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Integrating Non-Storable Renewable Energy into the Australian Electricity Industry

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Abstract

This paper presents a framework for analyzing and designing decision-making in the context of an electricity industry or, more broadly, a stationary energy sector. It uses that framework to analyze the approach taken in Australia for preparing for high levels of renewable energy penetration, demonstrating the importance of adopting a systematic approach to this problem and illustrating the outcomes that can be achieved if that is done. The Australian approach has achieved notable successes to date. However, it is a work in progress that is hampered by contested policy-making and the partial privatization of the Australian electricity industry. The paper suggests ways in which further progress could be achieved. These include refinements to wind (and solar) forecasting, enhanced end-user engagement and improvements to gas industry arrangements and electricity-gas compatibility.

1. Introduction

Non-storable renewable energy resources such as solar and wind energy are seen as important contributors to addressing concerns about climate change and/or fossil fuel price or availability. However, solar and wind energy resources are also rapidly varying, stochastic, distributed energy fluxes that introduce new issues for electricity industry design and operation, which have traditionally assumed that primary energy resources are storable. Thus the new environmental objectives may conflict with traditional objectives such as reliability of supply. Moreover, policies to promote renewable energy are innovative and their effects may be uncertain [25]. Hence the question of how to integrate non-storable renewable energy resources into electricity industries is currently receiving much international attention [1, 2, 3, 4, 5, 6].

When considering the complex innovation challenges involved in renewable energy integration, we should approach issues in a consistent and integrated fashion from a range of perspectives, including power system engineering, economics (including market design) and policy-making for the electricity industry (including both supply and demand sides) and for the stationary energy sector as a whole.

This is because we need to consider the broad context in which other (supply or demand side) energy resources can compensate for the variability of renewable energy fluxes. In some instances, the transport sector may also become relevant, for example to investigate the potential role of electric vehicles or joint use of biomass for transport fuels and electricity generation.

This paper first presents a systematic methodology for organizing consideration of this broad set of issues and then uses that methodology to assess Australian progress to date and future prospects in preparing for high levels of renewable energy penetration.

2. A decision-making framework for an electricity industry

An electricity industry consists of a supply side (an electric power system that converts a range of primary and energy resources into a flow of electrical energy) and a demand side (end-use equipment that converts the flow of electrical energy into end-use energy forms with associated end-use energy services that are valued by end-users).

Underlying the electricity industry is a complex technological system [7, 8] that implements the energy conversion chain. We may analyze its characteristics by adopting the concept that technology consists of hardware (items of equipment), software (technical knowledge) and orgware (institutional context) [7, 8].

The electricity industry hardware comprises a set of interconnected equipment components that implements an energy conversion chain. The industry components perform various functions such as energy conversion, energy flow and reversible energy storage, and are in turn manufactured and assembled using other components. They may be designed, constructed and operated by a wide range of actors and a further set of actors may be involved in design and oversight of the industry. All actors require appropriate software (technical knowledge) to undertake their particular tasks and should operate within an appropriate institutional context (orgware).

The orgware organizes the decisions taken by this large set of actors by formal and informal means. The formal means consists of rules and regulations that derive their authority from legislation at national and/or state level. The informal means consist of the culture of a particular electricity industry, international norms and broader community culture. They also influence design, manufacturing, operating and investment decision-making.

To analyse the formal rules or the informal culture, or to propose modifications to them, we may use the concept of a decision-making framework [1, 9] as set out in Table 1. Such a decision-making framework can assist in understanding the processes that coordinate, to varying degrees of succcess, the decisions of the multitude of actors involved in technology innovation, deployment and use in an electricity industry. An electricity industry decision-making framework sits within a broader societal context as illustrated in Figure 1 [8], which helps to illuminate the informal aspects of orgware. The boundary of an electricity industry is ambiguous, for example with respect to primary energy resources or equipment design and manufacture.

As indicated in Table 1, decision-making can be characterized as being undertaken in a set of regimes – governance, commercial, security and technical – each of which have important but distinct roles to play in delivering sound industry outcomes. The decision-making regimes should be actively designed and their performance monitored. Moreover, there are important interfaces between the different regimes that should also be designed and monitored to minimize the risk of poor industry outcomes.

3. Decision-making frameworks for the stationary energy sector

3.1. Motivation for a stationary energy sector perspective

When considering the integration of non-storable renewable energy resources, which may be promoted by climate change policy, the role of complementary energy resources must also be considered. These include storable primary energy resources such as hydro or natural gas, reversible energy storage and flexible end-use energy services.

Some complementary resources such as hydro or flexible end-use services lie within the ambit of a typically defined electricity industry, while others introduce links to what are usually regarded as separate industries (eg natural gas).

Moreover, when new technologies such as wind turbines or photovoltaic systems are being introduced to an electricity industry, the designers of those new technologies may not yet have been initiated into the formal or informal orgware and software associated with an electricity industry. This can create mismatches in performance expectations, for example with respect to “fault ride through” or “islanding”. Over time, expectations may change, for example with respect to the electricity demand drawn by residential appliances in “stand-by” mode.

Table 1. Decision-making framework for an electricity industry [1, 9]

Regime	Role
Governance regime	The set of formal institutions, legislation and policies that provide the framework in which a competitive electricity industry operates. This includes the formal regulatory arrangements for industry participants as well as the broader social context in which the industry operates. It may involve more than one jurisdiction. A desire to reduce the environmental impacts of electricity industries has added new complexity to the governance regime, because environmental objectives may conflict with traditional objectives like reliability of supply.
Commercial regime	The commercial arrangements for an electricity industry. This may include spot and derivative markets for electrical energy as well as ancillary service markets and commercial interfaces for regulated industry participants, such as network service providers.
Technical regime	The set of rules that allow the various components of an electricity industry, when connected together, to function effectively as a single machine, providing a continuous flow of electrical energy of appropriate availability and quality between generation and end-use equipment, rejecting disturbances and degrading gracefully if equipment faults occur.
Security regime	The task, assigned to one or more system operators, of maintaining short-term integrity of a local or the industry-wide core of an electricity industry in the face of threats posed by plausible large disturbances. The security regime typically has authority to restrict and, if necessary, override the commercial regime in defined circumstances. For example, it may direct participants to operate their components at specified levels and, under defined circumstances, disconnect components.

To ensure consistency, it is desirable to establish an analytical frame that is sufficiently broad to encompass all relevant issues, which may imply broadening its scope to the stationary energy sector as in Figure 2 [8] or beyond [1]. For example, international trade treaties may become relevant and the transport sector would have to be included if a significant role for electric vehicles was under consideration.

It seems unlikely that many if any countries have yet implemented decision-making frameworks that recognize issues of the scope and complexity as we now face due important but unidentified interactions between different technological systems. In particular, decision-makers may exploit unintended arbitrage opportunities between different commercial regimes. As a result, decision-making may become inefficient and/or unstable.

3.2. Decision-making framework for the stationary energy sector in Australia

Table 2, based on [7], summarizes the decision-making framework for the Australian stationary energy sector. The intent of this framework is to provide consistency across the stationary energy sector and uniformity between Australian jurisdictions.

The framework is still a work in progress that has evolved from a predominantly state-owned industry structure in which gas and electricity were usually separately implemented and regulated. Important on-going tasks include effective and efficient engagement of end-users, resolution of state-ownership issues. Climate change policies could apply solely within the framework, extend its scope to other activities in Australia, or even broader if international offsets were permitted. In such cases, commercial activities should not be permitted beyond governance regime ambit.

4. Renewable energy integration in the Australian context

4.1. History of renewable energy integration in Australia

Australia, like many other countries, is in the process of integrating renewable energy into its electricity industry. As in most countries, wind energy has been the first non-storable renewable energy resource to raise practical issues of renewable energy integration, particularly in South Australia.

Perhaps uniquely, the Australian National Electricity Market (NEM) was designed from the outset to accommodate renewable energy resources. In particular, the electricity market design concepts introduced in [10, 11] and incorporated into the Australian NEM design, were partly motivated by an expectation of "increasing exploitation of distributed renewable resources, such as wind, solar and small hydro, often by independent groups that wish to sell excess power to utilities and buy back-up power when needed" [11].

Table 2. Decision-making framework for the Australian Stationary Energy Sector

Regime	Implementation
Governance regime	• Organized under the Council of Australian Governments, which coordinates legislation and policies at Federal and State levels • Implemented by the Australian Energy Regulator and the Australian Energy Market Commission, which have authority across all jurisdictions to develop and regulate industry rules of stationary energy sector scope. • Consistent, market-compatible regulation of transmission & distribution network services • Supplemented by climate-change policies intended to reduce climate change emissions
Commercial regimes	• Defined by National Electricity and Gas Rules, with the policy intent of achieving consistency between electricity and gas and uniformity between jurisdictions • Designed with the policy intent of achieving efficiency and effectiveness from short-term operation to long-term investment. • National Electricity and Gas Markets implemented by the Australian Energy Market Operator (AEMO) from July 2009 • Environmental externalities addressed in market-compatible fashion, for example via tradable renewable energy certificates.
Technical regime	• Governed by National Electricity and Gas Rules and managed by AEMO and network service providers • Linked to National and International Technical Standards
Security regime	• Organized under the Council of Australian Governments • Governed by National Electricity and Gas Rules and managed by AEMO and network service providers

In a report undertaken for the Australian government in 2003, [12], Outhred reviewed the ability of the NEM design to accept high levels of wind energy penetration. This report concluded that effective operating strategies could be devised to cope with a high level of wind energy penetration, provided that:

- The wind farms were installed in a progressive manner over a period of about 10 years;
- The wind farms were widely and evenly dispersed within the NEM and, where necessary, local voltage or network flow constraints were overcome;
- The wind farms used advanced wind turbine technology, such as DFIG or alternator technology and advanced wind farm control

systems that allowed the wind farm output to be remotely monitored and controlled; and
- Advanced wind forecasting techniques were developed and used to predict the future behavior of wind farms and groups of wind farms, and in particular to accurately predict significant changes in the output of regional groups of wind farms up to two days in advance.

Outhred recommended the following policy options [12]:

- Integrated regional wind development strategies should be developed, which systematically take into account resource distribution, land use issues, turbine technology and network connection requirements, network voltage and flow constraints, and other planning issues.
- Advanced wind forecasting techniques should be developed to predict the future behavior of wind farms and groups of wind farms, and in particular to accurately predict significant changes in the output of regional groups of wind farms up to two days in advance.

Also in 2003, the Electricity Supply Industry Planning Council of South Australia (ESIPC) undertook a high-level assessment of wind integration issues in that State [13]. It found no significant correlation between electricity demand and wind speed and concluded, “an estimated 8% or the installed capacity of the wind farms could be statistically firm”.

In a later (2005) study [14], ESIPC:

- Reviewed the technical capabilities of the wind turbines and the connection arrangements with the South Australian network service providers, concluding “that the combination of improving machine types and the commendably high quality of network agreements delivers adequate assurances that power quality will not be adversely affected by increased levels of wind generation”.
- Concluded, “wind generators seeking to connect should comply with clearer and more appropriate technical standards” that are “updated to reflect emerging world’s best practice”.
- Concluded, “the security and reliability of the power system with up to 500 MW of wind generation in South Australia should be maintained provided there is attention given to particular and rare situations”. “With higher levels of wind generation, we need to introduce state of the art forecasting”.

As reported in [14], COAG established a Wind Energy Policy Working Group (WEPWG) in mid 2004 to consider the range of policy level issues associated with the anticipated entry of large amounts of wind generation into the National Electricity Market in the coming years. In turn, WEPWG requested that National Electricity Market Management Company (NEMMCO) establish the Wind Energy Technical Advisory Group (WETAG), consisting of industry participants, to assist the WEPWG with the analysis of technical and policy aspects of wind penetration in the National Electricity Market.

WETAG identified a number of key tasks [14, 15]:

- Review technical standards for grid connection.
- Manage the impact of “intermittent generation” on network flows,
- Investigate wind-farm behavior in respect of power system operational implications
- Require appropriate information disclosure, and
- Review cost recovery for Regulation Frequency Control Ancillary Services.

NEMMCO itself undertook a series of investigations into renewable energy integration. Significant issues identified in [16] were forecasting, frequency control ancillary services and network management and connection issues. In [17], NEMMCO reported on the issue of forecasting and recommended that steps be taken to create a forecasting capability with associated obligations on wind farm owners to contribute.

The Australian Government accepted the various recommendations on forecasting and funded NEMMCO to specify and implement an Australian Wind Energy Forecasting System (AWEFS), which is now fully integrated into the security and commercial decision-making regimes in the Australian National Electricity Market.

AWEFS has a set of forecasting horizons from five minutes to two years and draws on SCADA information from all transmission-level wind farms connected to the Australian National Electricity Market. Amongst other functions, AWEFS will support recently implemented “semi-scheduled” arrangements, whereby wind farms will be required to participate in the dispatch process if an associated network flow constraint appears likely to bind. As a result of these developments, the Essential Services Commission of South Australia proposed to withdraw its 2005 requirement for wind farms greatly than 30 MW rating to be classified as scheduled generators [27]. See www.aemo.com.au/electricityops/awefs.html for more information on AWEFS.

Further research is underway to ensure that AWEFS has adequate capacity to forecast large, rapid changes in aggregated wind farm output, eg. [18]. AWEFS will also be used to forecast other renewable energy resources, such as solar energy, when justified by their level of penetration.

Photovoltaic (PV) systems are becoming increasingly important in Australia although at a much lower penetration level than wind energy. In [19], Passey et al report on a study for Western Australia (WA), concluding, “the present values earned by PV in offsetting conventional baseload and peaking generation are significant compared to its installed cost in WA. They are most strongly influenced by the insolation profile and largely independent of where the PV is located on the grid. In contrast, the present values earned by PV in deferring network augmentation and reducing line losses on the WA ‘main grid’ are very low compared to its installed cost and are very site specific”.

4.2. The current state of play

The situation in South Australia was reviewed in the ESIPC Annual Planning Reports of 2008 [20] and 2009 [28]. The 2008 report [20] states that analysis of wind farm data “indicates that the total variability from all of the wind farms is less severe than predicted”. This is consistent with the prediction of [12].

Thorncraft et al [21] presents the results of simulation studies as well as reviewing the actual effect of increasing wind energy penetration on frequency control ancillary service markets in the NEM (timescale less than 30 minutes). These studies suggest that the short-term operational impacts are of the order of \$5/MWh or 0.5 c/kWh, comparable with the results quoted in [2] for Europe and North America. In the Australian case, \$5/MWh represents about 10% of the average wholesale price and about 5% of a typical retail price for electricity.

With respect to potential network flow constraints in South Australia, [20] notes “swings in power flows as a result of the variation in output from individual wind farms that appear minor for the State as a whole may have as yet unforeseen impacts on individual network elements”, while [28] notes “further development of wind in South Australia will, however, require significant investment in networks”. This is because power systems compensate for variations in the outputs of generators by corresponding fluctuations in flow patterns in the network [12].

With respect to wind-demand correlation, [20] notes “contribution [of wind energy] at the actual time of peak demand [in March 2008] was… limited on all but a few occasions”. The weather conditions in the main population regions of South Australia are such that still days can also be very hot with high electricity demand [28].

With respect to greenhouse emissions, [28] notes “reduced emissions in the last couple of years reflect the increasing contribution of wind generation and reduced imports”.

Table 3, based on information from slide 42 of the presentation associated with [20] augmented by recent research at UNSW [22], compares the prices achieved by South Australian wind farms with other South Australian generators, noting that wind farms can also receive income from selling Renewable Energy Certificates or from other “clean energy” support schemes.

Table 3 shows that wind farms earn less from electricity sales than other generators and that they are earning relatively less as wind penetration has increased. This indicates that the NEM design is providing an intuitively correct response to rising wind farm penetration – declining market value for wind farms as penetration increases and increasing market value assigned to complementary, flexible resources. The trend is likely to continue, as there are plans to build many more wind farms in South Australia [20].

This outcome follows from the NEM energy-only market design and was foreshadowed in [12]. As indicated in [12], a more even distribution of wind farms among Australian NEM regions may deliver a better commercial outcome for individual wind farm owners. It may also provide a better economic outcome for the community as a whole. However, this conclusion is subject to consideration of other issues, such as wind resources, project approval requirements, grid connection costs and network flow constraints.

Table 3. Volume-weighted prices in the South Australian Region of the NEM for wind farms and other generators [20, 22]

Year	Volume-weighted average price for SA wind farms, \$/MWh		Volume-weighted average price for other SA generators, \$/MWh	
	Full year	Summer	Full year	Summer
July 04-June 05	NA	NA	39.3	32.6
July 05-June 06	32.6	39.6	43.9	67.5
July 06-June 07	49.7	51.6	58.7	67.2
July 07-June 08	63.3	63.9	102	150
July 08-June 09	46.7	NA	70.5	165

With respect to environmental issues, the Australian Government recently increased the target for its existing Renewable Energy Target Scheme (RET) and plans to introduce a Carbon Pollution Reduction Scheme (CPRS). In 2008, CRA International reviewed the expected impact of these policies on reliability of electricity supply in the NEM, concluding [23]:

- The theoretical design of an energy-only market should be able to accommodate and adapt to the changes that a CPRS and RET will bring and ensure that there will be sufficient revenues to support investment to meet the long-term reliability standard in the NEM. However, this requires that investors take a long-term view of potential revenues and have good knowledge and confidence about a range of future conditions;
- The CPRS and MRET will lead to dramatic changes in the generation technology mix in a relatively short time. There is a risk that the uncertainty created by the rate of change may be too short or beyond the capacity of the overall NEM design to respond without significant short-term fluctuations in national and regional unserved energy;
- Management of supply reliability within a day may also be affected. The characteristics of the future technology mix may invalidate the presumption that market participants will deliver sufficient "standby reserve" beyond the time for which the National Electricity Market Management Company (NEMMCO) directly manages system security (using ancillary services and mandatory technical standards). In particular, wind output is intermittent and requires that other controllable plant be installed and available in a "standby" mode to operate when needed. It is not clear that market incentives in the current design will ensure sufficient short- term standby reserve will be present, especially during the transition to a CPRS regime. Further study is recommended and, if appropriate, consideration of alternative standby reserve mechanisms;
- Reliability outcomes were very sensitive to the price cap in the energy spot market. This result is consistent with previous analysis for the Reliability Panel. The results reaffirm that the then spot market price cap ($10,000/MWh without indexing, about 200 times the average wholesale market price) is unlikely to allow sufficient investment to meet the NEM reliability standard in the future. The studies also showed that (subject to the caveats concerning investor behaviors) the recently increased price cap of $12,500/MWh (about 250 times the average wholesale price) if incremented over time at the assumed inflation rate as measured by the Consumer Price Index (CPI), has the potential to support sufficient investment to meet the reliability standard. The Reliability Panel has previously noted that a number of factors need to be taken into account in setting a recommended price cap, including the effects on financial risk, and these remain; and
- If demand elasticity and the timing, availability and cost of new technologies can be forecast sufficiently far in advance, the market will adapt and offer revenue for new investment to meet reliability standard. These factors made little difference to results for reliability in the long run, but had significant effects on the technology mix and market prices.

CRA International also noted "The NEM energy-only design expects that investors will take a long term view. We would expect that, in the circumstances, some investors may seek a 'first mover' advantage and discount the risk and make early investments, while others may act more conservatively and discount the potential revenues and delay investment. Therefore, there will be increased variability in outcomes and increased risk that market incentives will not be sufficient to drive investment in the locations and at the times needed to ensure the reliability standard is met" [23].

In a recent paper [24], Bowker considered the following objectives to be important for high levels of renewable energy penetration in the Australian electricity industry:

- Maintenance of security and efficiency in the market with high levels of renewables;
- Adequacy of the ancillary services market arrangements in this context;
- Achievement of efficient transmission investment for remote renewable generation; and
- Safeguarding of investor confidence to ensure sufficient new generation is built to deliver system reliability.

After reviewing the design features of the existing electricity industry framework for the Australian National Electricity Market, Bowker concluded [24]:

- "System security needs to be managed in the light of the variability of wind and some other renewables. In the NEM this is achieved by providing a dispatch cap to wind farms which represent a maximum dispatch for them for the 5 minute dispatch interval. This provides an automated and robust basis for limiting wind when there are system security concerns. The market and system operator has implemented a sophisticated wind forecasting system to reduce the impact of the intermittency of wind";

- "The NEM uses co-optimisation between energy and ancillary services to provide the lowest cost dispatch. In some circumstances a generator must reduce its energy output to provide raise ancillary services. The dispatch engine will balance off the increase in energy cost with the reduction in ancillary services costs. The spot ancillary service markets are one-sided markets in that the market operator procures services and recovers its costs from market participants in accordance with cost allocation provisions within the market rules. Cost allocation is currently based on energy output/consumption. With more variable renewable generation, the question of whether this is a good basis for charging needs to be raised. In general, renewables are currently poor providers of ancillary services. The market may drive technology developments to allow them to provide these services or they may find it more economic to be a net purchaser."
- "The RET scheme will cause around half of all new generation to 2020 to be renewable for the target to be met. This will cause a major increase in new transmission. The NEM rules are based around incremental growth and there are reviews underway to ensure this change delivers economically efficient solutions. One particular weakness in the current rules concerns the development of hubs. If there is a good resource of renewable energy at some location remote from existing transmission, the rules do not facilitate developers getting together to build a single large transmission line. There is a danger that multiple small lines will be built."
- "With the advent of new transmission connecting to the existing shared network there is a strong likelihood of more congestion. The challenge here is to provide good price signals to a new generator to ensure its generation is located efficiently. The incumbent is unable to move his plant so some form of compensation may well be appropriate. A proposal of contractually allocating available capacity has been proposed but has several implementation difficulties."
- "Continuing on the theme of the point above, in a purely administrative process, there is a requirement for each application to be progressed bilaterally between the applicant and network service provider. Confidentiality provisions seriously inhibit the ability of network businesses to coordinate applications. This may not be the most efficient way of managing significant growth which is already underway in the planning stage. Possible approaches such as an open season or other ways of combining applications are under consideration".

Bowker [24] also noted the importance of investor confidence to maintaining reliability of supply in a competitive electricity industry and refers to "the existence in Australia of a sound governance structure for the management and evolution of the [National Electricity] market".

Kann [25] considered the issue of wind farm investor confidence from a project finance perspective. He identified key barriers as being regulatory risk, semi-privatization of New South Wales electricity retailers and capital availability following the global financial crisis. He noted that some wind farm developers had responded by formulating strategies involving corporate rather than project finance, "develop and delay", "develop and sell" or joint development with stronger financial partners.

The Australian Energy Market Commission (AEMC) is conducting a comprehensive review of energy (electricity and gas) market frameworks in light of climate change policies, which will report to the Council of Australian Governments on any desirable changes to the electricity and/or gas market designs. Visit www.aemc.gov.au for more information.

In its second interim report in June 2009 [26], the AEMC highlighted the following issues:

- The need for increased flexibility in regulated retail pricing in the presence of increased uncertainty and volatility in the costs of supply;
- The need to efficiently the connection of new generation remote to existing networks, including planning, pricing and funding;
- The need to efficiently manage congestion costs associated with new patterns in and increased volatility of network flows, including more cost-reflective charges for generators;
- The need to efficiently manage short-term system operation in the light of increased short-term uncertainty.

5. Conclusions

This paper has presented a framework for analyzing and designing decision-making in an electricity industry or, more broadly, a stationary energy sector. It used that framework to analyze the approach taken in Australia to prepare for high levels of renewable energy penetration, demonstrating the importance of a systematic approach to this problem and illustrating the outcomes that can be achieved if that is done.

The Australian approach has achieved notable successes to date. However, it is a work in progress that is hampered by contested climate change policy-making and partial electricity industry privatization.

On-going refinement of the AWEFS forecasting scheme, along with increased end-user participation and changes in the generation mix to reflect the increasing role of wind energy, should result in further improvement to the ability of the Australian electricity industry to efficiently and effectively accept high levels of renewable energy penetration.

A broader set of issues should also be addressed, including end-user engagement, exploration of the role of energy storage technologies, improvement of gas industry arrangements and the management of interactions between electricity and gas industries. In a similar vein, preparatory work should be undertaken for the possibility of high levels of penetration of electrical vehicles. A general theme is the need to effectively manage the increasing complexity in all aspects of decision-making for the stationary energy sector.

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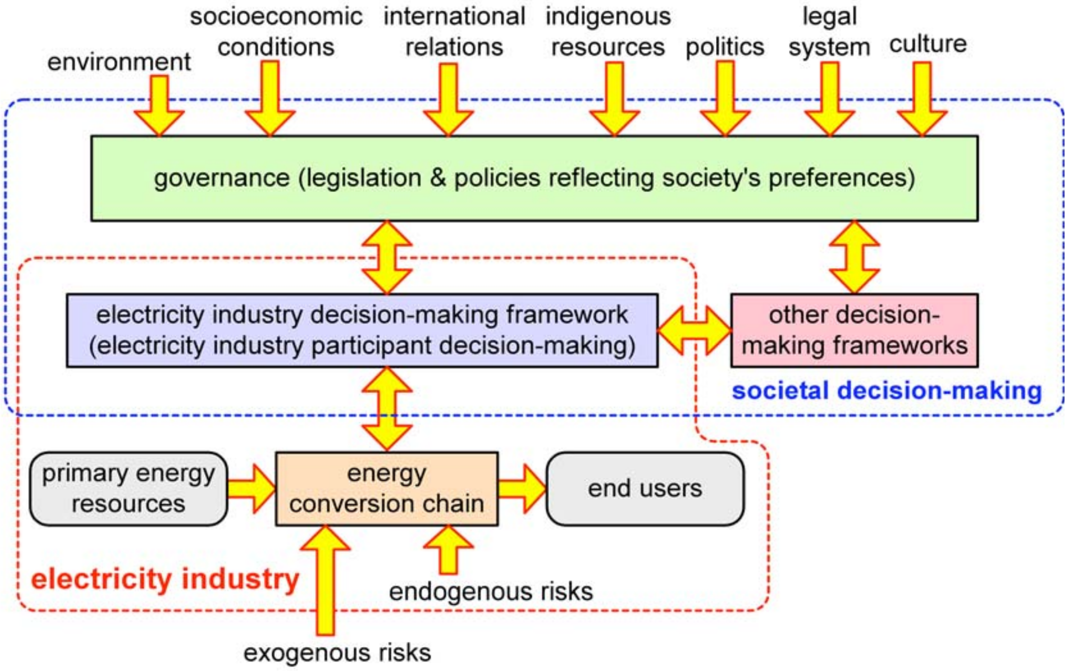

Figure 1. An electricity industry decision-making framework in the broader societal context [8]

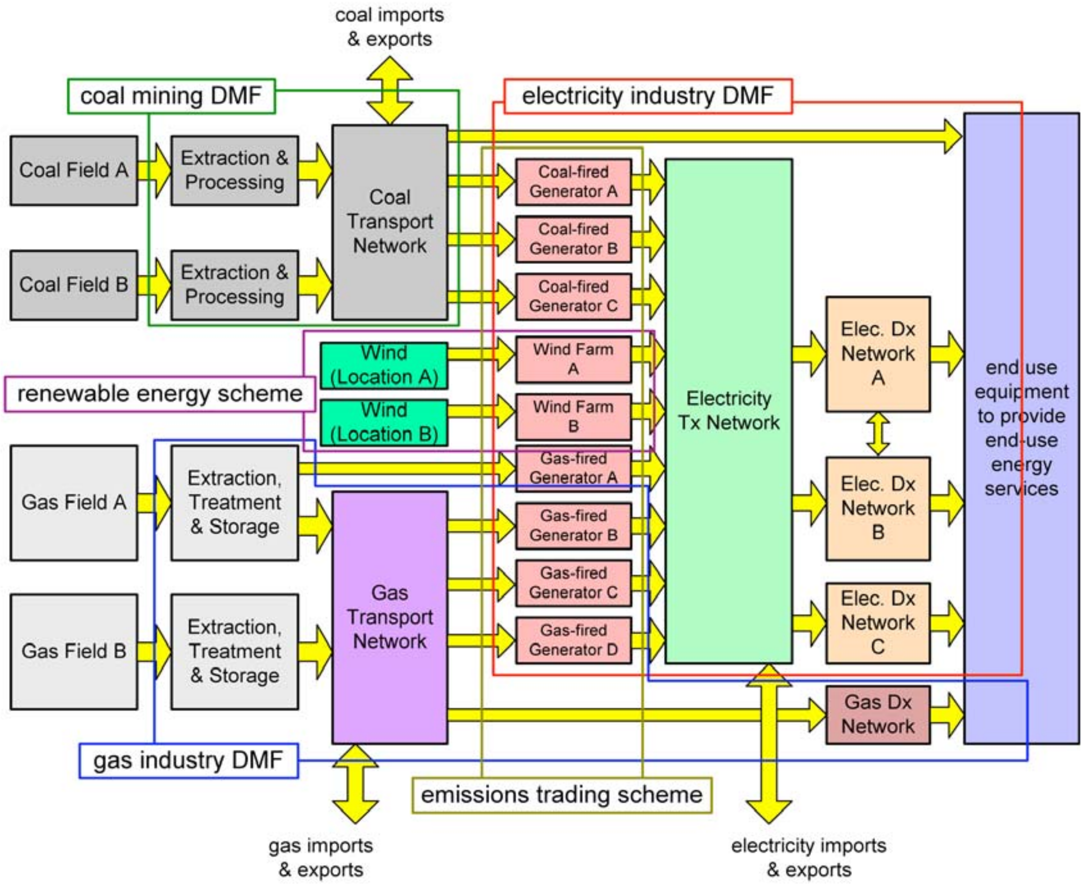

Figure 2. Illustrative decision-making frameworks for a stationary energy sector [8]