Horizon Scanning Series

The Effective and Ethical Development of Artificial Intelligence: An Opportunity to Improve Our Wellbeing

Energy

This input paper was prepared by Sylvie Thiebaux

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AI and Future Energy Systems

Input to ACOLA report on AI
Sylvie Thiebaux

Overview of the sector

The energy sector is currently undergoing profound changes triggered by:

- **High energy prices:** high loads on relatively sparse networks are driving high network costs and high market prices. In Australia we are also seeing a dramatic rise in domestic natural gas prices.
- **Renewable generation**: the affordability of solar photovoltaics has led to its mass deployment, including in particular in the residential sector on distribution networks. Australia has the largest uptake of rooftop solar of any country in the world.
- **Energy storage**: in the future, a similar trend can be expected of energy storage, including the deployment of residential battery storage and electric vehicles. Household batteries have entered the market and predictions have one in five Australian households equipped with a battery in 20 years time.
- **Consumer push**: consumers are keen to use technology to more actively shape their demand and reduce bills without overly compromising their comfort. A new class of consumers -- the prosumers -- are producing their own electricity to cover part of their demand and are exporting surplus to the grid.
- **Security and reliability:** renewable generation makes it more challenging to maintain frequency following incidents and balance demand with supply. In Australia, a few large incidents have put these challenges at the forefront of the ideologically charged debate.
- **Sensors, data, comms:** smart meters, a range of cheaper sensors, and new communication technologies are being rolled out at all levels of the distribution grid. They provide greater visibility and open the way for better analytics and automation.
- **Diverse energy and storage sources**: the sector is actively mapping the diverse range of renewable and storage sources available. Australia has abundant solar, wind, coal and gas, but also has biomass, wave, tidal, hydro, and geothermal. Storage technologies include pumped hydro, batteries, and storage associated with solar thermal plants (e.g. molten salt).

The above trends have far-reaching implications on the way power systems should be planned and operated, and on the policies and governance arrangements in the sector.

In particular **Distributed Energy Resources** (DER) such has rooftop solar and household batteries are creating an increasing degree of decentralisation. They are challenging distribution systems with reverse power flows, overload, voltage and intermittency issues. Moreover, our current energy markets are not designed to handle such a large number of generation sources over which they have no visibility. However, DER also present great opportunities for both consumers and networks. If properly coordinated, DER will not only to solve the issues they created, but also help support the distribution network during peak periods and help defer capital investment. With adequate coordination and market structures, DER will also have the flexibility and incentives to act in a way that improves the performance of the wholesale markets. The Australian Market Energy Operator (AEMO) and Energy Networks Australia (ENA) have recently published a consultation paper on how best to transition to a DER rich grid that benefits consumers.

The changes in technologies are putting pressure on existing business models. This creates the need for changes in **regulations, policies and incentives**. For example, power systems services are now unbundled from retailers and present opportunities for aggregators and consumers alike.

There is also significant uncertainty in other aspects of the transition to a cost-effective, secure, reliable and sustainable energy future. One example is in the **planning of a carbon-free, cost-effective and secure future grid**, including the ideal mix of generation and storage technologies over the next 30 years, the ideal locations of these generation and storage sources, and the expansion of the network.

The role artificial intelligence and recent advancements

Without doubt, AI will play a crucial role in addressing these challenges and providing technological solutions. Below we first provide details on some of the specific problems and technological advances needed to which AI can contribute. We then provide a list of the most relevant AI subfields -- in fact each problem requires a whole gamut of AI techniques and approaches.

1. **Residential and building energy management systems**: at the lowest level, there is a need for systems that manage and optimise energy consumption, production and storage, at the level of a household or a single building, on behalf of the owners or occupants. This includes deciding how to schedule shiftable loads, when to charge/discharge batteries to shift solar, and when to export power to the grid in response to price signals, to optimise the finances and comfort of the household or building. This is a well developed research area, and a range of commercial systems already exist that already perform some of these functions[1]. The remaining technical challenges relate to the ability to accurately forecast household/building load, solar, electricity prices, cope with the uncertainty in these forecasts, and capture consumer preferences.
2. **Coordination of distributed energy resources to manage network constraints:** at the level of the distribution network, there is a need to incentivise DER and residential energy management systems to behave in a coordinated way that also benefits the distribution network. Lack of coordination is already creating issues of overload and

[1] In Australia, examples include Building IQ 5i platform for heating, ventilation and air-conditioning management in buildings, the Evergen Energy Management System, Reposit Gridcredits, to cite a few.

voltage, leading certain DNSPs to deny further solar installation. However, if properly coordinated, consumer-owned DER can not only help managing the issues but also provide additional support the distribution network and defer investment. Coordination is a difficult problem as it must take into account the physics of power systems (nonlinear equations), respect prosumer privacy, and scale up to a large number of DER. Research in coordination distributed algorithms at the intersection of power systems, AI, and optimisation is currently investigating this challenge. In Australia, the CONSORT Bruny Island battery trial has demonstrated R&D in this area.[2]

3. **Aggregation of distributed energy resources to reduce electricity prices:** a different issue is to aggregate prosumer resources into a virtual power plant (VPP) to bid in the wholesale market and reduce peak electricity prices. One important research question is how to best incentivise and fairly reward prosumers for their participation into a VPP. In AI, the multi-agent systems community is conducting extensive research in this area. In Australia, a number of aggregators and VPP projects are starting to emerge -- some of these are both in the residential energy management and aggregation business.[3] A very topical issue in Australia is how aggregation of DER interacts with the need to manage network constraints at the distribution level using a coordinated approach.
4. **Electric vehicles:** from the standpoint of the electricity grid, they can be seen as a mobile battery. They will amplify the benefits and challenges raised by residential batteries, and present new ones, such as finding appropriate business models and locations for charging stations. They will also reinforce the coupling between the power and transport infrastructures. Transport is an area where AI applications are well-developed.
5. **Planning of the deployment of renewables and storage**: from an AI standpoint, the planning of the transition to a low carbon, cost-effective, secure and reliable grid is a large scale constrained optimisation problem, under uncertainty. Research and commercial tools exist[4] that go part way in facilitating this but much progress remains to be done to incorporate more detailed network models, incorporate storage, generate robust expansion plans, and improve their cost.
6. **Market design and operations:** besides the challenging renewable integration problems described above, traditional market design and operations are also ripe of problems to which AI is relevant. Such problems include designing cost-effective markets that ensure efficient allocation and are hard to manipulate. They also include the automated generation and adaptation of strategies for the various participants.
7. **Forecasting, prediction, and analytics:** these capabilities are crucial for all of the above problems, and forecasting load and generation can become the bottleneck of any approach to problems 1-6 when insufficient data is available. Utilities are particularly

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[2] In Australia, the CONSORT Bruny Island battery trial funded by ARENA and led by ANU has demonstrated R&D in this area.

[3] See the ARENA funded projects Virtual Power Station and Virtual Power Station 2 headed by CSIRO; Tesla and the South Australian Government are embarking on a large 250MW VPP project. Australian companies such as Evergen, Greensync and Reposit, amongst others, have demonstrated VPP capabilities.

[4] Australian examples include Plexos, Nemo, Mureil, and the more recent ARENA-funded grid modelling and integration software developed by ITPower.

interested in using smart meter and other data to understand their customers and their network. Predicting consumer behavior at a fine grained level is one of the current challenges.

8. **Policies:** there is a need for evidence-based assessment of policy choices, in the short term at the distribution level, and in the longer term for evaluating future grid scenarios. There is also a need of testing the coherence of policies at various levels.

The following AI subfields are particularly relevant to addressing the above problems.

- **Algorithmic game theory**: is ubiquitous as the grid is an environment where many actors collaborate or compete to consume, produce, buy or sell electricity, and efficient mechanisms are needed to enable this and incentivise desirable behavior.
- **Automated planning and scheduling**: is relevant to many of these problems, whether to schedule loads, EV charging, coordinate DER, plan renewable deployment and the expansion of the future grid, or restore the power system following outages.
- **Computer vision:** its use is more limited, but computer vision, on board drones or on mobile phones in crowdsourcing platforms, has been used to inspect the grid infrastructure or perform the automatic acquisition of network models.
- **Constraints and optimisation:** absolutely central and widely used since most network problems are constrained optimisation problems. *Distributed* constrained optimisation is becoming crucially important in the prosumer era.
- **Intelligent user interfaces** and human computer interaction more generally: this is particularly relevant to energy management systems and to help network providers understand their networks and consumers.
- **Machine learning:** again, this is central for most problems, as they require as load and generation forecast, consumer behavior prediction, and understanding of network patterns. Other applications include predicting the best location for renewable energy sources (e.g. wind, geothermal).
- **Multi-agent systems:** in addition to the algorithmic decision theory angle mentioned above, this is used to generate strategies for agents competing in markets (see the Power TAC competition), providing simulation of markets and networks, and in providing automated verification tools to assess the consequences of different policy settings (e.g. tariff structures).

Gaps in Australia as it relates to AI

Even despite the popularity of double degrees in Australia, it is **difficult to find well-rounded graduates with the multidisciplinary background** underpinning the application of AI in future energy systems. For instance, the typical Australian engineering graduate has very low computer science and AI skills, usually limited to matlab/python programming and usage of basic analytics and optimisation. The typical Australian computer science graduate has no knowledge of electrical engineering. Some universities propose **multidisciplinary**

postgraduate degrees in the future energy systems space[5], but in Australia, unlike in Europe[6], CS and AI rarely make it into the curriculum. At the PhD level, European countries have training networks dedicated to data/AI/CS in energy systems.[7] No equivalent **Industrial Transformation Training centre** (ITTC) with AI for energy systems at its core exists in Australia.

Many countries have **public and/or private R&D institutes dedicated to future energy systems**, which are well-versed in state of the art data analytics, AI and optimisation techniques. (As examples, the US has NREL and EPRI amongst others; the french company EDF has over 2000 R&D staff in 6 research centres in Europe, and Iran has the Niroo Research Institute). This much needed layer of specialised R&D labs is lacking in Australia (not just in energy), and this makes it much more difficult for research from university and CSIRO (which does use AI in the energy space), to find its way into consumer products. Moreover, **specialised laboratories in CS/AI**, such as the former NICTA and now Data61 are essential to the adoption of AI industry sectors such as Energy, and to the development of globally competitive products and services in this sector. Government support for these should be amplified, and be used to fund a suitable balance of basic and applied research. As another example, France (which already has a large and high-performing national research labs in computer science and control, INRIA), is starting to harness the power of AI by creating **artificial intelligence interdisciplinary institutes** in selected public higher education and research establishments; each institute will focus on a specific application area.

In terms of R&D funding, the Australian energy sector is very fortunate to have the **Renewable Energy Agency, ARENA**. Some of the projects funded by ARENA are using AI to provide solutions to the problems mentioned above and have received multi-million dollar funding. One regret is that the ARENA R&D program has been very small compared to the rest of the ARENA programs portfolio, irregular in time, and more focused on renewable technology development than on the planning and operations of future grids. This is somewhat paradoxical given the profound transformation the sector is going through and the complexity (technical and otherwise) of the solutions that will be needed. Other ARENA programs (the bulk of ARENA's project portfolio) target industry-led projects with relatively short term outcomes. To rip off the benefits of AI, regular R&D funding rounds, focused on the planning, operations, and markets for renewable-rich grids would lead to tremendous outcomes for Australia.

Cooperative Research Centre Projects (CRC-P) in collaboration with industry (including at least one SME per project) are a welcome recent addition to the Australian R&D funding

[5] See for instance the Master of Energy Change at ANU, and the Master of Energy Systems at the University of Melbourne.

[6] See for instance the Master of Electrical Engineering for Smart Grids and Smart Buildings at the French National Polytechnic Institute in Grenoble which has a CS module, and the joint Master Degree in Smart Grid from the ICAI School of Engineering in Madrid and the University of Strathclyde in Glasgow which has a Data Analytics and AI module.

[7] See for instance the DFG Training Network "Energy Status Data" hosted by Karlsruhe Institute of Technology.

landscape. They have regular 6 monthly funding rounds and provide up to $3 million per project based on matching funds. Oil, Gas and Energy Resources is one of the 7 growth sectors identified by the Australian Government as a priority, and moreover, the latest CRC-P round has special funding dedicated to AI! One issue is that neither universities nor state-owned companies cannot be lead applicants. This can be problematic in this particular field where many of the most innovative network providers are state-owned, and where SMEs are time-poor and competing. This might explain why only one project at the intersection of AI and future energy systems has received funding so far, out of about 60.

Funding multi-disciplinary projects has never been the **Australian Research Council'**s forte. Even factoring in low expectation, a search in the ARC database for grants/fellowships in the past 5 years at the intersection of AI and future energy systems revealed an abysmally low number of relevant projects.[8] We suggest the ARC investigates this, and if verified, takes appropriate action.

The elephant in the room is the **Australian Federal Government inability to adopt a climate and energy policy** that is driving down emissions and prices, and increases reliability. Whilst this isn't an AI issue, this is slowing down the transformation of the industry and limiting the positive role that AI can play in facilitating this transformation.

What will the next 10 years bring, what are the risks, and what actions will be needed to realise this.

To summarise, AI has a crucial role to play in many aspects of the transition to a carbon-free, cost-effective and reliable grid. In particular, machine learning, planning and scheduling, game theory, distributed (constrained) optimisation, and multi-agent simulation, provides us the tools with which to attack some of the major problems the transformation raises.

Within the next 5-10 years, AI will be the technology deployed in residential and building management systems, and is likely to become the core technology to coordinate or aggregate DER, manage constraints on distribution networks, determine prosumer incentives, implement demand response, and undertake certain aspects of power systems restoration. The use of AI for forecasting load, generation, electricity prices, and understanding other network and consumer patterns, will be ubiquitous. AI will be used by government, investors and industry to plan the transition of the grid to 100% renewables, and to investigate the effects of new policies

[8] Various search configurations including FOR codes 0801, 0906, 0102, keywords such as "grid", "power", "machine learning", "AI", and names of people working in the broad area of smart grid, revealed a grand total of 11 projects between 2014-2018. Most of these were DPs more broadly about AI for complex systems or cyber-physical systems (including power systems). Only three were core to the agenda outlined above. An additional search focusing on LP projects with no FOR code and keywords "smart grid" or "power systems" identified a couple more relevant projects. Even though this quick experiment is not designed to identify all relevant projects, we believe it is sufficient to outline the deficiency.

before they are adopted. AI is unlikely to be used directly in applications requiring second and sub-second reactions, e.g. reacting to frequency fluctuations, which is the realm of control and power electronics.

The risk is that, over-specialisation of our education, conservativeness of the industry, lack of consistent large scale research funding, and deficient (or absent) government policies slow this potential down or reduce it to a piecemeal integration where AI technology is used just punctually or just behind the meter by consumers, but not as a key technology to help plan and operate the whole system.

Ethics is currently at the center of the public debate concerning AI. There are a few sources of concern in the energy space.

- One concern is that **data analytics and smart meters might be used to intrude on consumers**. Note that the technology itself doesn't mandate this at all: there are privacy preserving analytics and non-intrusive distributed optimisation methods which incentivise prosumer systems rather than performing direct control.
- Another concern is that the **sharing of benefits or resources amongst participants in the energy systems** (e.g consumers and prosumers) might not be fair if AI automation is used to optimise purely economic criteria. It might also increase inequalities between prosumers and ordinary consumers who can't afford rooftop solar, batteries and energy management systems. Again, the area of algorithmic game theory does study these questions and further research in this area, if appropriately funded, will come up with appropriate technical and ethical solutions.
- **Automation**, in particular using AI, is needed to cope with the complexity of the transformation of our energy system. **This will inevitably replace certain types of jobs by others**. However, the scope of the opportunity is so large that the balance is very likely to be positive.

There doesn't seem to be much point in trying to regulate AI systems in the energy space at present. Too much regulation would hinder innovation in an area where a wide range of technical solutions and business models need to be explored and where AI will surely bring greater good. Instead, the focus should be on understanding how to **design AI systems that reflect our values**.

Here are some of these actions that would facilitate the realisation of AI's potential to transform the energy sector:

- **Education sector:** Embrace the big tent view of computer science and AI, and integrate them as first-class citizens into engineering and economics curriculum. Develop masters degrees at the intersection of energy and AI, and for the continual education in CS and AI of the energy industry workforce. Create PhD training networks and centres that are focused on harnessing the benefits of AI and analytics into energy (and other sectors).
- **Government:** Create a number of interdisciplinary AI institutes to harness the potential of AI in key sectors. Continue to fund ARENA and Data61, and to foster innovation (this has improved in the past couple of years), and collaboration between universities,

government, and industry. Develop a energy and climate policy and get it passed parliament!

- **Funding agencies:** Dedicate funding to multidisciplinary proposals and improve ways of assessing them (ARC especially). Consider (or continue for CRC-P) dedicating funding to AI and AI applications in key sectors such as energy. Do not undervalue the benefits that longer term projects with a longer timeline to commercialisation can deliver (ARENA). Abolish rules restricting leadership of collaborative projects to certain categories of participants. Provide regular R&D funding opportunities with sufficient time between calls and proposals due (ARENA).
- **Industry:** Whenever possible, share data with academic and research partners. Partner in the organisation of hackathons to demonstrate the short-term potential of AI. Integrate AI versed graduates and interns in innovation teams. Initiate and participate more actively in projects in collaboration in university and research laboratory groups which do understand the use of AI in energy systems. Take more advantage of ARC and CRC programs (not just ARENA). See AI as a transformative technology, not just as a technology to improve business as usual operations.