation only).

Latin America and The Caribbean

In the Jazz scenario, hydro-based electricity is the dominant source, with gas emerging as a fuel for power generation, e.g. in Brazil. In the Symphony scenario, the development of hydropower is facilitated by improvements in grid infrastructure such as the creation of an LAC-wide grid. Natural gas-fired generation is used mainly for peak load generation. The total investment needed to meet energy demand in 2050 in this region will be $1.3 trillion in both the Jazz scenario and the Symphony scenario (US$2010) (investment in power generation only).

Middle East and North Africa

In the Jazz scenario, natural gas is the main choice for power generation. Oil-generated electricity drops sharply by 2050. Solar and nuclear capacity is added. In the Symphony scenario, natural gas remains the main choice for power generation. Large investments in solar take place. Nuclear electricity is led by the governments. The total investment needed to meet energy demand in 2050 in this region will be between $0.7 trillion in the Jazz scenario and $1.4 trillion in the Symphony scenario (US$2010) (investment in power generation only).

North America

In the Jazz scenario, the share of gas in power generation increases at the expense of coal due to the shale gas revolution. Wind generation increasingly displaces fossil fuels and nuclear from 2030. In the Symphony scenario, the share of natural gas-fired generation drops in 2050 replaced by renewables and CC(U)S generation (IGCC). Nuclear investments are mainly to replace retirements of plants, with the number of nuclear power plants decreasing. The total investment needed to meet energy demand in 2050 in this region will be between $2.8 trillion in the Jazz scenario and $4.4 trillion in the Symphony scenario (US$2010) (investment in power generation only).

Sub-Saharan Africa

In the Jazz scenario, there is a gas boom in electricity generation. Investments in solar PV (mainly decentralised) take place. In the Symphony scenario, diversity in electricity production after 2040 increases, hydropower is starting to being exploited systematically by governments. and CC(U)S increases ('leapfrogging'). The total investment need to meet energy demand in 2050 in this region will be between $1.2 trillion in the Jazz scenario and $1.4 trillion in the Symphony scenario (US$2010) (investment in power generation only).

Cumulative investment needs are summarised in Table 31.

Table 30– Undiscounted investment needs to 2050 for Jazz and Symphony in electricity generation infrastructure

Source: World Energy Council (2013)

	Jazz	**Symphony**
	cumulative undiscounted investment (trillion US$2010) in electricity generation infrastructure	
East Asia	5.1	7.4
South and Central Asia	3.1	3.5
Southeast Asia and Pacific	1.8	1.9
Europe	3.3	4.4
Latin America and The Caribbean	1.3	1.3
Middle East and North Africa	0.7	1.4
North America	2.8	4.5
Sub-Saharan Africa	1.2	1.4
World	**19.3**	**25.8**

Wild cards and critical uncertainties

The WEC believes that CC(U)S technology, changing demand patterns and energy storage are the key uncertainties moving forward to 2050.

CC(U)S technology is already available and is potentially one of the lower-cost, deep decarbonisation options, but it will always be an added cost and will require major pipeline and other infrastructures. For CC(U)S to work, clear legislative frameworks are needed, combined with infrastructure investment and the right incentives. The carbon price signals that need to be developed in the coming years to allow the emergence of CC(U)S will also improve renewable learning curves and scalability (i.e. digression of capital cost over time). CC(U)S might only be feasible in geographical regions of the world with the right geology. The WEC assumes that it is most likely that, in Symphony, initial CC(U)S projects will involve aquifer storage in Europe under the North Sea, and major EOR projects in gas and oil reservoirs in the US, driven by US Environmental Protection Agency restrictions on CO_2 emissions from power generation. The WEC assumes that, in the Jazz scenario, without government interventions the market will be slow to optimise on CO_2 due to the high initial infrastructure costs involved, unless there are commercial drivers such as EOR.

As far as energy storage technologies are concerned, pump storage is a well-developed and widely applied technology, with its use limited by site limitations. Power-to-gas (hydrogen or methane) could be an early option given it could use existing gas pipeline infrastructures. Other new and emerging energy storage technologies, such as batteries and hydrogen, still need more R&D before they become commercially viable. Investment in R&D is therefore needed to promote these technologies which could play a key role up to 2050, especially to overcome the problem of intermittency of renewables.

Energy transition and transition strategies

A future with low-carbon emissions is not only linked to more renewables. CC(U)S can contribute a significant share in reaching this goal, even with more coal in the energy mix. Other technologies, including smart grids, are likely to play a key role in defining transition strategies towards a future energy system.

The transition period we are entering now is likely to be key in defining the energy landscape by 2050. This global energy transformation will be influenced by three aspects: (i) complexity; (ii) high speed; and (iii) institutional tipping points. Complexity in energy systems grows exponentially, then low speed has gone and change happens at a faster pace than before. Finally, existing institutions fail to deliver (for example, the last big event like this was in the 1970s with the oil crisis).

As far as global institutions are concerned, China wants to be part of the new institutions and so new ways of incorporating perspectives from the developing world need to be found to achieve a more balanced representation of interests. In turn, this might also benefit the developed world.

Assessing Jazz vs. Symphony

While most widely known scenarios are normative, the WEC has adopted a different, exploratory approach. 'Normative' in this context means that the scenarios are being used to drive the world towards a specific objective, such as a particular atmospheric CO_2 level. In contrast, the WEC with its exploratory scenarios Jazz and Symphony, attempts to provide decision makers with a neutral fact-based tool that they will be able to use to measure the potential impact of their choices in the future.

Rather than telling policymakers and senior energy leaders what to do, in order to achieve a specific policy goal, the WEC's World Energy Scenarios to 2050 will allow them to test the key assumptions that they decide to make to shape the energy of tomorrow. Investors can use this tool to assess which are likely to be the most dynamic areas and real game-changers of tomorrow. These scenarios are therefore likely to change the way energy decision makers consider the choices they make in understanding the real impact of their actions in the long term.

Clearly, each policy option has some cost associated with it. The cost of one scenario versus the other must not only be considered in terms of necessary capital investments and the impact on and of GDP growth; the overall environmental benefits and avoided climate change adaptation costs also need to be taken into account. This means that one scenario is not necessarily better than the other and should not be judged as such. Instead, a wider view needs to be adopted when assessing the overall implications of each of the scenarios.

The WEC believes that a balanced trilemma can only be achieved through compromises and global initiatives. Together with energy efficiency, CC(U)S, solar and wind will be the key technologies driving change forward.

Final outlook

The WEC is convinced that, by publishing its World Energy Scenarios to 2050, a dialogue can be started among its member committees, policymakers and industry leaders to explore strategies that help to ensure the provision of sustainable and affordable energy for the greater benefit of all.

9. Notes

Energy amounts of total primary energy supply are accounted differently in different statistical publications. In this report, we use the following conventions.

- The primary energy content of renewables (hydro, wind, solar photovoltaic, solar thermal power, geothermal power) is the energy of the output of electricity (1 TWh = 3600 TJ = 0.08597 Mtoe); geothermal and solar heating energy are in amounts of heat energy.
- In IEA's yearly Key World Energy Statistics the geothermal supply is assumed to have generally a multiplication factor of 10 with respect to output, which yields higher numbers.
- The primary energy content of biomass is the energy content (lower heating value) of the biomass. In our case, biomass includes also waste. Note that some other publications report secondary amounts of biofuel as primary energy, resulting in lower numbers.
- The primary energy content of nuclear supply is calculated with an average thermal efficiency of 33%. That is, the primary energy content is three times the electricity output.
- The primary energy content of coal, gas and oil supply is the (averaged) lower heating value.

10. Appendix 1: Key scenario data at a glance

Scenario data tables: Global overview

Table 31 – Scenario data tables: Global overview

Source: World Energy Council (2013)

		Jazz					Symphony				
	2010	2020	2030	2040	2050	% CAGR (2010-50)	2020	2030	2040	2050	% CAGR (2010-50)
Population (million)	6,896	7,601	8,145	8,511	8,703	0.6	7,673	8,354	8,924	9,374	0.8
Urbanization (%)	52	55	60	64	68	0.7	54	58	61	64	0.5
GDP (trillion USD2010 MER)	63	87	118	156	201	2.9	83	108	138	172	2.5
GDP per capita (USD2010 MER)	9,162	11,428	14,478	18,373	23,139	2.3	10,829	12,898	15,409	18,317	1.7
Car ownership (cars/1000 people)	124	148	176	212	244	1.7	139	155	175	193	1.1
Energy intensity (MJ/USD2010 MER)											
- Primary (a)(b)	8.6	7.4	6.3	5.3	4.4	-1.7	7.1	5.8	4.8	4.1	-1.9
- Final (c)	5.9	5.2	4.4	3.7	3.1	-1.6	5.1	4.3	3.5	2.9	-1.8
Primary energy (EJ) (a)(b)(d)	**546**	**643**	**741**	**825**	**879**	**1.2**	**592**	**630**	**654**	**696**	**0.6**
Coal	148	181	200	224	223	1.0	146	125	101	106	-0.8
Oil	172	193	225	231	216	0.6	177	185	170	141	-0.5
Gas	114	151	189	216	234	1.8	141	160	170	166	0.9
Nuclear	30	36	37	37	37	0.5	40	52	66	79	2.4
Biomass (a)(d)	66	60	59	71	97	1.0	62	66	79	111	1.3
Hydro (b)	13	14	16	19	21	1.3	16	19	24	28	2.0
Other renewables (b)	2	7	14	28	51	8.0	10	23	45	65	8.7
Final Energy (EJ) (c)(d)	**373**	**448**	**523**	**584**	**629**	**1.3**	**423**	**460**	**478**	**491**	**0.7**
Industry (c)	113	143	166	184	199	1.4	134	145	150	156	0.8
Transport	99	114	139	160	173	1.4	106	116	121	121	0.5
Residential/Commercial (d)	129	145	161	175	189	1.0	139	148	152	158	0.5
Non-energy uses	34	46	57	65	68	1.8	44	51	56	56	1.3
Coal (c)	47	48	43	36	30	-1.1	44	35	27	21	-2.0
Oil	148	177	204	208	190	0.6	166	172	157	130	-0.3
Gas	56	79	102	122	133	2.2	75	87	89	90	1.2
Electricity	64	85	108	139	171	2.5	80	99	126	155	2.2
Heat	12	15	20	25	30	2.4	14	19	23	21	1.4
Biomass & Biofuels (d)	46	40	38	41	53	0.4	42	40	42	52	0.3
Other (e)	1	4	7	13	22	9.3	4	7	14	23	9.4
Electricity generation (TWh)	**21,476**	**27,961**	**35,198**	**44,454**	**53,647**	**2.3**	**26,316**	**31,897**	**39,598**	**47,918**	**2.0**
Coal	8,666	11,920	14,792	18,565	19,272	2.0	9,289	7,949	5,280	1,383	-4.5
Coal (with CCS)	0	10	87	346	1,007	NA	41	301	1,587	7,100	NA
Oil	980	0	0	0	0	NA	0	0	0	0	NA
Gas	4,777	7,232	9,734	11,427	12,869	2.5	6,609	8,127	9,049	7,012	1.0
Gas (with CCS)	0	2	31	140	558	NA	11	113	789	2,505	NA
Nuclear	2,763	3,255	3,430	3,395	3,279	0.4	3,651	4,706	5,888	6,950	2.3
Hydro	3,491	4,003	4,550	5,146	5,789	1.3	4,337	5,408	6,530	7,701	2.0
Biomass	337	287	390	884	1,923	4.4	362	535	1,056	1,913	4.4
Biomass (with CCS)	0	8	28	160	441	NA	16	100	295	800	NA
Wind	358	818	1,435	3,142	4,513	6.5	1,386	2,418	2,994	4,003	6.2
Solar	34	302	462	732	2,979	11.8	519	2,054	5,752	7,741	14.5
Geothermal	69	125	257	504	949	6.8	94	182	346	654	5.8
Other	0	0	2	12	69	NA	0	5	32	155	NA
Installed generation capacity (GW)	**5,069**	**6,253**	**7,100**	**8,880**	**11,669**	**2.1**	**6,319**	**8,012**	**11,434**	**13,865**	**2.5**
Coal	1,606	2,087	2,507	3,039	3,006	1.6	1,619	1,365	1,007	485	-2.9
Coal (with CCS)	0	2	14	49	141	NA	9	47	226	1,006	NA
Oil	426	289	168	86	41	-5.7	289	168	86	41	-5.7
Gas	1,325	1,578	1,629	1,830	2,338	1.4	1,508	1,641	2,174	2,019	1.1
Gas (with CCS)	0	4	20	63	178	NA	8	40	206	603	NA
Nuclear	373	417	438	434	421	0.3	468	603	751	884	2.2
Hydro	1,026	1,136	1,267	1,414	1,575	1.1	1,223	1,505	1,854	2,161	1.9
Biomass	71	62	65	124	256	3.3	73	87	156	292	3.6
Biomass (with CCS)	0	2	9	28	78	NA	5	18	52	141	NA
Wind	191	404	621	1,290	1,824	5.8	667	1,059	1,274	1,654	5.5
Solar	39	255	326	445	1,654	9.8	437	1,451	3,585	4,439	12.6
Geothermal	11	19	38	75	141	6.5	14	28	54	102	5.7
Other	0	0	0	3	15	NA	0	2	10	39	NA
Environmental Impact											
CO_2 emissions (Gt CO_2)	30.5	36.4	41.8	45.2	44.1	0.9	31.5	30.4	26.0	19.1	-1.2
- CO_2 capture (Gt CO_2)	0.0	0.0	0.1	0.5	1.4	NA	0.1	0.4	1.7	6.8	NA
- CO_2 per capita (t CO_2)	4.4	4.8	5.1	5.3	5.1	0.3	4.1	3.6	2.9	2.0	-1.9
- CO_2 intensity (kg CO2/USD2010)	0.5	0.4	0.4	0.3	0.2	-2.0	0.4	0.3	0.2	0.1	-3.6
Depletion of non-renewable resources (%) (f	100	94	88	80	72	-0.8	94	89	82	76	-0.7
Energy Security											
Diversity of primary energy supply (g)	71	70	69	72	77	0.2	74	79	86	94	0.7
Share of net imports in primary energy suppl	21	22	23	21	21	-0.1	24	26	23	19	-0.3
Social Equity and Energy Access											
GDP per capita (USD2010 MER)	9,162	11,428	14,478	18,373	23,139	2.3	10,829	12,898	15,409	18,317	1.7
Final energy consumption per capita (GJ) (h)	50	56	62	67	71	0.9	52	53	52	51	0.1
Population without access to electricity (millio	1,267	1,012	733	486	319	-3.4	1098	885	660	530	-2.2

Annotations:

a. Primary energy content of biomass is the energy content (lower heating value) of the biomass (in comparison, some other publications report secondary amounts of biofuel as primary energy, resulting in lower numbers). Includes waste.
b. The primary energy content of renewable electricity (hydro, wind, solar photovoltaic, solar thermal power, geothermal power) is reported as equal to generation; primary energy amounts for geothermal and solar heating represent thermal energy.
c. Includes coal use in coke ovens, blast furnaces and gas works.
d. Including non-commercial biomass.
e. Solar thermal heating, geothermal, hydrogen.
f. Remaining resources a percentage of the 2010 resource base. Oil and gas resources only.
g. Simpson diversity index (higher = more diverse).
h. Excluding non-commercial (traditional) biomass. This indicator combines elements of energy access and efficiency.

The share of net imports in primary energy supply is defined as the sum of net imports of those aggregated world regions which are net importers, divided by the total global primary energy supply.

Scenario data tables: Regional summary (I)

Table 32 – Scenario data tables: Regional summary (I)

Source: World Energy Council (2013)

		Jazz					Symphony				
	2010	2020	2030	2040	2050	% CAGR (2010-50)	2020	2030	2040	2050	% CAGR (2010-50)
Population (million)	**6,896**	**7,601**	**8,145**	**8,511**	**8,703**	**0.6**	**7,673**	**8,354**	**8,924**	**9,374**	**0.8**
Sub-Saharan Africa	857	1,070	1,281	1,478	1,648	1.6	1,089	1,354	1,648	1,961	2.1
Middle East & North Africa	381	442	490	526	551	0.9	448	507	558	601	1.1
Latin America & the Caribbean	473	518	551	570	577	0.5	522	562	589	603	0.6
North America	462	504	541	571	594	0.6	509	552	588	619	0.7
Europe	820	834	837	831	819	0.0	842	854	856	853	0.1
South & Central Asia	1,700	1,920	2,085	2,195	2,256	0.7	1,938	2,142	2,298	2,402	0.9
East Asia	1,573	1,619	1,620	1,572	1,475	-0.2	1,624	1,629	1,592	1,519	-0.1
Southeast Asia & Pacific	631	694	740	768	782	0.5	699	755	795	817	0.6
GDP (trillion USD2010 MER)	**63**	**87**	**118**	**156**	**201**	**2.9**	**83**	**108**	**138**	**172**	**2.5**
Sub-Saharan Africa	1	2	3	6	12	6.0	2	3	6	11	5.7
Middle East & North Africa	3	3	5	8	11	3.8	3	5	7	10	3.5
Latin America & the Caribbean	4	6	9	13	18	3.9	6	8	12	15	3.4
North America	17	21	25	30	36	1.8	21	24	28	33	1.6
Europe	20	24	29	34	39	1.7	24	27	31	35	1.4
South & Central Asia	2	4	8	16	27	6.3	4	7	13	20	5.6
East Asia	13	20	28	35	42	3.0	19	25	30	35	2.5
Southeast Asia & Pacific	3	6	9	13	17	4.2	6	8	11	14	3.7
Primary Energy (EJ) (a)(b)(d)	**546**	**643**	**741**	**825**	**879**	**1.2**	**592**	**630**	**654**	**696**	**0.6**
Sub-Saharan Africa	23	24	29	38	50	2.0	23	27	35	46	1.8
Middle East & North Africa	37	44	55	67	79	1.9	43	52	59	67	1.5
Latin America & the Caribbean	29	38	49	58	67	2.1	35	43	47	51	1.4
North America	116	128	135	136	130	0.3	118	114	108	105	-0.3
Europe	121	127	133	136	135	0.3	119	117	114	114	-0.2
South & Central Asia	43	52	69	102	136	2.9	47	57	75	96	2.0
East Asia	145	187	215	222	211	0.9	167	174	166	164	0.3
Southeast Asia & Pacific	32	44	56	66	71	2.0	40	46	50	54	1.3
Final Energy (EJ) (c)(d)	**373**	**448**	**523**	**584**	**629**	**1.3**	**423**	**460**	**478**	**491**	**0.7**
Sub-Saharan Africa	17	17	21	27	37	2.0	17	20	26	33	1.7
Middle East & North Africa	23	32	40	48	57	2.2	31	37	44	49	1.8
Latin America & the Caribbean	20	29	37	43	45	2.1	27	33	36	36	1.5
North America	78	85	92	93	90	0.4	82	83	78	73	-0.1
Europe	86	93	96	97	94	0.2	89	86	81	75	-0.3
South & Central Asia	29	35	49	73	97	3.1	33	43	55	69	2.2
East Asia	97	123	144	152	153	1.1	113	121	119	114	0.4
Southeast Asia & Pacific	23	33	44	52	56	2.2	31	36	40	41	1.4
Oil production (EJ)	**172**	**193**	**225**	**231**	**216**	**0.6**	**177**	**185**	**170**	**141**	**-0.5**
Conventional	167	181	207	208	173	0.1	175	185	170	141	-0.4
Unconventional	5	13	17	23	43	5.5	2	1	0	0	-9.1
Sub-Saharan Africa	13	16	9	12	15	0.5	17	9	14	21	1.3
Middle East & North Africa	62	96	143	132	100	1.2	95	142	123	88	0.9
Latin America & the Caribbean	17	16	18	24	30	1.5	22	11	13	10	-1.2
North America	28	33	33	38	38	0.7	12	6	5	5	-4.1
Europe	30	18	10	11	14	-2.0	18	8	7	6	-4.1
South & Central Asia	8	6	6	7	8	-0.1	8	5	5	5	-1.1
East Asia	8	4	4	5	8	0.1	4	2	3	4	-1.5
Southeast Asia & Pacific	7	3	2	2	3	-2.2	3	2	1	1	-4.3

Annotations:

a. Primary energy content of biomass is the energy content (lower heating value) of the biomass (in comparison, some other publications report secondary amounts of biofuel as primary energy, resulting in lower numbers). Includes waste.

b. The primary energy content of renewable electricity (hydro, wind, solar photovoltaic, solar thermal power, geothermal power) is reported as equal to generation; primary energy amounts for geothermal and solar heating represent thermal energy.

c. Includes coal use in coke ovens, blast furnaces and gas works.

Scenario data tables: Regional summary (II)

Table 33 – Scenario data tables: Regional summary (II)

Source: World Energy Council (2013)

		Jazz					Symphony				
	2010	2020	2030	2040	2050	3.25147561	2020	2030	2040	2050	3.59400931
Gas production (EJ)	**114**	**151**	**189**	**216**	**234**	**1.8**	**141**	**160**	**170**	**166**	**0.9**
Conventional	111	141	165	173	186	1.3	140	159	167	161	0.9
Unconventional	3	10	24	42	49	7.3	1	1	3	4	0.8
Sub-Saharan Africa	2	2	4	7	8	4.1	2	3	4	7	3.6
Middle East & North Africa	23	30	32	38	49	1.9	29	29	29	36	1.2
Latin America & the Caribbean	6	10	15	15	13	2.0	8	11	11	8	0.8
North America	28	38	44	49	48	1.4	36	35	36	29	0.1
Europe	34	45	53	56	59	1.4	41	46	48	46	0.8
South & Central Asia	9	7	12	16	18	1.8	8	10	15	16	1.5
East Asia	3	8	16	19	27	5.3	6	12	17	15	3.7
Southeast Asia & Pacific	10	11	14	15	12	0.6	10	13	11	9	-0.2
Coal production (EJ)	**148**	**181**	**200**	**224**	**223**	**1.0**	**146**	**125**	**101**	**106**	**-0.8**
Sub-Saharan Africa	6	5	6	7	7	0.5	5	4	4	4	-1.1
Middle East & North Africa	0	0	0	0	0	1.9	0	0	0	0	1.9
Latin America & the Caribbean	2	1	2	3	3	1.1	1	1	2	1	-1.0
North America	24	23	19	18	16	-1.0	18	13	10	14	-1.4
Europe	18	23	29	33	39	2.0	17	13	13	18	0.0
South & Central Asia	12	20	23	38	57	3.9	15	14	16	21	1.4
East Asia	67	95	106	106	81	0.5	78	68	48	38	-1.4
Southeast Asia & Pacific	19	14	14	20	20	0.0	13	12	9	10	-1.6
Net energy imports (EJ)	**0**	**0**	**0**	**0**	**0**	**NA**	**0**	**0**	**0**	**0**	**NA**
Sub-Saharan Africa	-13	-14	-4	-4	-5	-2.4	-14	-5	-7	-13	0.1
Middle East & North Africa	-50	-86	-125	-111	-84	1.3	-85	-126	-105	-76	1.1
Latin America & the Caribbean	-6	-2	0	-5	-12	1.9	-10	3	-1	-3	-1.3
North America	16	14	16	7	3	-3.8	30	32	25	17	0.1
Europe	15	16	14	0	-22	NA	16	16	4	-11	NA
South & Central Asia	2	7	17	29	38	8.1	4	14	18	22	6.7
East Asia	45	56	64	63	57	0.6	52	54	50	45	0.0
Southeast Asia & Pacific	-10	9	19	22	24	NA	7	12	17	18	NA
CO_2 emissions (Gt CO_2)	**30.5**	**36.4**	**41.8**	**45.2**	**44.1**	**0.9**	**31.5**	**30.4**	**26.0**	**19.1**	**-1.2**
Sub-Saharan Africa	0.7	0.8	1.1	1.5	1.7	2.5	0.7	0.8	0.9	0.9	0.7
Middle East & North Africa	2.1	2.3	2.7	3.1	3.5	1.3	2.2	2.5	2.4	2.3	0.2
Latin America & the Caribbean	1.2	1.5	2.0	2.2	2.1	1.4	1.3	1.5	1.3	0.8	-1.0
North America	6.5	7.2	7.3	7.2	6.7	0.1	6.2	5.4	4.4	3.1	-1.8
Europe	6.2	6.4	6.7	6.4	5.6	-0.2	5.6	5.0	3.9	2.5	-2.3
South & Central Asia	2.3	3.0	4.1	6.3	8.4	3.4	2.5	2.8	3.1	2.7	0.5
East Asia	9.8	12.7	14.7	14.7	12.3	0.6	10.8	10.1	7.8	5.1	-1.6
Southeast Asia & Pacific	1.7	2.5	3.2	3.8	3.7	1.9	2.1	2.3	2.1	1.7	0.0
CO_2 capture (Gt CO_2)	**0.0**	**0.0**	**0.1**	**0.5**	**1.4**	**NA**	**0.1**	**0.4**	**1.7**	**6.8**	**NA**
Sub-Saharan Africa	0.0	0.0	0.0	0.0	0.1	NA	0.0	0.0	0.1	0.5	NA
Middle East & North Africa	0.0	0.0	0.0	0.0	0.1	NA	0.0	0.0	0.1	0.4	NA
Latin America & the Caribbean	0.0	0.0	0.0	0.0	0.1	NA	0.0	0.0	0.1	0.2	NA
North America	0.0	0.0	0.0	0.1	0.2	NA	0.0	0.1	0.3	1.1	NA
Europe	0.0	0.0	0.0	0.1	0.3	NA	0.0	0.1	0.3	1.2	NA
South & Central Asia	0.0	0.0	0.0	0.0	0.1	NA	0.0	0.0	0.2	1.2	NA
East Asia	0.0	0.0	0.0	0.1	0.2	NA	0.0	0.1	0.4	1.6	NA
Southeast Asia & Pacific	0.0	0.0	0.0	0.1	0.2	NA	0.0	0.0	0.2	0.7	NA

Scenario data tables: Regional electricity generation (I)

Table 34 – Scenario data tables: Regional electricity generation (I)

Source: World Energy Council (2013)

		Jazz					Symphony				
Electricity generation (TWh)	2010	2020	2030	2040	2050	% CAGR (2010-50)	2020	2030	2040	2050	% CAGR (2010-50)
Sub-Saharan Africa	**414**	**612**	**996**	**1,857**	**3,087**	**5.2**	**597**	**936**	**1,687**	**2,836**	**4.9**
Coal	254	415	436	493	452	1.4	368	303	244	1	-13.4
Coal (with CCS)	0	0	5	17	48	NA	0	18	96	400	NA
Oil	26	0	0	0	0	NA	0	0	0	0	NA
Gas	24	39	285	772	979	9.7	15	155	252	280	6.3
Gas (with CCS)	0	0	14	42	117	NA	0	24	115	403	NA
Nuclear	12	13	14	16	17	0.8	16	28	42	67	4.3
Hydro	90	115	141	173	212	2.2	154	241	358	507	4.4
Biomass	5	12	34	90	236	10.4	16	39	94	225	10.3
Biomass (with CCS)	0	0	4	11	30	NA	2	6	15	49	NA
Wind	0	3	19	71	118	17.8	3	17	64	116	17.8
Solar	0	4	18	114	752	29.1	12	79	344	651	28.6
Geothermal	2	10	26	54	104	11.2	10	26	54	104	11.2
Other	0	0	0	5	23	NA	0	0	9	33	NA
Middle East & North Africa	**1,150**	**1,445**	**1,951**	**2,693**	**3,644**	**2.9**	**1,485**	**1,911**	**2,476**	**3,314**	**2.7**
Coal	46	75	74	77	104	2.0	52	38	24	6	-4.9
Coal (with CCS)	0	0	4	15	55	NA	1	17	89	214	NA
Oil	334	0	0	0	0	NA	0	0	0	0	NA
Gas	731	1,307	1,725	2,272	2,689	3.3	1,304	1,514	1,207	964	0.7
Gas (with CCS)	0	2	15	51	117	NA	5	22	104	565	NA
Nuclear	0	0	48	102	157	NA	48	115	198	308	NA
Hydro	35	41	43	45	57	1.2	41	43	45	44	0.5
Biomass	0	8	25	76	197	22.8	10	35	101	228	23.3
Biomass (with CCS)	0	0	4	11	30	NA	2	6	18	49	NA
Wind	3	5	3	4	15	4.6	5	3	2	2	-1.0
Solar	0	7	8	30	196	21.7	18	119	681	920	26.5
Geothermal	0	0	3	11	27	NA	0	0	7	15	NA
Other	0	0	0	0	0	NA	0	0	0	0	NA
Latin America & the Caribbean	**1,147**	**1,648**	**2,422**	**3,131**	**3,701**	**3.0**	**1,571**	**2,209**	**2,750**	**3,221**	**2.6**
Coal	34	86	154	258	284	5.4	35	42	24	0	-10.7
Coal (with CCS)	0	3	8	31	89	NA	7	27	109	112	NA
Oil	144	0	0	0	0	NA	0	0	0	0	NA
Gas	185	523	991	1,004	632	3.1	370	594	519	313	1.3
Gas (with CCS)	0	0	0	0	0	NA	0	0	16	49	NA
Nuclear	22	25	28	31	32	1.0	29	51	73	107	4.0
Hydro	708	886	998	1,111	1,183	1.3	951	1,169	1,366	1,491	1.9
Biomass	47	88	113	228	555	6.4	147	201	290	512	6.1
Biomass (with CCS)	0	1	7	22	60	NA	4	13	36	97	NA
Wind	3	21	74	252	299	11.8	21	74	112	143	9.8
Solar	0	3	21	139	457	29.1	8	37	205	385	28.6
Geothermal	3	11	27	55	106	9.0	2	1	1	1	-3.5
Other	0	0	0	0	4	NA	0	0	0	12	NA
North America	**5,214**	**6,152**	**6,903**	**7,728**	**8,024**	**1.1**	**6,100**	**6,733**	**7,695**	**8,057**	**1.1**
Coal	2,120	2,245	1,887	1,813	1,719	-0.5	1,689	1,229	735	179	-6.0
Coal (with CCS)	0	0	17	56	160	NA	11	56	302	1,304	NA
Oil	97	0	0	0	0	NA	0	0	0	0	NA
Gas	1,208	1,889	2,357	2,601	2,686	2.0	1,960	1,652	2,171	1,483	0.5
Gas (with CCS)	0	0	0	2	17	NA	0	6	45	87	NA
Nuclear	917	990	1,010	820	555	-1.2	1,068	1,182	1,308	1,409	1.1
Hydro	648	702	781	844	912	0.9	762	888	1,014	1,135	1.4
Biomass	85	0	0	14	2	-9.0	0	0	21	23	-3.2
Biomass (with CCS)	0	0	0	14	45	NA	1	9	40	122	NA
Wind	111	233	717	1,406	1,683	7.0	480	1,095	1,065	1,133	6.0
Solar	4	61	74	50	51	6.5	84	534	846	920	14.4
Geothermal	24	34	60	108	194	5.3	46	82	147	263	6.1
Other	0	0	0	0	0	NA	0	0	0	0	NA

Scenario data tables: Regional electricity generation (II)

Table 35 – Scenario data tables: Regional electricity generation (II)

Source: World Energy Council (2013)

		Jazz					Symphony				
Electricity generation (TWh)	**2010**	**2020**	**2030**	**2040**	**2050**	**% CAGR (2010-50)**	**2020**	**2030**	**2040**	**2050**	**% CAGR (2010-50)**
Europe	**5,104**	**5,932**	**6,869**	**7,803**	**8,439**	**1.3**	**5,656**	**6,363**	**7,037**	**7,961**	**1.1**
Coal	1,191	1,195	1,664	2,055	1,929	1.2	843	685	501	25	-9.2
Coal (with CCS)	0	4	14	80	224	NA	8	45	239	1311	NA
Oil	98	0	0	0	0	NA	0	0	0	0	NA
Gas	1,422	2,093	2,504	2,131	1,733	0.5	1,653	2,021	1,591	900	-1.1
Gas (with CCS)	0	0	0	0	0	NA	3	7	185	212	NA
Nuclear	1,219	1,188	1,169	1,126	1,148	-0.1	1,303	1,388	1,572	1,711	0.9
Hydro	833	876	938	1,025	1,120	0.7	887	963	1,137	1,300	1.1
Biomass	146	164	171	332	578	3.5	169	186	369	499	3.1
Biomass (with CCS)	0	5	9	68	185	NA	6	25	69	182	NA
Wind	160	285	262	867	1,380	5.5	581	726	883	1,238	5.2
Solar	24	111	118	85	82	3.1	197	306	468	554	8.2
Geothermal	11	11	19	34	60	4.2	7	12	21	31	2.5
Other	0	0	0	0	0	NA	0	0	0	0	NA
South & Central Asia	**1,331**	**1,861**	**2,881**	**5,055**	**8,429**	**4.7**	**1,749**	**2,476**	**4,339**	**6,560**	**4.1**
Coal	735	1,323	1,937	3,844	6,714	5.7	999	989	1,191	779	0.1
Coal (with CCS)	0	0	9	36	107	NA	0	16	214	1,330	NA
Oil	68	0	0	0	0	NA	0	0	0	0	NA
Gas	263	132	337	399	384	0.9	202	364	553	494	1.6
Gas (with CCS)	0	0	0	27	76	NA	2	12	121	404	NA
Nuclear	30	90	100	110	116	3.4	90	193	305	443	6.9
Hydro	209	244	324	402	498	2.2	356	527	662	847	3.6
Biomass	4	3	14	47	129	9.1	6	21	74	222	10.6
Biomass (with CCS)	0	0	2	6	16	NA	0	9	30	102	NA
Wind	21	52	53	63	210	5.9	54	125	476	779	9.4
Solar	0	16	95	86	85	21.0	34	199	663	998	28.7
Geothermal	0	0	8	27	62	NA	7	15	27	70	NA
Other	0	0	2	7	31	NA	0	5	23	91	NA
East Asia	**6,121**	**8,761**	**11,070**	**13,064**	**14,298**	**2.1**	**7,749**	**9,223**	**10,916**	**12,571**	**1.8**
Coal	3,911	6,048	7,957	8,684	6,622	1.3	4,898	4,276	2,281	389	-5.6
Coal (with CCS)	0	0	16	64	190	NA	9	87	353	1,717	NA
Oil	144	0	0	0	0	NA	0	0	0	0	NA
Gas	559	512	528	1,212	3,004	4.3	444	810	1,974	1,974	3.2
Gas (with CCS)	0	0	0	6	192	NA	0	26	107	559	NA
Nuclear	563	950	1,061	1,192	1,254	2.0	1,080	1,691	2,277	2,708	4.0
Hydro	842	993	1,155	1,345	1,570	1.6	992	1,304	1,593	1,951	2.1
Biomass	40	3	13	47	108	2.5	6	32	55	129	3.0
Biomass (with CCS)	0	0	0	6	27	NA	0	21	50	136	NA
Wind	53	172	227	344	533	6.0	196	334	344	488	5.7
Solar	6	74	90	116	701	12.7	122	636	1,864	2,485	16.3
Geothermal	3	10	24	50	96	9.2	2	7	18	35	6.5
Other	0	0	0	0	3	NA	0	0	0	0	NA
Southeast Asia & Pacific	**996**	**1,549**	**2,106**	**3,123**	**4,024**	**3.6**	**1,409**	**2,045**	**2,699**	**3,398**	**3.1**
Coal	374	533	682	1,342	1,448	3.4	406	386	280	4	-10.8
Coal (with CCS)	0	3	15	48	134	NA	7	36	185	712	NA
Oil	69	0	0	0	0	NA	0	0	0	0	NA
Gas	385	737	1,006	1,037	764	1.7	662	1,018	782	604	1.1
Gas (with CCS)	0	0	2	12	38	NA	1	15	95	227	NA
Nuclear	0	0	0	0	0	NA	16	59	112	198	NA
Hydro	124	146	170	200	237	1.6	196	273	356	428	3.1
Biomass	10	8	19	50	117	6.3	8	21	52	74	5.1
Biomass (with CCS)	0	1	4	23	49	NA	2	9	36	64	NA
Wind	7	47	81	134	273	9.6	46	43	48	105	7.0
Solar	1	25	36	112	655	19.5	45	145	681	829	20.2
Geothermal	26	49	90	165	302	6.4	20	38	72	136	4.2
Other	0	0	0	0	8	NA	0	0	0	19	NA

The WEC's assumptions about regional carbon prices

Table 36 – Carbon prices (US\$2010/tCO_2)

Source: World Energy Council (2013)

	Jazz				Symphony			
	2020	**2030**	**2040**	**2050**	**2020**	**2030**	**2040**	**2050**
South & Central Asia	0	5	10	23	10	23	42	70
East Asia	0	5	10	23	10	23	42	70
Latin America & The Caribbean	0	5	10	23	10	23	42	70
Middle East & North Africa	8	15	21	28	21	28	55	70
Southeast Asia & Pacific	0–8	5–15	10–30	23–45	10–30	23–40	50–60	75–80
Sub-Saharan Africa	0	5	10	23	10	23	50	75
World	**0–6**	**5–12**	**10–24**	**23–38**	**10–24**	**23–38**	**50–60**	**75**

Table 37 – Population without access to electricity (in millions)

Source: World Energy Council (2013); IEA 2000–2012 (historical data)

Population without access to electricity (in millions)

		Jazz	Symphony
	2010	**2050**	**2050**
South and Central Asia	471	44.7	101.7
East Asia	22	0.0	0.0
Latin America and The Caribbean	29	0.1	0.6
Middle East and North Africa	20	0.0	0.1
Southeast Asia and Pacific	135	8.0	25.8
Sub-Saharan Africa	589	266.1	401.4
World	**1,267**	**319.0**	**529.6**

Table 38 – The world in 2050

Source: World Energy Council (2013)

MER: market exchange rate

		2010	2050		2050	
			Jazz	Symphony	Jazz	Symphony
Basic data	Population (million)	6,895.9	8,703.3	9,373.6	26%	36%
	GDP per capita (US$2010 MER)	9,161.9	23,139.3	18,317.4	153%	100%
	Car ownership (cars/1000 people)	123.6	244.3	193.5	98%	57%
Energy	Total primary energy supply (equal to consumption, globally) (EJ/y)	546.0	878.8	695.5	61%	27%
	Primary energy intensity (MJ/US$2010 MER)	8.6	4.4	4.1	-50%	-53%
	Final energy (total fuel consumption) (EJ/y)	373.4	629.5	490.8	69%	31%
	Final energy per capita (GJ/y) (excl. non-energy uses)	49.3	64.5	46.3	31%	-6%
	Final energy intensity (MJ/US$2010 MER) (excl. non-energy uses)	5.4	2.8	2.5	-48%	-53%
Electricity	Installed generation capacity for electricity (GW)	5,155.8	11,680.5	13,880.7	127%	169%
	Electricity generation (TWh/y)	21,475.7	53,646.7	47,917.7	150%	123%
	Share of fossils – coal with carbon capture and storage (CCS), coal, oil, gas (with CCS), gas.	67.2%	62.8%	37.6%		
	Share of renewables (hydro, wind, solar, geothermal, biomass (with CCS), biomass)	20.0%	30.9%	47.6%		
	Share of nuclear	12.9%	6.1%	14.5%		
	Electrification (in terms of the share of electricity in final energy) (%)	17%	27%	32%		
	Electricity consumption per capita (kWh/y)	2,590	5,440	4,600	111%	78%

Climate implications	CO_2 emissions ($Gt\ CO_2$)	30.5	44.1	19.1	45%	▲	-37%	▼
	CO_2 including captured emissions ($Gt\ CO_2$)	30.5	45.5	25.9	49%	▲	-15%	▼
	CO_2 per capita ($t\ CO_2$)	4.4	5.1	2.0	15%	▲	-54%	▼
	Carbon intensity of primary energy (tCO_2/TJ)	55.8	50.2	27.5	-10%	▼	-51%	▼
Resources	Total resources and reserves (EJ)							
	Gas (conventional and unconventional)	27409.6	20705.4	21558.1	-24%	▼	-21%	▼
	Oil (conventional and unconventional)	26078.5	17869.5	19028.1	-31%	▼	-27%	▼
	Diversity of primary energy supply (Simpson Index)	70.8	76.9	94.0	9%	▲	33%	▲
	Share of net imports in primary energy supply (%)(for aggregated world regions)[18]	21.5	20.5	19.2	-4%	▼	-11%	▼
	Share of gas in final energy (%)	15.0	21.1	18.2	41%	▲	22%	▲

18 The share of net imports in primary energy supply is defined as the sum of net imports of those aggregated world regions which are net importers, divided by the total global primary energy supply.

11. Appendix 2: WEC approach towards GMM MARKAL modelling

The Energy System Model GMM – an overview

The scenarios were quantified using the Global Multi-Regional MARKAL (GMM) energy system model. GMM is a technologically detailed cost-optimisation model that has been developed by the Energy Economics Group at the Paul Scherrer Institute (PSI) over a number of years (Rafaj, 2005; Gül et al., 2009; Densing et al., 2012). The WEC joined as a model partner to support continued development and dissemination of the model with the goal of improving transparency, accessibility and credibility of global energy scenario modelling. In this regard, the WEC and PSI are currently developing GMM into a fully open-source model available to all WEC members (subject to licensing).

Concept and model approach

GMM belongs to the family of MARKAL (MARKet ALlocation) type of models, where the emphasis is on a detailed representation of energy supply, conversion and energy end-use technologies (i.e. a so-called 'bottom-up' model). Such tools do not seek to directly model the economy outside of the energy sector, which is represented as a set of exogenous inputs to the model, based on a coherent scenario storyline.

GMM is applied to identify the least-cost combination of technology and fuel options to supply energy services using a market-clearing optimisation algorithm. This algorithm simultaneously determines equipment investment and operating decisions, and primary energy supply decisions for each region represented in the model to establish an equilibrium between the cost of each energy carrier, the quantity supplied by producers, and the quantity demanded by consumers. This market equilibrium is assured at every stage of the energy system (primary, secondary, end-use) and across time. Thus, the output from GMM represents a globally optimal allocation of society's energy resources and technologies over the time horizon of the model (which assumes perfect foresight) given the specific scenario assumptions. Non-cost decisions or short-sighted factors, like behavioural aspects of technology choice, public acceptance, or social/institutional capacity are taken into account by additional constraints and appropriate cost assumptions. Future expenditures are discounted to account for time preferences and cost of capital.

The focus on technologies and costs in the GMM modelling has two strong advantages: (i) optimisation of costs has an evident economic interpretation (nevertheless, non-cost factors are still included parametrically through assumptions);

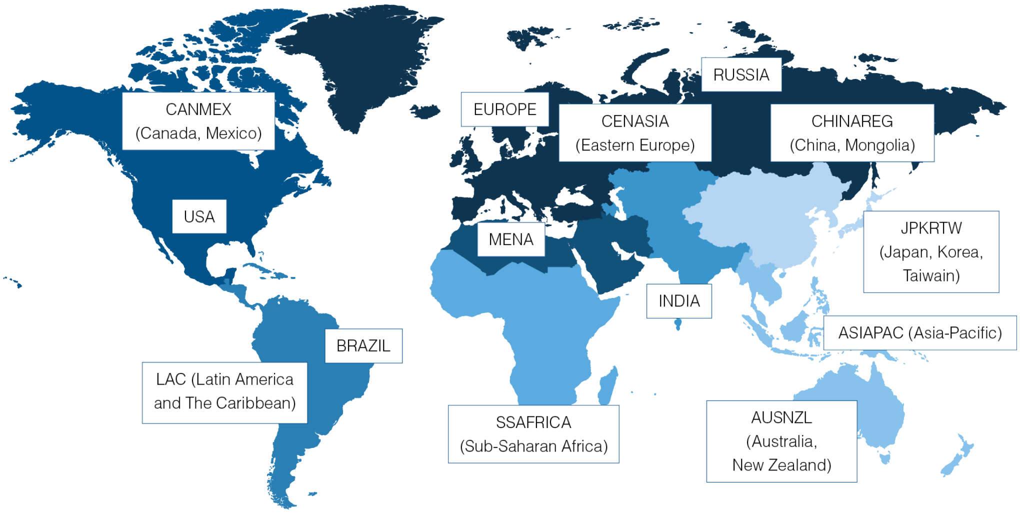
and (ii) the model can be technology-detailed, which is computationally not possible for models that try to represent the general equilibrium of the whole economy (general equilibrium models). Nevertheless, like the storylines, the scenario quantification from GMM should not be seen as a prediction of the future, but rather a framework for understanding different future pathways of the energy system and exploring alternative strategies. In addition, the model does not seek to predict market prices of energy carriers, because GMM is concerned primarily with economic costs (also taking into account scarcity costs of energy carriers), assumes competitive markets, and the social allocation of resources (e.g. excluding cartel profits, windfall profits, and certain taxes (although, cost/taxes for GHGs are accounted for).

In addition, it should be noted that GMM has been designed for long-term planning and scenario analysis, not for short-term forecasting, short-term engineering analysis of the electricity system, or for simulating shock impacts (for which other specialised tools are available). In addition, GMM lacks spatial information and representation at a level below the aggregated regions, and thus can only provide limited insights about divergence within regions, or the development of intra-regional distribution and transport infrastructure. Further, risk factors associated with different technologies are currently not explicitly represented, although the framework has the potential to represent some elements in the perception of the cost of technologies and the weighted average costs of capital, both in demand and supply sectors. Uncertainty is not modelled with probabilistic approaches, which would render the rather complex structure difficult to manage in a reasonable computing time.

Temporal and spatial resolution

The reported time horizon of GMM covers the period 2010–-2050, with a step length of 10 years. For consistency, the optimisation is executed until an internal horizon of year 2100 to address long-term energy issues – for example, resource depletion, climate change policy, economic development and technology learning. In addition, GMM incorporates a simplified seasonal and day-night disaggregation of each year, to account for variations in demands and limitations on the use of some electricity and heat-generation technologies. This is important for equipment which depends on the availability of resources that cannot be stored or that can be only partially stored.

Figure 92 – The 15 world regions of the GMM model
Source: World Energy Council (2013)



The spatial resolution of GMM has been defined to cover the eight WEC world regions. Currently, the full spatial resolution of the model consists of 15 world regions. Major countries are modelled as separate regions: Brazil, China, the European Union,[19] India, Russia, and the US. Aggregated regions include: Eastern Europe;[20] South and Central Asia (excluding India); the developed Far East (Japan, Korea and Taiwan); Australia together with New Zealand; the Latin American region together with The Caribbean (excluding Brazil and Mexico); the Middle East and North Africa; Canada together with Mexico; and Southeast Asia and the Pacific. For each region, scenario assumptions influence the dynamics of demand and supply technologies (cost, efficiencies, availability). The regional and technology differentiation leads to a large-scale optimisation model with approximately over 200,000 equations.

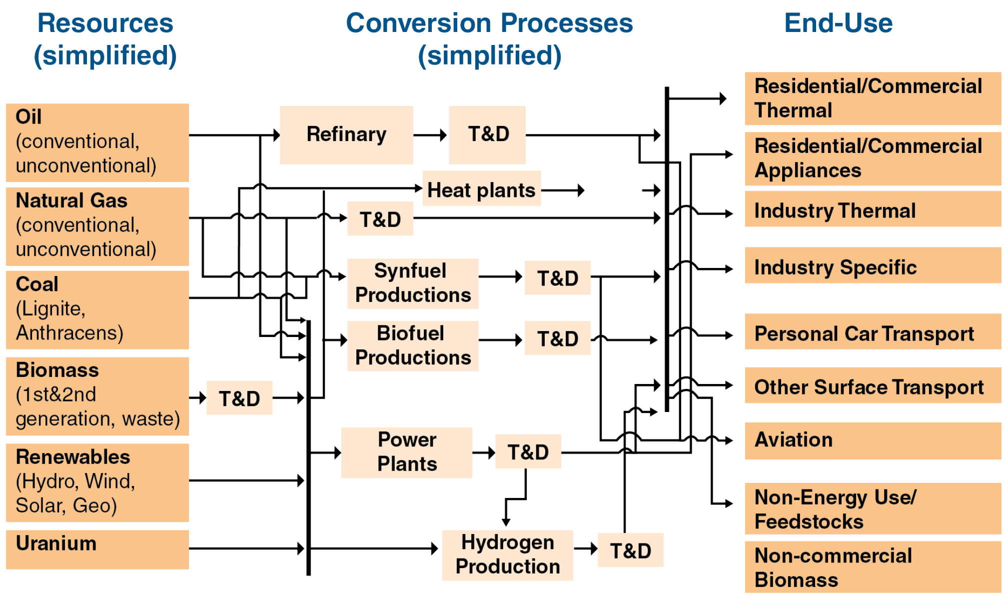
Energy system structure and technologies in GMM

The flows of energy carriers – that is, their extraction, conversion, blending trough processes and their consumption in energy demand sectors, is depicted in GMM by a so-called 'reference energy system' (RES). GMM's energy economy consists of demands that represent the energy services, energy sources (mining or imports) that represent methods of acquiring energy carriers, technologies that transform the energy carriers, and commodities consisting of energy carriers, energy services, materials and emissions that are either produced or consumed by the demands, the energy sources and the technologies. A heavily simplified RES of GMM is shown in Figure 92.

19 Including Croatia (which joined in year 2013), together with Iceland, Norway and Switzerland.
20 Albania, Armenia, Belarus, Bosnia and Herzegovina, Georgia, Macedonia, Moldavia, Serbia, Turkey, Ukraine.

Figure 93 – Reference energy system of the GMM model (single region, simplified)

Source: World Energy Council (2013)



Energy end-use demands and technologies

The demand sectors in GMM are grouped by the three main aggregated energy sectors of the IEA's Energy Balances (IEA 2012a): industry, transport and other (comprising primarily, and the residential and commercial sectors). Within the industry and residential and commercial sectors, GMM distinguishes demands for thermal and for non-thermal (specific) end uses (see above). In the transport sector, the model distinguishes between air transport and surface transport demand, with the latter disaggregated to treat separately personal car travel demand (which is further disaggregated to include a short-range demand sub-sector covering a small percentage of total car demand).

GMM represents a range of demand technology options in the end-use sectors. For example, heating demand in the residential and commercial sectors can be satisfied by conventional technologies or by more efficient, but more costly, options such as heat pumps. Similarly, demand for car travel can be satisfied by either conventional technologies or, for example, more efficient hybrid, plug-in hybrid, pure battery, and fuel cell hybrid drive trains, and with different fuels. Hence, the consumption (demand) of final energy is determined in GMM's optimisation according to the trade-off between efficiency and costs, which are influenced by the scenario assumptions. Accordingly, the energy demand inputs to GMM are not in terms of final energy, but in terms of useful energy, which is, for example, heating demand, or kilometres of car travel.

These useful demands are derived from scenario assumptions based on a coherent scenario storyline, with key drivers including population and economic development.[21] Other drivers from a scenario storyline are also incorporated directly or implicitly – for example, in the transport sector, the modal choice is implicitly linked to the level of

21 For example, the demand for personal car travel is derived from scenario assumptions on population and regional assumptions on the development of the motorisation rate, which in turn is related to the level of GDP per capita in the scenarios.

motorisation and demand for commercial transport demand. Similarly, the thermal heating demand in the residential and commercial sectors incorporates assumptions about both energy service demand and the degree of insulation.

Energy supply and conversion technologies

In the energy supply and conversion sector, GMM incorporates a detailed representation of technology options. For instance, GMM includes a comprehensive set of current and future technologies for electricity generation. These include a range of existing and new coal-fired generation technologies: with and without CC(U)S, combined cycle turbines and/or heat co-generation (and as energy plexes capable of producing electricity and hydrogen). Nuclear production includes conventional technologies and Generation 3+/4 technologies (depending on scenario assumptions). Renewables include thermal and solar PV, onshore and off-shore wind, hydro and geothermal plants; the reduced availability of intermittent renewables is taken into account by appropriate requirements for reserve capacity. The GMM model includes distribution and transmission costs of electricity (though a grid topology is not explicitly modelled).

The GMM model represents a variety of technologies for the production of synthetic and alternative fuels: ethanol, methanol, fatty acid methyl ester (FAME) fuel, biodiesel, Fischer-Tropsch diesel, synthetic gas from biomass and waste, dimethyl ether (DME). Biofuels are produced from different first and second (e.g. cellulosic) biomasses having specific costs, potentials and efficiencies. Hydrogen pathways are represented from different fossil fuels with optional CC(U)S, from specially equipped nuclear plants, from biomass and from renewables (e.g. by electrolysis).

Carbon capture, use and storage (CC(U)S) may reduce CO_2 emissions from the global energy system. In GMM, CC(U)S is technically available for new power plants that are fuelled by coal, gas or biomass; power plants with CC(U)S have higher costs and are less efficient than those without CC(U)S. The carbon storage potential is capped in each world region (Hendriks, 2004; and other sources); the availability of CC(U)S is influenced by scenario assumptions regarding climate policy, public acceptance, and geological uncertainty.

Input parameters for technologies include the dynamics of efficiency and costs (investment cost, fixed and variable operation and maintenance costs) for current and future technologies. Cost reductions over time depend on scenario assumptions on technology learning. GMM also accounts for the co-evolution of technologies using similar components, and international technology spill-overs. As an option, these technology dynamics can be modelled endogenously in GMM based on concept of learning-by-doing in which the unit investment cost of a technology decreases with increasing experience in manufacture and deployment.

Calibration of energy demands, technologies and energy resource potentials

The GMM model is calibrated to recently published statistics for the year 2010. This calibration covers current demands for each energy sub-sector, the technology and fuel shares, and estimates on current costs and efficiencies of technologies. A primary source used for much of the calibration of fuel production and consumption is the IEA's Energy Balances (IEA 2012a). To ensure a better representation of developments since 2010 (up to the year 2013), the model uses additional statistics for recent years for which reliable data are available (EIA, 2012; GEO, 2012; IEA, 2012b; see Turton et al., 2013 for full list).

Figure 94 – Modelling approach: Objective function, optimal variables and constraints

Source: World Energy Council (2013)

Minimize discounted energy system costs (total over world regions):

MIN

Capital cost, fixed and variable O&M cost (for each technology at each time step)
\+ **Revenues/Costs from import/export** (for each traded energy carrier, each time step)
\+ **CO_2-emissions costs** (tax or price, each time step)
\- **Salvage value** (for investment still active at time horizon)

By choosing optimal variables:

- **Investment, installed capacity, energy output** (for each technology at each time step)
- **CO_2-emissions** (per region)
- **Import/export amount** (for each traded energy carrier and region)

Subject to constraints:

on energy carriers:
- Balance equations (over time and between processes)
- Potential (for fossil resources and biomass)

on technologies:
- Growth: Maximal/minimal change of capacity or output
- Availability: Capacity must be sufficient for energy output
- Demand: End-use technologies must satisfy demand
- Efficiency: Input/output of energy carriers
- Potential: Renewables maximal installation

on te energy system:
- Minimal reserve capacity in power generation
- CCUS potential

additional constraints by scenario assumptions

GMM also incorporates recent estimations for resources and potentials of fossil energy carriers and of renewables. The fossil estimates are mainly based on BGR (2012) and GEA (2012). The GMM model distinguishes between proven conventional reserves, proven unconventional reserves, likely conventional resources, and likely unconventional resources. These unconventional resources include shale gas, coal bed methane and oil shales (but not more speculative resources such as clathrates). Whether unconventional reserves or resources are exploited depends on the corresponding dynamics of mining costs and the scenario assumptions. The GMM model also includes regional technical potentials for first- and second-generation types of biomass: corn grains, sugar cane, oil crops, stover, wood and waste, as well as technical potentials for renewables: wind (onshore and off-shore), solar, hydro and geothermal (Krewitt et al., 2009; WEC, 2010; see Turton et al., 2013 for full list of literature sources).

Summary

GMM is a tool used to quantify and enrich the scenario storylines developed by the WEC. GMM's detailed technology enables the model to provide a consistent and integrated representation of the global energy system, accounting for engineering and technical factors in the quantification of long-term energy transitions. The model is driven by input assumptions reflecting the scenario storylines and applies an optimisation algorithm to determine the least-cost, long-term configuration of the global energy system from a global social perspective with perfect foresight.

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12. Appendix 3: Useful information

Abbreviations

ASEAN	Association of South-East Asian Nations
BANANA	build absolutely nothing anywhere near anyone
bcm	billion cubic metres
BEV	battery electric vehicle
bpd	barrels per day
BRIC	Brazil, Russia, India and China
BRICS	Brazil, Russia, India, China and South Africa
B-S-P	bijli, sadak and pani (electricity, road and water)
CAGR	compound annual growth rate
CC(U)S	carbon capture, utilisation and storage
CCGT	combined cycle gas turbine
CCS	carbon, capture and storage
CDM	Clean Development Mechanism
CH_4	Methane
CHP	combined heat and power
CIF	climate investment funds
CIS	Commonwealth of Independent States
CNG	compressed natural gas
CO_2	carbon dioxide
COP	Conference of Parties
CPS	cyber-physical systems

CTL	coal to liquid
DAS	Deutsche Anpassungs Strategie
Defra	Department for Environment, Food and Rural Affairs
DS	degrees Celsius, e.g. 6DS: 6°C Scenario
E&P	exploration and production
EJ	exajoule
EOR	enhanced oil recovery
ESM	energy system model
ESO	energy savings obligations
ETL	endogenous technology learning
ETP 2010	Energy Technology Perspectives 2010 report (International Energy Agency)
ETS	Emissions Trading Scheme
ETSAP	Energy Technology Systems Analysis
EU	European Union with its 28 member states as of 1 July 2013 (EU-28)
EU-ETS	EU Emissions Trading Scheme
EUR	Europe
EURELECTRIC	The association of the electricity industry in Europe
EV	electric vehicle
FDI	foreign direct investment
FICCA	Finnish research programme on climate change
FMCGs	fast moving consumer goods
FTA	free trade area
FY	financial year
GCC	Golf Cooporation Council
GDP	gross domestic product
GHG	greenhouse gas
GMM	global multi-regional MARKAL model

HFCs	hydrofluorocarbons
IBM	International Business Machines Corporation
ICE	internal combustion engine
ICEVs	internal combustion engine vehicles
ICT	information and communication technology
IEA	International Energy Agency
IGCC	integrated gasification combined cycle
IMF	International Monetary Fund
JI	joint implementation
LAC	Latin America and The Caribbean
Li-ion	lithium-ion batteries
LNG	liquid natural gas
MARKAL	market allocation modelling framework
MENA	Middle East and North Africa
MEPS	minimum energy performance standard
MER	market exchange rate
Mg-Sb	magnesium-antimony
Mtoe	Million tonnes of oil equivalent
N_2O	nitrous oxide
NAM	North American region
Na-S	sodium sulphur batteries
NGLs	natural gas liquids
NGOs	non-governmental organisations
NIMBY	not in my back yard
NiMH	nickel metal hydride
NOC	National Oil Company
NO_x	nitrogen oxides
OECD	Organisation for Co-operation and Development

OPEC	Organization of the Petroleum Exporting Countries
p.a.	per annum
P2G	power-to-gas
PFCs	perfluorocarbons
PHEVs	plug-in hybrid electric vehicles
PPP	purchasing power parities
PV	photovoltaic
R&D	research & development
R/P ratio	reserves/production ratio
REDD	reducing emissions from deforestation and forest degradation, UN programme
REDD+	REDD on a national level, supported by the UN-REDD programme
REE	rare earth elements
RES-E	renewable energy sources for electricity generation
SF_6	sulphur hexaflourid
Sinopec	China Petroleum & Chemical Corporation
SO_2	sulphur dioxide
SPV	solar photovoltaic
SSA	sub-Saharan Africa
STEM	science, technology, engineering, mathematics
T&D	transmission and distribution
TPES	total primary energy supply
UAE	United Arab Emirates
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
UN-HABITAT 2003	UN Global Report on Human Settlements 2003: Challenge of the Slums
UNIDO	United Nations Industrial Development Organization

USD	US dollar
VAT	value added tax
VR	vandium redox
WTO	World Trade Organization
Zn-Br	zinc bromide

Conversion factors used

Table 39 – Conversion factors used

Source: World Energy Council (2013)

To:	EJ	PWh	Mtoe	mio t SKU	bcm natural gas	bio barrel crude oil
From:	Multiply by:					
EJ	1	0.28	23.88	34.1	28.80	0.18
PWh	3.6	1	85.97	122.76	103.69	0.63
Mtoe[1]	0.042	0.012	1	1.43	1.21	0.0073
mio t SKU[4]	0.029	0.008	0.70	1	0.84	0.0051
bcm natural gas[2]	0.035	0.010	0.83	1.18	1	0.0061
bio barrel crude oil[3]	5.7	1.58	136.12	194.37	164.17	1

Note: Exa: = 10^18; PWh = 10^6 MWh; bio := 10^9 = 1000 mio
[1,2]: IEA Key World Energy Statistics (natural gas: global simple average of net heat content)
[2,3,4]: Bundesministerium für Wirtschaft und Technologie; [3]: Lower (net) heating value (upper heating value: 6.1 GJ/bbl)

Glossary of key terms

1P reserves: proven oil and gas reserves.

2P reserves: proven and probable oil and gas reserves.

Black liquor gasification: Black liquor is an energy-rich liquid waste product formed when wood chips are cooked to make paper pulp. Fuel can be derived from the gasification process of black liquor.

Boom and bust: An economic cycle where periods of growth and increased GDP is followed by a down-trend of decreased GDP, un-employment, etc.

Cap and trade: A market-based approach to reduce emissions with economic incentives.

Carbon cost: Is defined as the technology cost of avoiding CO_2 emissions.

Carbon price: Is the marginal price that society is prepared to pay to abate CO_2 emissions. It doesn't need a market. Feed-in tariffs, biofuel obligations and renewable subsidies impose a carbon price.

Energy efficiency measures: A design, operation, or technology change for the purpose of reducing energy consumption.

Energy equity: The accessibility and affordability of energy supply across the population.

Energy security: The effective management of primary energy supply from domestic and external sources, reliability of energy infrastructure, ability to meet current and future energy demand.

Energy trilemma: The WEC's definition of energy sustainability based on three core indicators: energy security, energy equity and environmental sustainability.

Environmental mitigation impact: The achievement of supply and demand-side energy efficiencies and the development of energy supply from renewable and other low-carbon sources.

Feed-in-tariff: An economic policy created to promote active investment in and production of renewable energy sources, typically through a top-up payment for each unit of renewable electricity produced.

Leapfrog: To leapfrog means we jump directly to a higher level of technology by bypassing intermediate steps – that is, a greater level of technology can be achieved quicker.

Mezzanine debt: Mezzanine debt is a type of liability financing often used by businesses to fund specific projects and, occasionally, as a source of operational capital. Mezzanine debt commonly refers to subordinate obligations of a company that are repaid only after all other debt has been financed by the company.

Molten salt fuel cell: High-temperature fuel cells with higher efficiency rate (~60% compared to standard fuel cell efficiencies around 40%), using a molten carbonate salt mixture instead of phosphoric acid.

Oil originally in place: The total amount of oil, gas or coal contained in a reservoir before production begins.

Probable reserve: The volume that is thought to exist in accumulations that have been discovered and have a 50% probability that it can be produced profitably.

Proven reserve: The volume of oil, gas or coal that has been discovered and for which there is a 90% probability that it can be extracted profitably on the basis of prevailing assumptions about cost, geology, technology, marketability and future prices (1P reserve).

Rare earth elements: There are 17 different chemical elements in the periodic table that are considered rare earth elements, commonly found in the same type of ore. Uses for rare earth elements include electronic devises and batteries.

Recovery factor: The share of oil or gas originally in place that is ultimately recoverable.

Renewable obligations: An obligation on UK electricity suppliers to source an increasing proportion of their electricity from renewables.

Renewable storage: Technological solutions to store the energy generated from intermittent renewable energy sources.

Reserves growth: The typical increases in 2P reserves that occur as oil or gas fields that have already been discovered are developed and produced.

Senior debt: Debt that has priority for repayment in liquidation.

Sheddable loads: Electrical load that is deprioritised at peak demand or power supply shortages.

Smart grids: An electrical power distribution network that, in addition to transmitting electricity, includes two-way, digital communications between producers and consumers.

Smart meters: An electrical meter that continuously monitors energy consumption and communicates the data back to the consumer.

Subcritical coal-fired unit: Conventional coal-fired power plant operating that operates a lower, ‘subcritical’ temperatures and pressures, and reduces the emission of NO_x, SO_2, and particular matter (PM).

Super-cycles: A sustained demand cycle of certain commodities, e.g. coal.

Ultimately recoverable resources: The latest estimates of the total volume of hydrocarbons that are judged likely to be ultimately producible commercially, including initial 1P reserves, reserve growth and as yet undiscovered resources.

Unconventional gas: Gas resources that cannot be explored, developed and produced by conventional processes, e.g. shale gas and tight gas.

White certificates: Documents with the obligation to achieve a certain energy target, usually tradable between organisations.

Legends

Regional abbreviations

CENTASIA	Central and South Asia
EUROPE	Europe and Russia
LAC	Latin America and The Caribbean
MENA	Middle East and North Africa
NAM	North America
PACIASIA	Pacific Asia
SSAFRICA	Sub-Saharan Africa

Regional colours

Middle East and North Africa
North America
Latin America and The Caribbean
South and Central Asia
Africa
Southeast Asia and Pacific
East Asia
Europe
Asia

13. Appendix 4: WEC regional definition and countries

Asia

East Asia
China
Hong Kong
Japan
Macao
Mongolia
North Korea
South Korea
Taiwan

South and Central Asia
Afghanistan
Azerbaijan
Bangladesh
Bhutan
India
Kazakhstan
Kyrgyzstan
Maldives
Nepal
Pakistan
Sri Lanka
Tajikistan
Turkmenistan
Uzbekistan

Southeast Asia and Pacific
Australia
Brunei Darussalam
Cambodia
Cook Islands
Fiji
French Polynesia
Guam
Indonesia
Kiribati
Laos
Malaysia
Marshall Islands
Micronesia
Myanmar (Burma)
Nauru
New Caledonia
New Zealand
Niue
Norfolk Island
Northern Mariana Islands
Palau
Papua New Guinea
Philippines
Pitcairn
Samoa
Singapore
Solomon Islands
Thailand
Timor-Leste
Tokelau
Tonga
Tuvalu
Vanuatu
Vietnam
Wallis and Futuna Islands

Europe
Albania
Andorra
Armenia
Austria
Belarus
Belgium
Bosnia and Herzegovina
Bulgaria
Croatia

Cyprus
Czech Republic
Denmark
Estonia
Finland
France
Georgia
Germany
Gibraltar
Greece
Greenland
Guernsey
Holy See (Vatican)
Hungary
Iceland
Ireland
Italy
Latvia
Liechtenstein
Lithuania
Luxembourg
Macedonia
Malta
Moldova
Monaco
Montenegro
Netherlands
Norway
Poland
Portugal
Romania
Russian Federation
San Marino
Serbia
Slovakia
Slovenia
Spain
Sweden
Switzerland
Turkey
Ukraine
United Kingdom

Latin America and The Caribbean

Anguilla
Antigua and Barbuda
Argentina
Aruba
Bahamas
Barbados
Belize
Bolivia
Bonaire, Saint Eustatius and Saba
Brazil
British Virgin Islands
Cayman Islands
Chile
Colombia
Costa Rica
Cuba
Curaçao
Dominica
Dominican Republic
Ecuador
El Salvador
Falkland Islands (Malvinas)
French Guiana
Grenada
Guadeloupe
Guatemala
Guyana
Haiti
Honduras
Jamaica
Martinique
Montserrat
Nicaragua
Panama
Paraguay
Peru
Puerto Rico
Saint Kitts and Nevis
Saint Lucia
Saint Martin (French part)
Saint Vincent and the Grenadines
Saint-Barthélemy
Sint Maarten (Dutch part)
Suriname
Trinidad and Tobago
Turks and Caicos Islands
United States Virgin Islands
Uruguay
Venezuela

Middle East and North Africa

Algeria
Bahrain
Egypt
Iran
Iraq
Israel
Jordan
Kuwait
Lebanon
Libya
Morocco
Oman

Palestine
Qatar
Saudi Arabia
Syria
Tunisia
United Arab Emirates
Yemen

North America

Bermuda
Canada
Mexico
Saint Pierre and Miquelon
United States of America

Sub-Saharan Africa

Angola
Benin
Botswana
Burkina Faso
Burundi
Cameroon
Cape Verde
Central African Republic
Chad
Comoros
Congo (Democratic Republic of)
Congo (Republic of)
Cote d'Ivoire
Djibouti
Equatorial Guinea
Eritrea
Ethiopia
Gabon
Gambia
Ghana
Guinea
Guinea-Bissau
Kenya
Lesotho
Liberia
Madagascar
Malawi
Mali
Mauritania
Mauritius
Mayotte
Mozambique
Namibia
Niger
Nigeria
Réunion
Rwanda
Saint Helena
Sao Tome and Principe
Senegal
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Zimbabwe

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Member committees of the World Energy Council

Albania
Algeria
Argentina
Austria
Bahrain
Belgium
Bolivia
Botswana
Brazil
Bulgaria
Cameroon
Canada
Chad
China
Colombia
Congo (Democratic Republic)
Côte d'Ivoire
Croatia
Cyprus
Czech Republic
Denmark
Egypt (Arab Republic)
Estonia
Ethiopia
Finland
France
Gabon
Germany
Ghana
Greece
Hong Kong, China
Hungary
Iceland
India
Indonesia
Iran (Islamic Republic)
Iraq
Ireland
Israel
Italy
Japan
Jordan
Kazakhstan
Kenya
Korea (Republic)
Kuwait
Latvia
Lebanon
Libya
Lithuania
Luxembourg
Macedonia (Republic)
Mexico
Monaco
Mongolia
Morocco
Namibia
Nepal
Netherlands
New Zealand
Niger
Nigeria
Pakistan
Paraguay
Peru
Philippines
Poland
Portugal
Qatar
Romania
Russian Federation
Saudi Arabia
Senegal
Serbia
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United Kingdom
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Uruguay
Zimbabwe

The World Energy Council (WEC) is the principal impartial network of leaders and practitioners promoting an affordable, stable and environmentally sensitive energy system for the greatest benefit of all. Formed in 1923, the WEC is the UN-accredited global energy body, representing the entire energy spectrum, with more than 3000 member organisations located in over 90 countries and drawn from governments, private and state corporations, academia, NGOs and energy related stakeholders. The WEC informs global, regional and national energy strategies by hosting high-level events, publishing authoritative studies, and working through its extensive member network to facilitate the world's energy policy dialogue.

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