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China’s Energy Futures

Report on the China Power Pathways Technology Roadmapping Event of 21-23 October 2013 at the Tsinghua-BP Clean Energy Centre

Part of Tasks 3.1 and 3.3 of the Europe-China High Value Engineering Network (EC-HVEN): Shaping Sustainable Engineering Sectors in Europe and China

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SEVENTH FRAMEWORK PROGRAMME

MARIE CURIE ACTIONS

Contents

Introduction

This report documents a workshop that was held at the Tsinghua-BP Clean Energy Centre at Tsinghua University on 21-23 October 2013. The focus of the workshop was the challenge of integrating intermittent power generation into China's electricity network. The workshop made use of technology roadmapping techniques in order to bring together a diverse set of perspectives. The workshop comprised the following elements:

- The development of a historical map to identify how the current state of China's electricity network has developed.
- The generation of multiple scenarios for China's energy situation in 2050.
- The creation of a technology roadmap that identifies some of the potential actions necessary to realise one of these scenarios (the "desired vision").

This report contains descriptions of the processes underpinning these workshop elements along with their outputs. The most significant of these outputs is a set of recommendations for the actions necessary to achieve the "desired vision". The report begins by providing descriptions of the power system context and the roadmapping methodology that underpinned the workshop.

Background to this report

Power systems context[1]

The potential for intermittent power generation such as wind and solar PV to de-stabilise electricity networks is a hotly debated and embryonic topic. In particular, there is much speculation as to what levels of penetration by intermittent generation electricity networks are able to absorb without facing major disruption. In addition, there is no single agreed approach to quantifying the costs of integrating renewable generation i.e. reserve margin, transmission, distribution, balancing, and losses.

A degree of instability is inherent in the operation of any electricity network with even established conventional types of power generation (i.e. coal, gas, nuclear etc), subject to short-term fluctuations in output and unplanned outages, key equipment components of transmission systems open to variable availability and failures, and demand unpredictable and in constant flux. Through long experience, System Operators responsible for the safe operation and integrity of electricity networks have developed a range of operational procedures and employ a range of technologies to deal with instability. In markets where intermittent wind and solar generation is increasingly establishing a material presence, the ability to maintain system stability is increasingly being challenged. While a range of technology options are available to System Operators to manage their networks, these are at different stages of maturity, have different performance and cost characteristics and are often designed to provide specific types of balancing and network support services (Figure 1).

[1] Thanks to Ian Jones, BP, for providing the content of this section.

	Application By Response Timeframe											Discharge Time/Duration
	Hours					Minutes				Seconds		
	Energy Arbitrage	Generation Capacity Deferral	T&D Investment Deferral	Congestion Management	Voltage Support	Blackstart	Spinning Reserve	Load Following	Renewable Ramp Reduction	Regulation	Power Quality	
Generation												
Conventional Generation		Mature	Mature		Mature	Mature	Mature	Mature	Mature	Mature		> Hours
Generation re-dispatch			Mature	Mature								> Hours
Hydro generation			Mature	Mature	Mature	Mature	Mature	Mature	Mature	Mature		> Hours
Distirbuted generation					Demonstration	Demonstration	Demonstration	Demonstration	Demonstration	Demonstration	Demonstration	Minutes/Hours
Demand Response												
Industrial	Mature	Mature		Demonstration	Demonstration		Mature					Hours
Commercial/Residential				Demonstration	Demonstration	Demonstration	Demonstration	Demonstration	Demonstration	Demonstration	Demonstration	Minutes/Hours
Network/Interconnection												
Interconnection	Mature	Mature	Mature	Mature		Mature	Mature	Mature	Mature			Hours
Transmission	Mature	Mature	Mature	Mature	Mature	Mature				Mature	Mature	> Hours
Static Compensation Devices			Mature		Mature							> Hours
Power Electronics											Mature	Seconds
Storage Technologies												
Pumped Hydro	Mature	Mature	Mature	Mature	Mature	Mature	Mature	Mature	Mature	Mature		Hours
Compressed Air	Commercial	Commercial	Commercial	Commercial	Commercial	Commercial	Commercial	Commercial	Commercial			Hours
Flywheel						Demonstration	Demonstration	Demonstration	Demonstration	Demonstration	Demonstration	Minutes
Super Capacitor											Demonstration	Seconds
Battery Technology						Commercial/Demonstration	Commercial/Demonstration	Commercial/Demonstration	Commercial/Demonstration	Commercial/Demonstration	Commercial/Demonstration	Hours/Minutes
Operational Measures												
Protection Measures			Mature	Mature								Seconds
Dynamic Line Rating			Commercial	Commercial								Hours
Forecasting	Mature											Hours

● Mature ● Commercial ○ Commercial/Demonstration ● Demonstration

Figure 1. Technology Options for non-Energy Electricity System Applications (Energy Technology Perspectives 2012 © OECD/IEA, 2012, fig. 6.16, p. 228, modified by the authors)

The planning of networks will increasingly need to look beyond the required functionality for today's systems and have forward compatibility, extensibility and interoperability at the heart of their design to meet changing needs in the long-term and benefit from the seamless integration of a raft of future technologies across the spectrum of generation, transmission, distribution and end-use.

Today fast start-up and rapid response plants such as gas-fired single cycle gas turbines (SCGTs) and pumped hydro storage together with flexing plant online, form the backbone of system balancing services and provide reserve margin capacity. There is an expectation that future technologies such as large scale utility battery storage and smart grids (particularly for demand response), will increase the options for electricity systems to access flexibility, although these technologies remain some way from being deployable at scale.

As well as planning for the potential physical destabilising effects of intermittent renewable generation, there are a number of commercial implications that will need to be considered:

- Increasing sources of instability in turn increases the need for the provision of flexibility to System Operators. Such flexibility, whether supplied by conventional generation, pumped or battery storage or demand response has a cost and, therefore, value associated with it. Developing appropriate commercial reward mechanisms will be critical in incentivising investment in and development of flexible services and technologies.

- Recent experiences in Europe in markets such as Germany and Spain highlight the effect that the addition of material volumes of new generation with a low or zero variable cost of producing electricity i.e. wind and solar PV, has on undermining the economics of both incumbent and new conventional forms of power generation in liberalised energy-only wholesale electricity markets.

- Typically liberalised wholesale electricity markets have not been designed to facilitate the transition from an erosion of value in delivering energy to an increase in value of both holding capacity and providing flexibility. Careful consideration will need to be given to the overhaul and design of market mechanisms to ensure appropriate price signals are sent and service providers rewarded.

- Typically responsibility for managing the day-to-day operation of electricity networks and real-time matching of demand with supply rests with System Operators who oversee the high-voltage transmission grid. However, a significant portion of new wind and solar generation is connecting directly to the low-voltage distribution grids owned and managed by Distribution Network Operators. In general, these operators are neither equipped nor funded to be able to monitor and deal with this emerging phenomenon.

Technology roadmapping

Roadmapping is a powerful technique regularly used by government organisations, companies and academic institutions to establish and support strategic planning. It is widely used to develop a common language, linking technology developments to value-generating opportunities and markets. As a generic tool, roadmapping aims to include multiple perspectives, primarily through a workshop-based methodology, with a variety of methods that can also be used to feed data into these workshops.

Roadmaps are created during the roadmapping process. They are structured time-based graphical representations of potential strategy. A basic roadmap template is illustrated in Figure 2. The layers in a roadmap represent the key dimensions of the system being considered, enabling stakeholder perspectives to be presented in a structured way. They facilitate communication between stakeholders, both through the process itself and the resultant visual output.

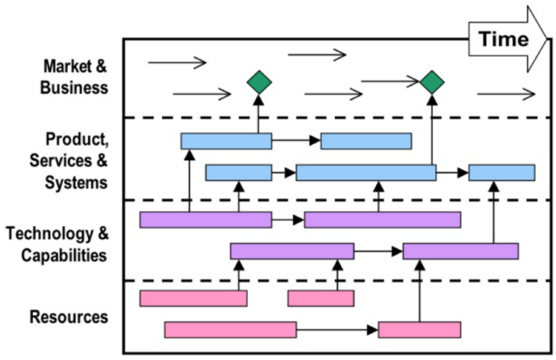


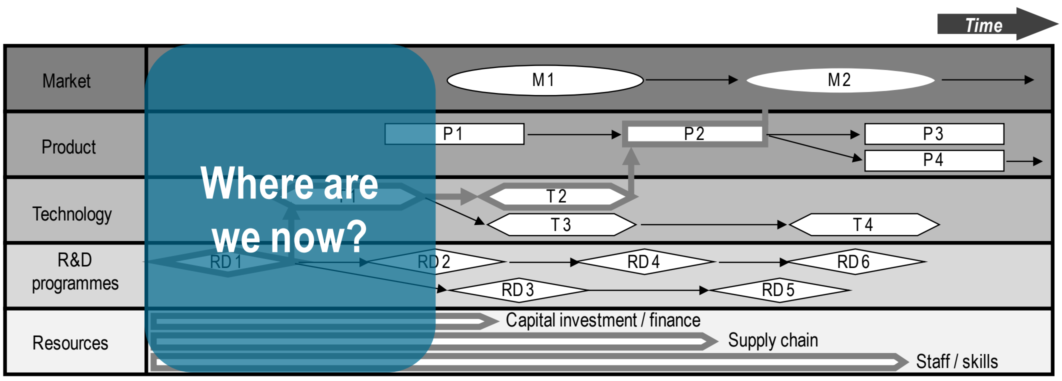
Figure 2. Schematic roadmap

Roadmaps comprise two axes:

1. Time, along the horizontal axis;
2. The scope, comprising thematic layers and sub-layers, along the vertical axis.

At the highest level, roadmaps comprise three broad layers:

1. The top layer(s) relates to the trends and drivers that govern the overall goals or purpose associated with the roadmapping activity, including external market and industry trends and drivers (social, technological, environmental, economic, political and infrastructural), and internal business trends and drivers, milestones, objectives and constraints. It may also include current and future user needs. Collectively, the type of information contained in the top layer can be thought of as representing the 'know-why' dimension of knowledge.
2. The middle layer(s) generally relates to the tangible systems that need to be developed to respond to the trends and drivers (top) layer. Frequently this relates directly to the evolution of products (functions, features and performance) but can also represent the development of services, infrastructure or other mechanisms for integrating technology, capabilities, knowledge and resources in a way that delivers benefits to customers and other stakeholders (and hence value to the business), such as engineering systems and organisational capabilities. Collectively, the type of information contained in the middle layer can be thought of as representing the 'know-what' dimension of knowledge.
3. The bottom layer(s) relates to the resources that need to be marshalled to develop the required products, services and systems, including knowledge-based resources, such as technology, skills and competences and other resources such as finance, partnerships and facilities. Collectively, the type of information contained in the bottom layer can be thought of as representing the 'know-how' dimension of knowledge.



Historical mapping

The historical mapping process

While technology roadmapping is a forward-focused approach for considering what steps might be necessary for realising future visions, its basic workshop-based principles have also been adapted for capturing perspectives on historical events to help give context and describe today's starting point. In a pre-workshop activity, six external experts participated in the development of a historical map, based on the Organisation Scan technique developed at the Centre for Technology Management, University of Cambridge.

The focus of this historical mapping exercise was the challenge of integrating intermittent power generation into China's electricity networks. In generating the map, participants sought to answer two questions:

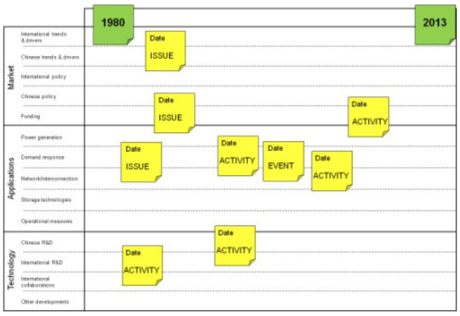
1. What have been significant milestones in the development of China's electricity network?
2. What activities and events have acted as enablers and barriers to the integration of intermittent power generation technologies to date?

A diagram summarising the process of the map's creation is provided in Figure 3.

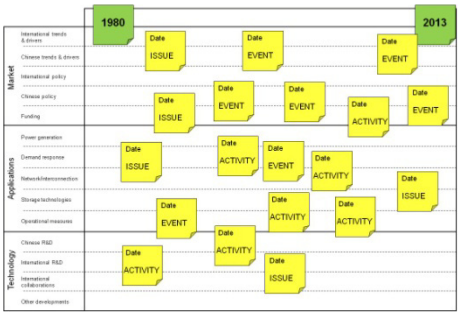
Prior to the workshop a template was created that specified a number of layers for the structuring of data. However, the timeframe for the mapping exercise was unknown so before beginning to generate the map it was first necessary to identify the boundary conditions. These were identified on the day as 1980 and 2013 (Figure 3, top left).

Having specified the timeframe, participants were then given 10 minutes to generate a number of notes answering the two questions above. Once participants had generated their notes, the map began to be built up. This involved going around the table, with one person at a time telling the group about the content of one of their notes and placing it on the map. If others had similar notes then these were also added at the same time. The process then continued to the next person around the table who then described one of their notes until all the notes were placed on the map (Figure 3, top right and bottom left).

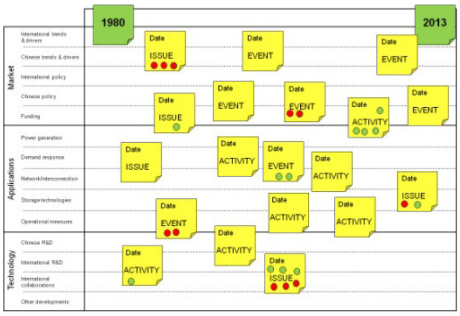
1. The timeframe is established



2. Notes begin to be added to the map



3. The map is completed when all notes are added



4. Votes are made for important enablers (green) and barriers (red)

Figure 3. Summary of the historical mapping process

Following the completion of the map, participants were invited to vote for the items on it that they thought were the most important enablers and barriers. To do this they were given a number of coloured dots with green dots representing votes for important enablers and red dots for important barriers (Figure 3, bottom right).

Results

A digitised version of the historical map is shown in Figures 4-7. This map does not show the result of the voting process. This led to the identification of clear enablers and barriers. A third category was created where there was ambiguity over the nature of the item.

Enablers	Barriers	Mixed views on enablers and barriers
Chinese renewables policy Increasing share of renewables in each Five Year Plan Beijing Olympics changing public perceptions of pollution	China struggles to meet demand Type of installed power generation (coal not gas) Difference in location of new resources (wind, coal) and demand	Chinese participation in WTO Power sector reforms Break up of SPCC and creation of State Grid and regional subsidiaries Debates between power companies and grid over wind power Fukushima disaster Energy trading systems

Table 1. Enablers and barriers to integration of intermittent power generation technologies into China's electricity network

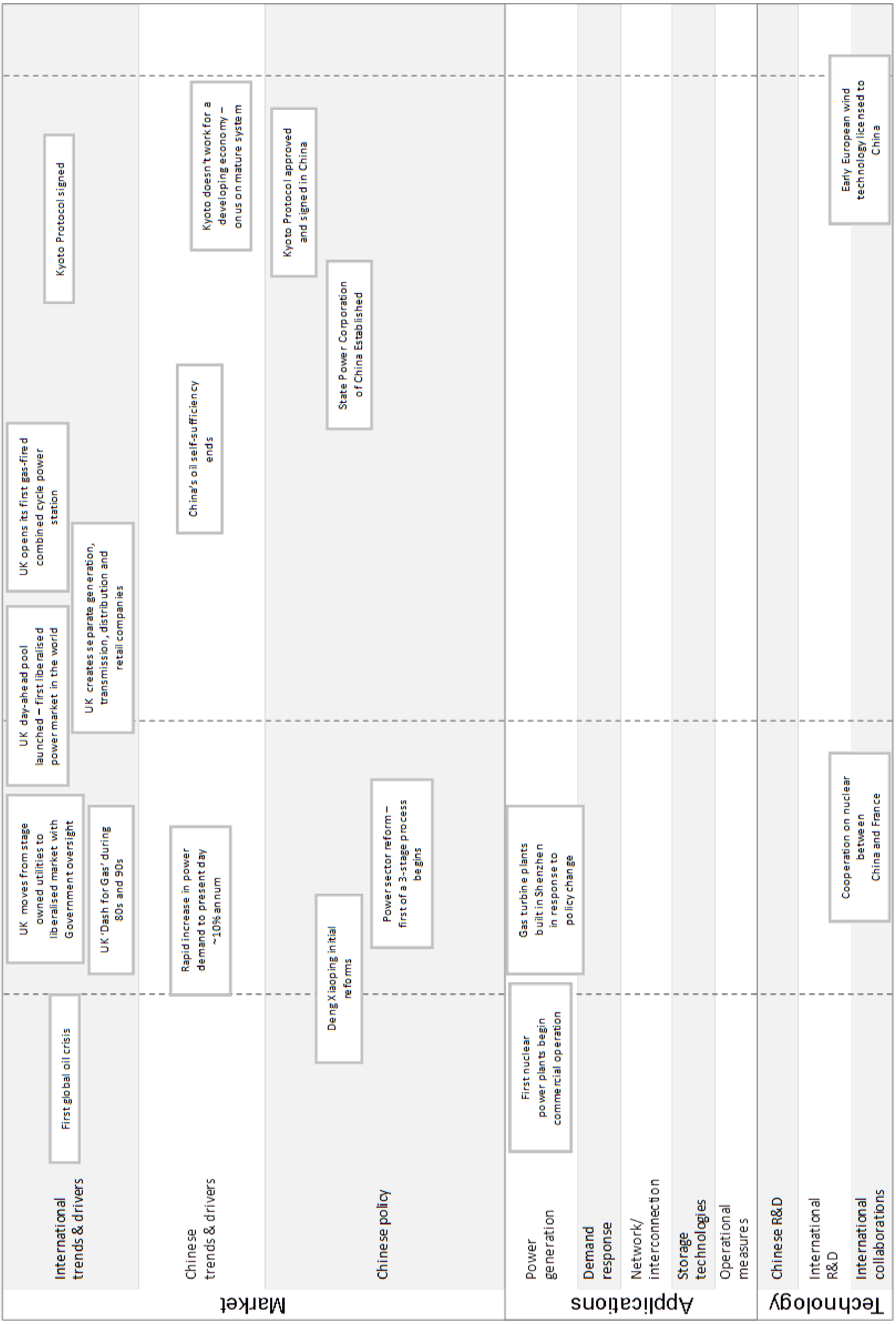


Figure 4. Historical map (1980-2000)

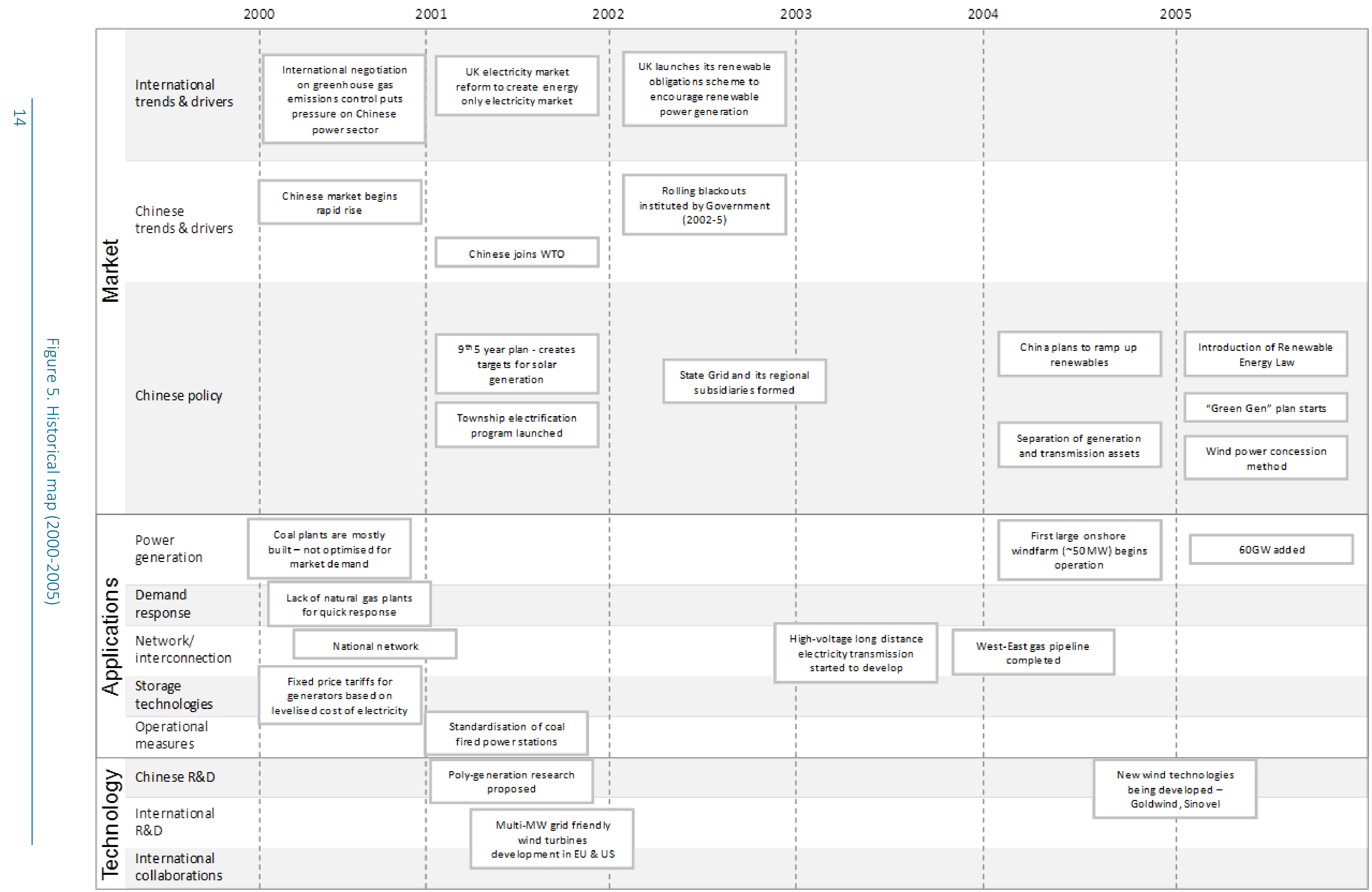


Figure 5. Historical map (2000-2005)

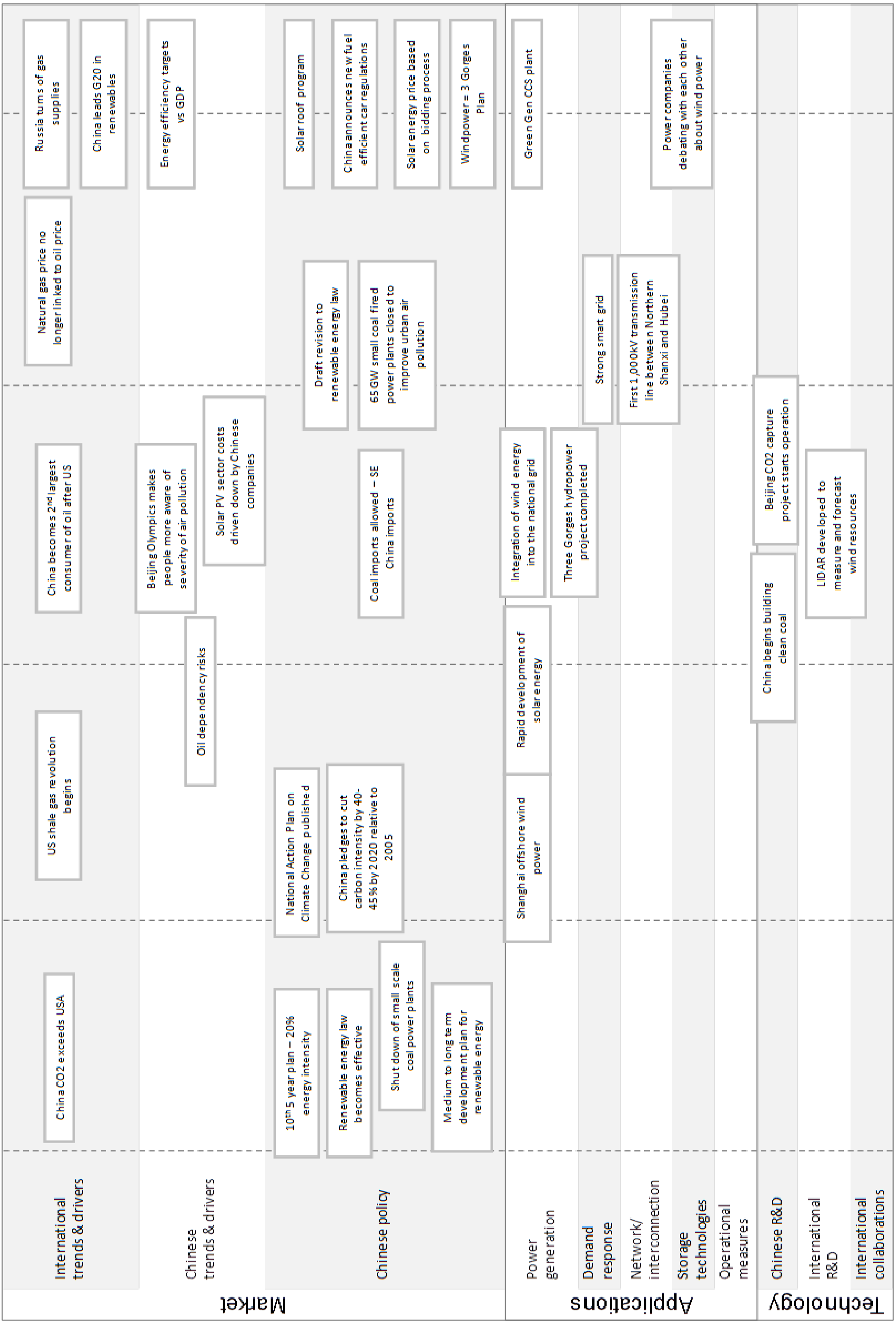


Figure 6. Historical map (2006-2010)

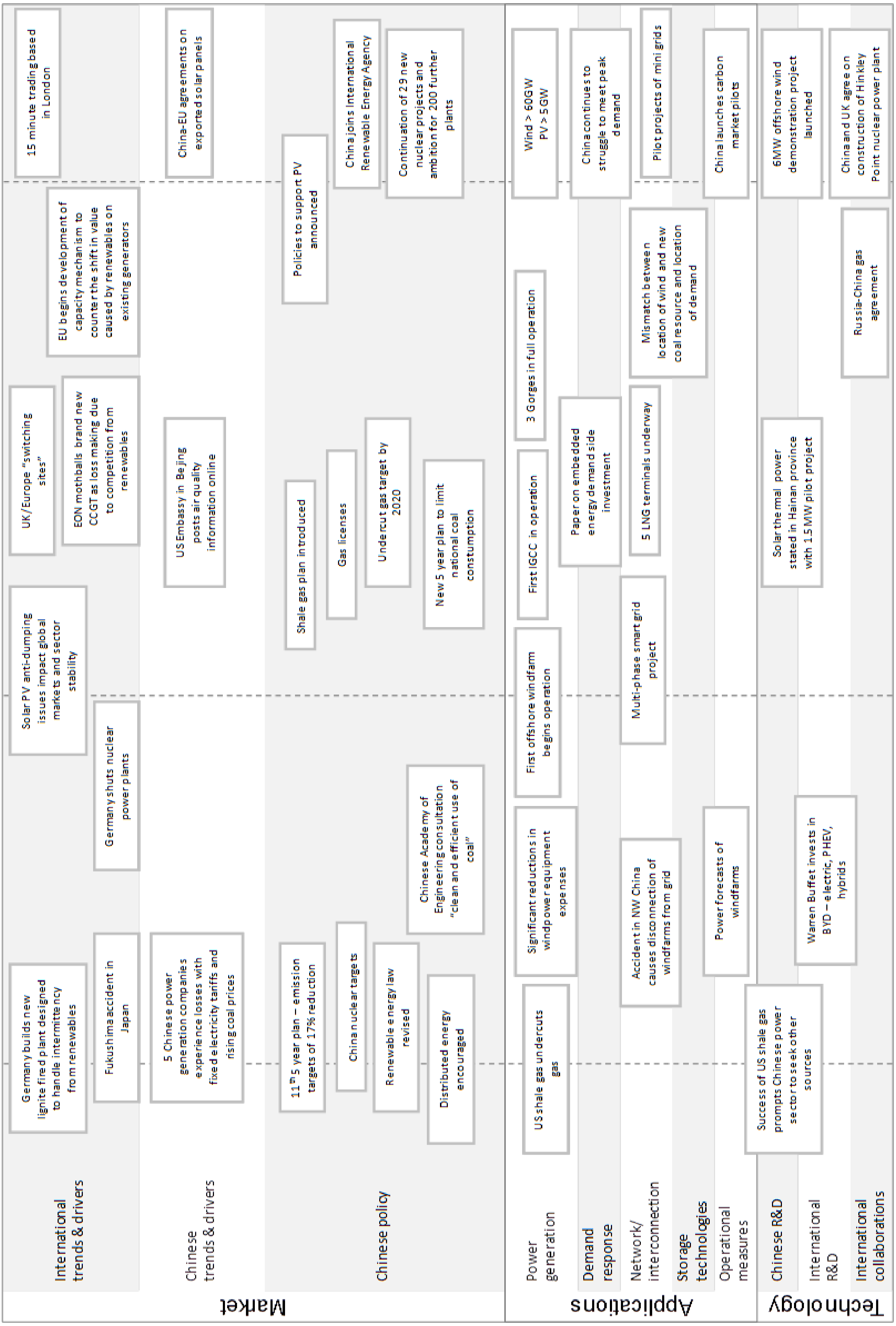
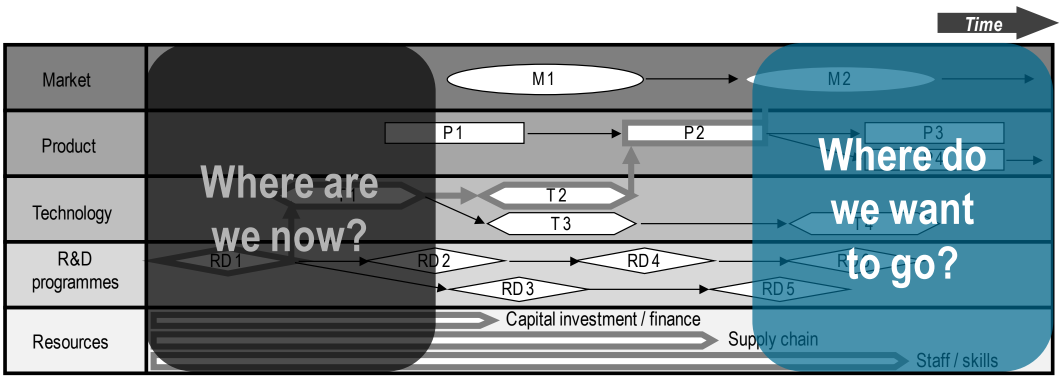


Figure 7. Historical map (2011-2013)



Scenario planning

The scenario planning process

Scenario planning is a technique used to develop a range of possible future outcomes for further analysis. The scenario planning technique was used as part of this workshop because developing a technology roadmap requires the workshop participants to work towards a single vision. By developing multiple scenarios using this process it was then possible for the group to come to agreement on a single scenario that could be used for the technology roadmapping. Had more time been available, it would have been possible to explore other scenarios.

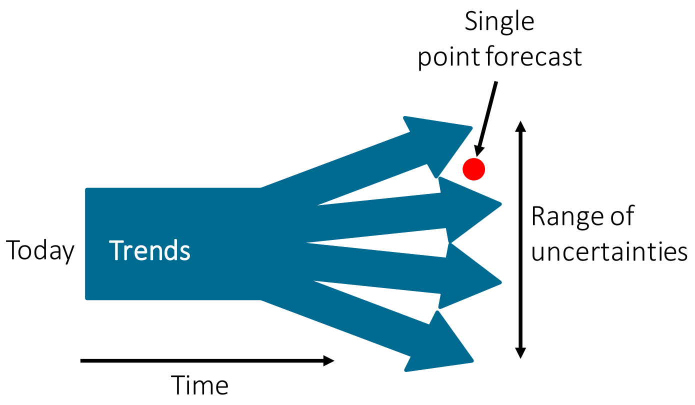


Figure 8. Scenario planning

As with the historical mapping, the first step in the scenario planning process was to identify the date for the scenarios. There was some discussion around this being 2030 or 2050. As there was a desire to explore scenarios in the long-term, consensus formed around 2050 so this was selected.

Four small groups were then formed and then guided through the following stages of the scenario planning process.[2]

[2] The scenario planning process used in the workshop is based on that developed by Peter Schwartz (1997) *The art of the long view: planning for the future in an uncertain world.*

1. Identify the driving forces

   Each group began the process by listing the macro-environmental factors they believed would influence the integration of intermittent power generation into China's electricity network. To support their identification of these factors, participants were introduced to the concept of PESTLE, an acronym that summarises the most common types of drivers: political, economic, social, technological, legal and environmental.

2. Rank each trend or driver in terms of their importance and uncertainty

   This was achieved using a 3-point scale of high (H), medium (M) and low (L). In some cases, groups used further modifiers to discriminate between the listed items (e.g. very high (VH) or very low (VL).

3. Select the scenario logics

   Following the ranking, each group identified two drivers that were ranked high in both categories of importance and uncertainty. These two drivers were then used to establish the axes of a 2x2 matrix, with the ends of each axis representing opposite ends of a scale or spectrum.

4. Identify the implications

   The creation of the 2x2 matrix allowed each group to then identify four different scenarios for 2050. The group considered each of these scenarios and the implications of these conditions for the integration of intermittent power generation.

5. Prepare to feedback to the whole group

   Each group gave a short presentation of their four scenarios to the other workshop participants.

6. Define the vision for the roadmapping session

   Following the presentations from the four groups, participants voted for the scenario that would be taken forward as the "vision" for the roadmapping session.

Results

The following tables show the scenarios developed by the four groups. Of the 16 total scenarios developed, Group D's 'Utopia' scenario was selected for use as the "vision" in the technology roadmapping activity.

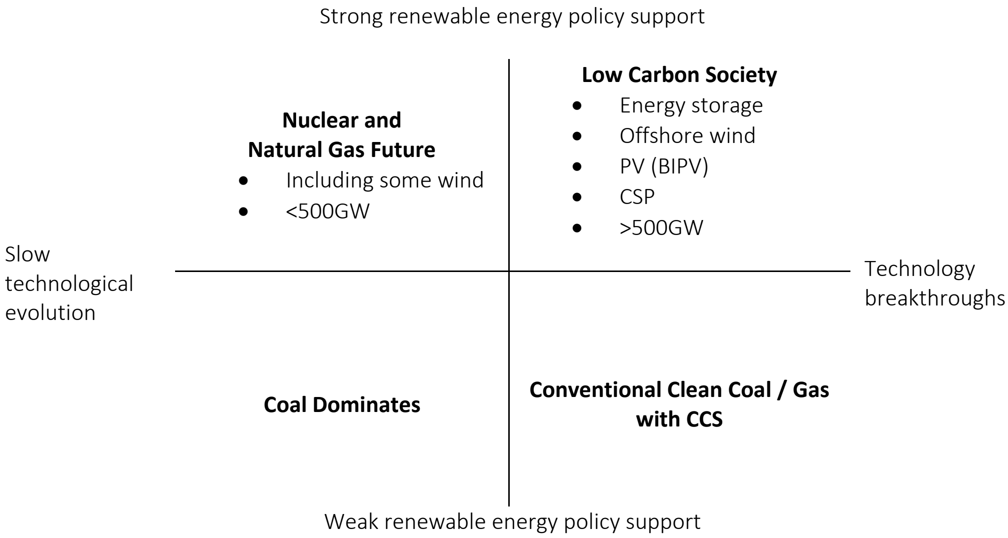


Figure 9. Scenarios developed by Group A

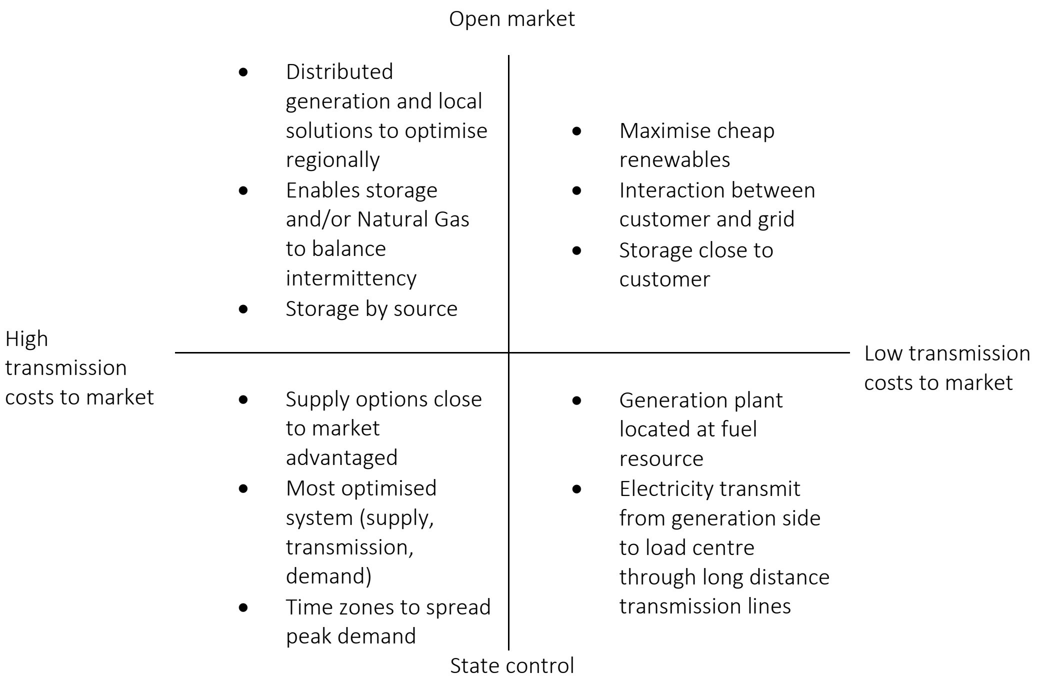


Figure 10. Scenarios developed by Group B

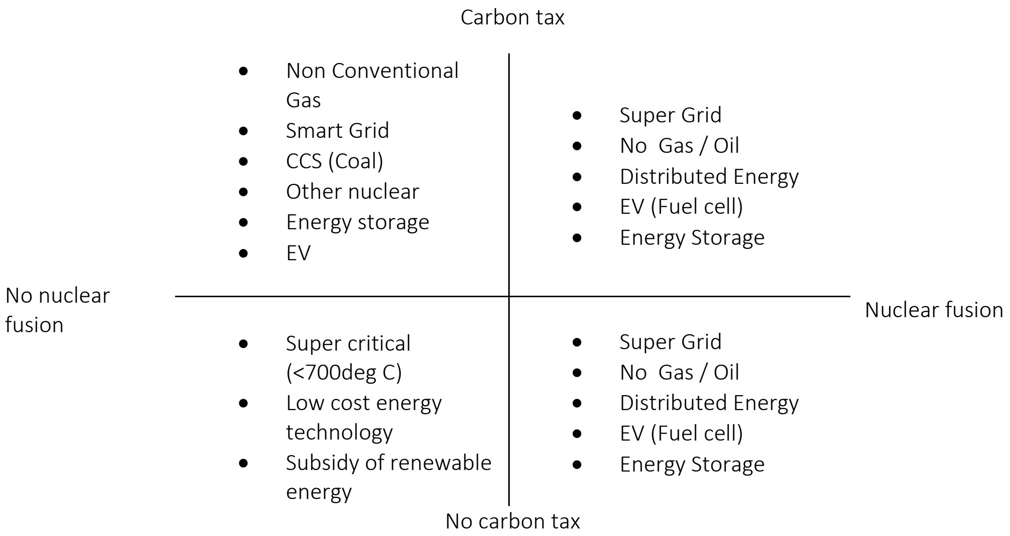


Figure 11. Scenarios developed by Group C

High wealth (GDP/capita)

King Coal

- Low intermittency
- High CO2
- Poor Air Quality
- Invest in long distance grid and transportation
- Coal to methanol
- Coal to liquids
- Constrained water
- CCS, IGSS, USC

Utopia

- Clear Air
- Renewables
- Nuclear
- Gas/Peakers
- Coal
- EVs
- CNG Trucks / Buses
- Smart Grid / Demand Response
- De-regulated markets
- Energy Efficiency
- Storage
- Unconventionals

Low diversity energy sources

Nuclear fusion

Degrading

- Environmental degradation
- Rural population
- Low electricity demand
- Energy sector shrinks
- Low energy efficiency
- Oil in transport
- Regulated markets
- Low intermittency

Energy Security

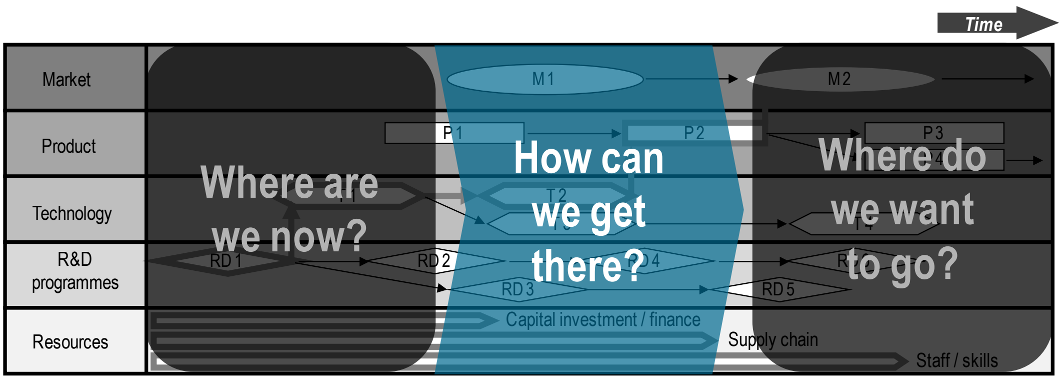
- Energy Price Lower
- Subsidies for renewables
- Good Air Quality
- Reduced Coal Dependency
- Nuclear
- Hydro
- Low coal demand
- Medium Intermittency

Low wealth (GDP/capita)

Figure 12. Scenarios developed by Group D

Expanding upon the 'Utopia' scenario, a spokesperson from Group D described it as follows:

- Characterised by high economic growth and high energy demand
- A wealthier nation demands secure energy supply and has concern for the environment. The energy mix is diversified to guarantee supply and support economic growth
- Carbon, NOx and SOx emissions are at their lowest levels
- To diversify the power sector, ALL renewable resources are accessed. This leads to high intermittency issues that are managed through:
    - Fast responding generation
    - Storage technologies
    - Demand response via smart grids
- Gas and nuclear have a large share of the generation mix
- High Voltage Direct Current (HVDC) allows the transfer of energy over long distances and additional security through international links
- Markets are de-regulated with generation, transmission, distribution and retail companies created
- The transport sector is diversified through biofuels, CNG trucks and buses and EVs



Technology roadmap

The technology roadmapping process

A technology roadmap helps to identify the steps that must be taken to achieve a given scenario or "vision". The process for developing the forward-focused roadmap is very similar to that used for the development of the historical map so these details will not be repeated here.

In this activity, participants were asked to generate notes for steps they thought necessary to achieve the agreed scenario. Once participants had generated these notes, they were added to the roadmap. Each person described one of their notes (with any similar or related notes from others also added at the same time) before going on to the next person around the entire group. This continued until all notes were added.

A voting process was also used for this stage. In this instance the participants were asked to vote for the items they thought were most important for achieving the selected scenario.

Results

A digitised version of the final roadmap is shown in Figures 13-16. The results of the voting process are discussed in the following section.

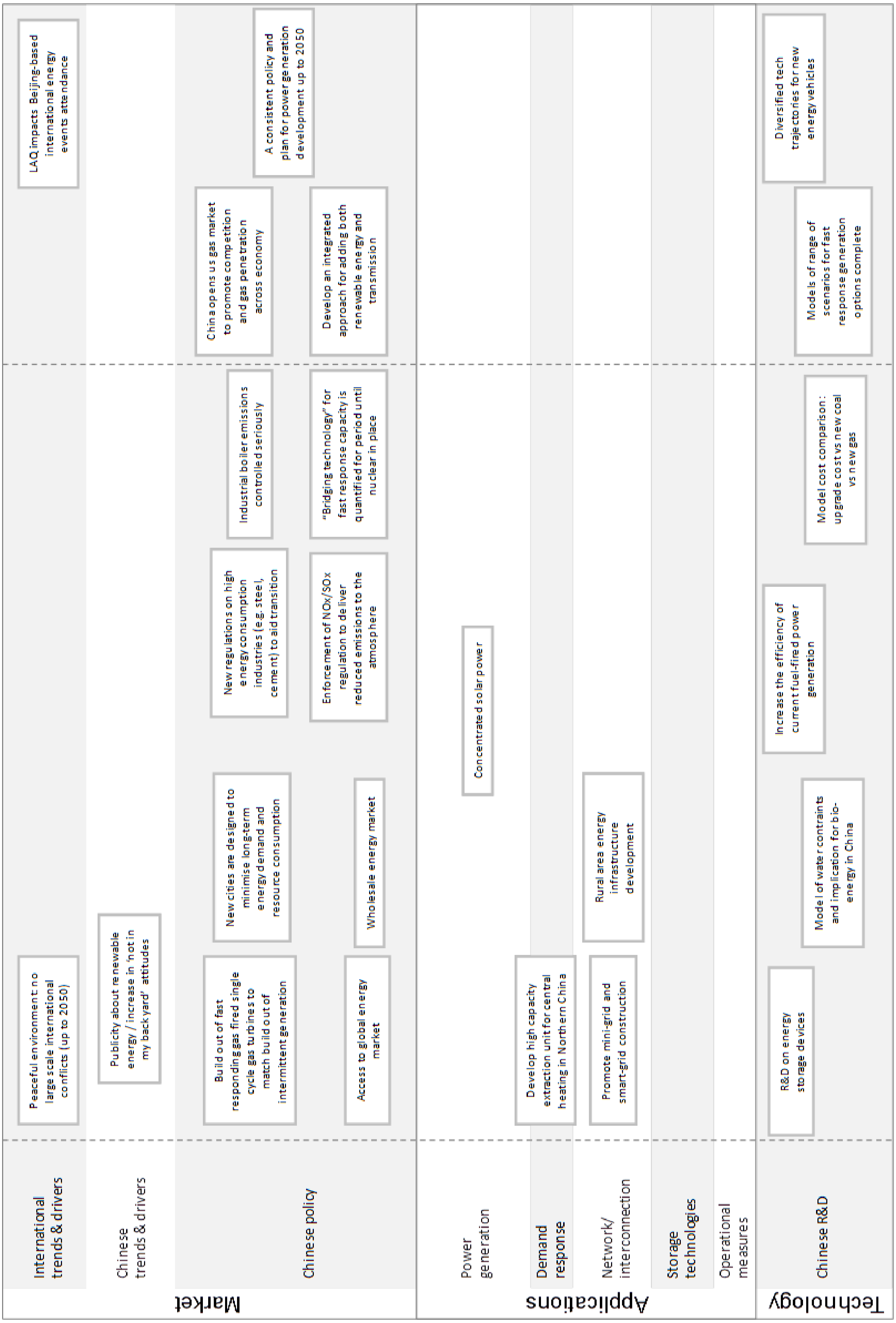


Figure 13. Roadmap towards Scenario D (2013-2015)

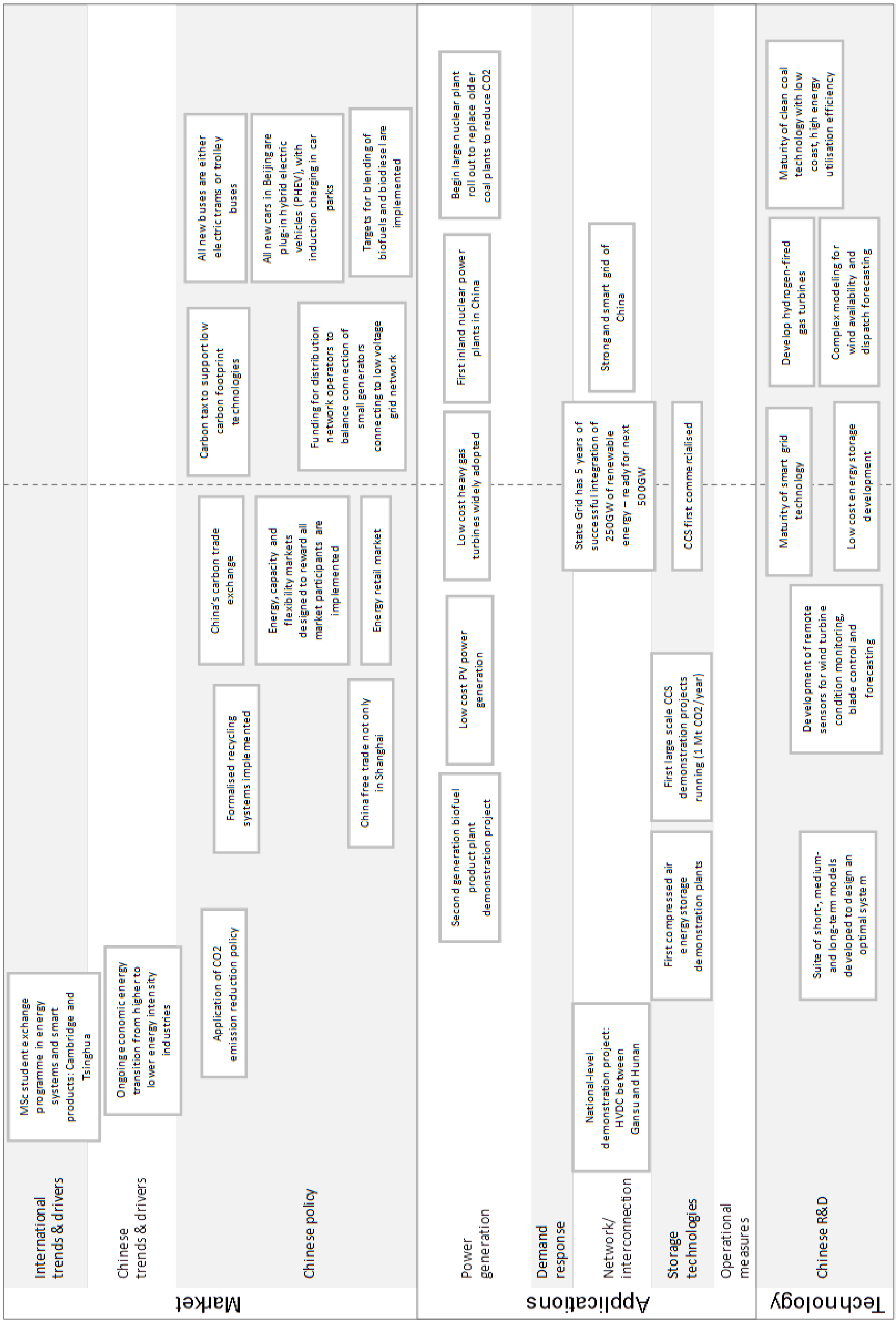


Figure 14. Roadmap towards Scenario D (2015-2020)

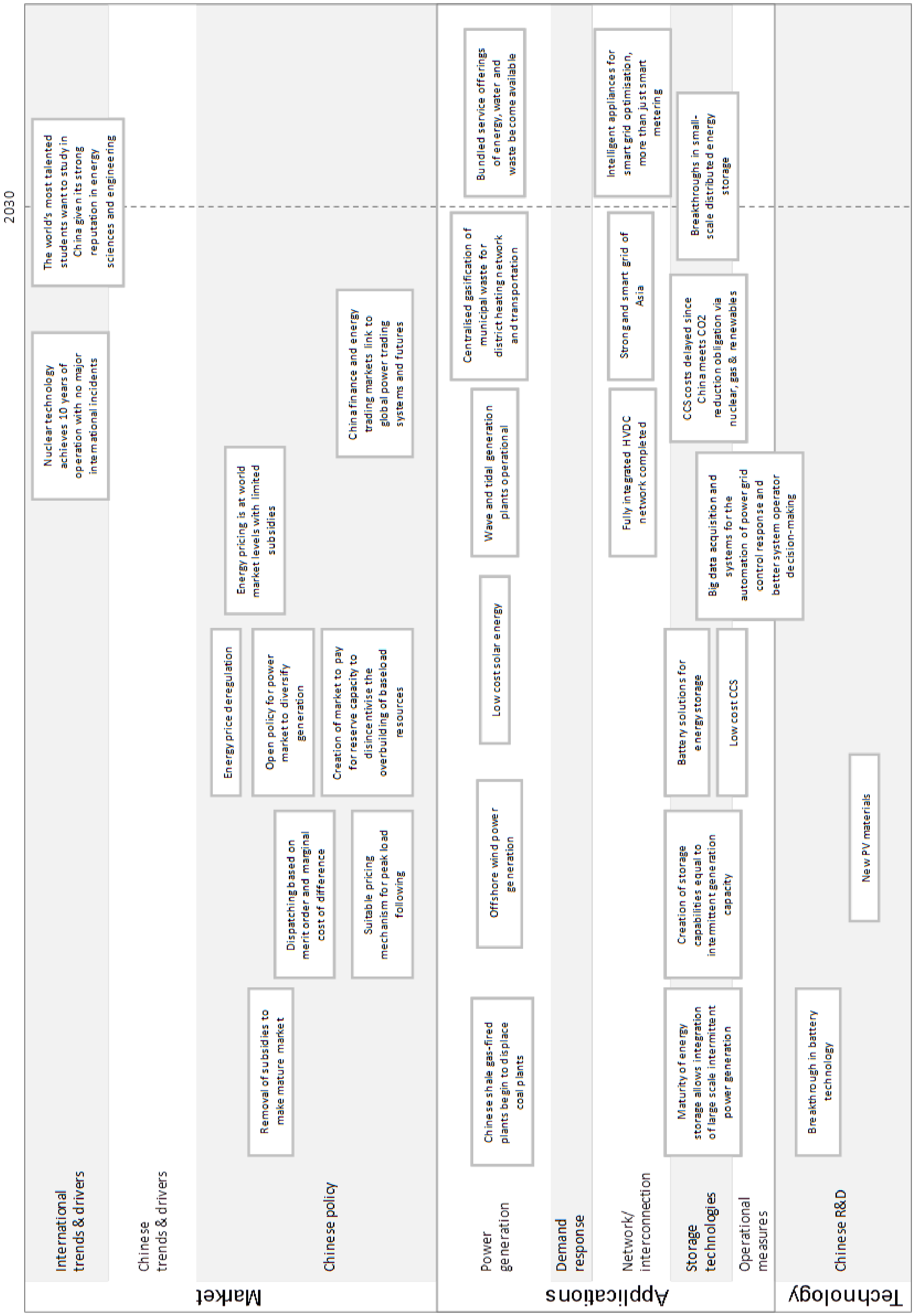


Figure 15. Roadmap towards Scenario D (2020-2030)

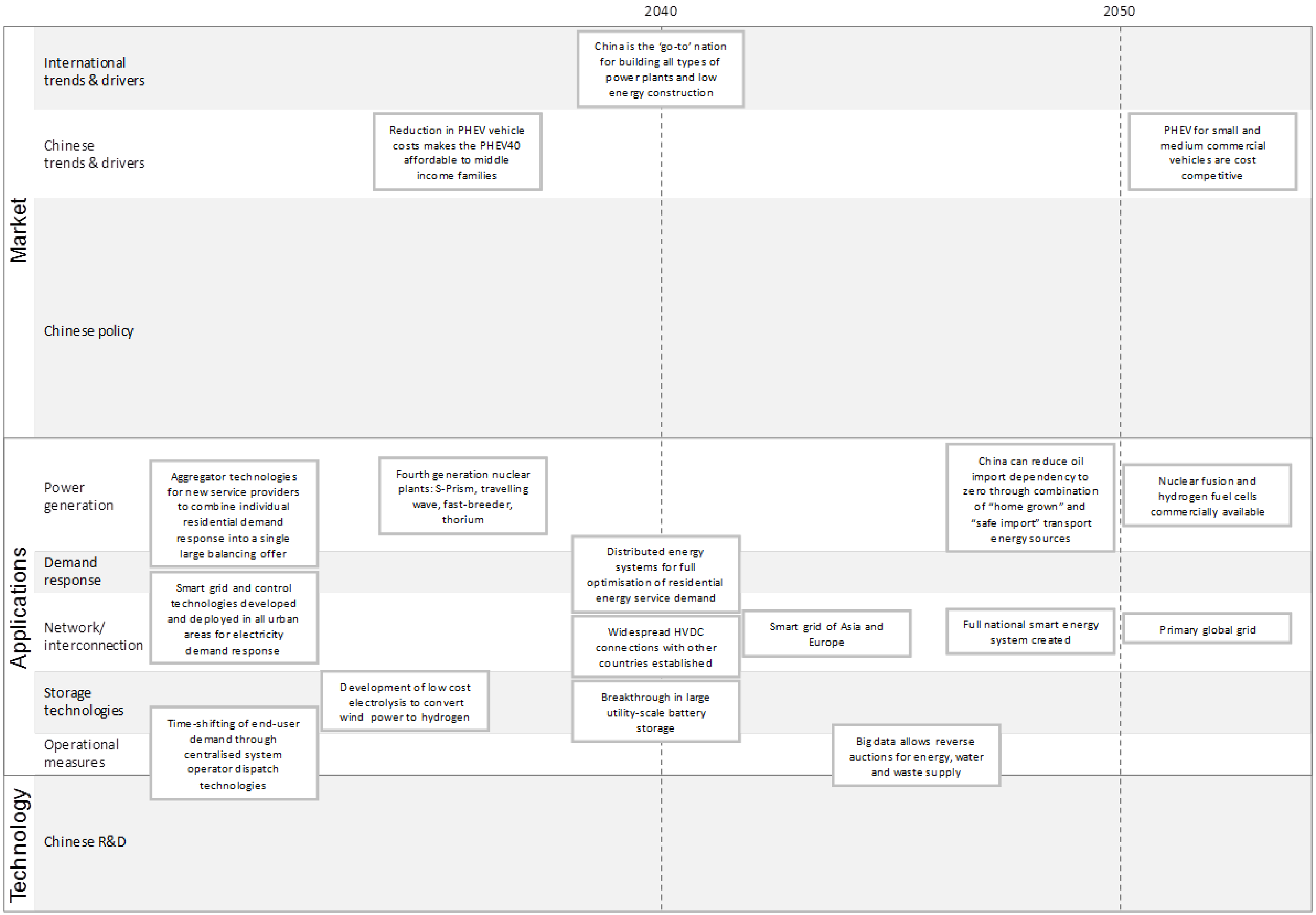


Figure 16. Roadmap towards Scenario D (2030-2050)

Recommendations

The voting process allowed the identification of 13 priority areas. In a post-workshop discussion activity on 23 October, the following actions were identified as necessary to realise the 2050 vision.

Theme	Current situation	Desired situation	Necessary actions
Chinese Renewable Policy	Targets from 9th plan	Consistency in 5 year plans going forward	Integrated approach to planning – generation, transmission & consumption Ambition commensurate with what grid can support & what technologies are available to aid integration
Integration of generation and transmission planning	Generation and transmission plans belong to different departments → risk of misaligned strategy as has happened in US and Europe (and elsewhere)	Single aligned strategy, which increasingly needs to consider the type of demand to be met (e.g. Peak vs off-peak)	Policy recommendation Involvement of key stakeholders in policy and market design
Carbon tax system	Conventional power generation technologies have subsidies Pilots in place to test different options for carbon pricing	Sets an incentive to deliver material reductions in carbon emissions Linkage to international schemes	Review pilot schemes and expand consistently Understand the carbon abatement options and price trigger points (abatement curve)
Energy capacity and flexibility markets	Heavily regulated price tariffs	Deregulated with specific energy, capacity and flexibility pricing mechanisms	Study European experience and develop models to understand impact of large volumes of renewable generation on grid operations

Theme	Current situation	Desired situation	Necessary actions
Fast response gas turbines to match intermittent power generation	No fast response turbines currently installed	Balanced generation portfolio incorporating single cycle turbines to provide necessary system flexibility	China to develop its own gas turbine technology (current alternatives are too expensive relative to coal)
New cities designed for smart & low energy	Urban investment being done as fast and as cheap as possible with little thought for sustainability and future technology integration	Best in class building standards and urban planning	Develop detailed regulations
China shale gas reform	Policies have so far not created effective shale gas exploitation with very limited access by expert technology holders.	Market liberalisation / opening up Access to land Supply chain to raise rig count Seismic studies to identify resource availability	Market liberalised Setting incentives at appropriate levels
Energy price deregulation	Subsidised	Remove subsidies	Controlled transition from state-subsidised system to market-based systems with international linkage Lessons to be learned from European transition, including mistakes
Batteries for energy storage	Early stage demonstration by State Grid Slow technological progress	Successful deployment (by 2030) including smaller scale distributed storage	Realistic evaluation of the potential and timing of battery contribution to storage

Theme	Current situation	Desired situation	Necessary actions
	Large scale utility		
Nuclear fusion	China's participation in the ITER project	International demonstration (2030)	Continue international collaboration
Primary global grid	Limited international linkage (Vietnam)	Increase cross-border trade in power	China itself needs to have a fully integrated grid International trading systems
R&D energy storage (i.e. electricity, heat etc.) devices	Generally limited internationally Major focus on electrical storage	Continue and reward progress	Incentives to encourage R&D and innovation
Smart grid technology maturity	Smart technologies are available but not widely deployed, limited to smart maters	Fully deployed smart electricity grid evolving into wider smart energy grid	Policies and market instruments to incentive smart grid deployment and end-user demand response

Table 2. Recommendations arising from the workshop

Appendices

Appendix A: Workshop participants

Name	Organisation	Workshop role	Scenario planning group
Rosie Albinson	BP	External expert	B
Angelo Amorelli	BP	External expert	A
Simon Ford	CTM, University of Cambridge	Facilitator	N/A
Anna-Marie Greenaway	BP	External expert	B
Huang Bin	Huaneng Group	Chinese expert	C
Ian Jones	BP	External expert	D
Li Bing	National Development and Investment Corporation	Chinese expert	D
Li Zheng	Department of Thermal Engineering, Tsinghua University	Chinese expert	A
Liu Pei	Department of Thermal Engineering, Tsinghua University	Facilitator	N/A
Lu Zongxiang	Department of Electrical Engineering, Tsinghua University	Chinese expert	B
Elliott More	CTM, University of Cambridge	Facilitator	N/A
Qi Cui	EDF	External expert	C
Sun He	NDRC	Chinese expert	C
Jose-Carlos Valle Marcos	EDF	External expert	A
Wang Zhe	Department of Thermal Engineering, Tsinghua University	Chinese expert	D
Aaron Weiner	BP	External expert	B
Xin Yaozhong	State Grid	Chinese expert	D
Yang Jiandao	Shanghai Electrical Group	Chinese expert	A
Zhou Yuan	School of Public Management, Tsinghua University	Chinese expert	C

Appendix B: Roadmapping template

Market	International trends & drivers	
	Chinese trends & drivers	
	International policy	
	Chinese policy	
	Funding	
Applications	Power generation	
	Demand response	
	Network/interconnection	
	Storage technologies	
	Operational measures	
Technology	Chinese R&D	
	International R&D	
	International collaborations	
	Other developments	

Appendix C: Trends & drivers identified during scenario planning

The following four tables list the trends and drivers that were identified by the groups during the first part of the scenario planning process. H, M and L correspond to high, medium and low respectively.

Trends and Drivers	Importance	Uncertainty
Urbanisation	L	L
Climate Change	H	M
Pollution	H	L
Diverse Future Energy Structure/Mix	H	H
Technology Progress – Renewable Energy	H	L
Technology Progress – Conventional	M	L
Technology Progress – Nuclear	L	L
Government Policy for Pollution	H (ST)	L
Government Support for Renewable Energy	H+	M
Public Awareness and Influence	M	M
Global Economic Situation	M	M
Nuclear Acceptability	M	M
CCS Potential in China	L (ST) M(LT)	H
CO2 Price / Tax	H	H
Compatibility between technologies	H	L
Energy Storage	H	H
Power Pricing / Market	M (ST) H(LT)	L

Table 3. Trends & drivers identified by Group A (ST=Short-term, LT=Long-term)

Trends and Drivers	Importance	Uncertainty
Energy price controlled by Government	M	M
Generators take pain	L	M
No capital for investment	M/H	M
Reduce CO2 emissions	M	M
5 Year Plan	H	L
Connect Intermittent to grid	H	H
20% wind not covered	L	M
Small generation	M	M
Ageing population	M	L
Increasing local air quality constraints	H (Beijing)	L
Powerful five year plans	H	L
5YPs are part of LT 50 Year Strategy	H	H
When will the market liberalise	H	M

Table 4. Trends & drivers identified by Group B

Trends and Drivers	Importance	Uncertainty
Nuclear Fusion	VH	VH
PV	M	M
Non Conventional Gas	H	M
Energy Storage	H	M
Smart Grid	H	L
CCS	H	H
Other Nuclear	H	M
Carbon Tax	H	H
Environmental Policy	H	L
Nuclear Social Acceptance	H	H
Urbanisation	H	VL
EV	H	H
Renewable Energy Policy	H	L

Table 5. Trends & drivers identified by Group C (V=Very)

Trends and Drivers	Importance	Uncertainty
Nuclear Fusion	VH	VH
PV	M	M
Non Conventional Gas	H	M
Energy Storage	H	M
Smart Grid	H	L
CCS	H	H
Other Nuclear	H	M
Carbon Tax	H	H
Environmental Policy	H	L
Nuclear Social Acceptance	H	H
Urbanisation	H	VL
EV	H	H
Renewable Energy Policy	H	L

Table 6. Trends & drivers identified by Group D (V=Very)