

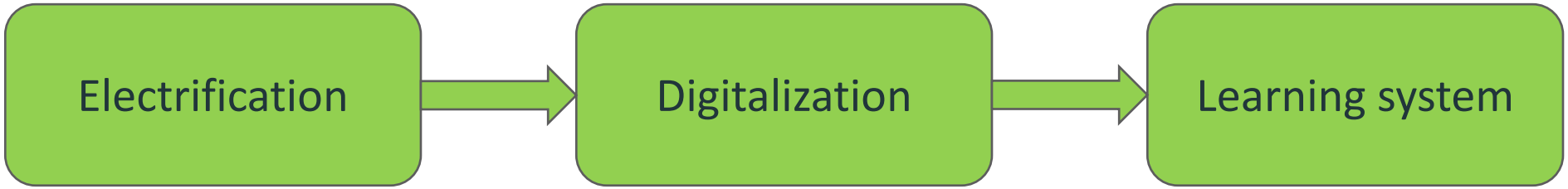
UPPSALA
UNIVERSITET

From electrification to intelligence: The role of AI in the future energy system

Thomas Schön
Uppsala University

September 29, 2026

My simplified view on the energy landscape



During the 20th century we built the electricity system.

During the early 21st century we digitized it.

During the coming decades will make it a learning system.

UPPSALA
UNIVERSITET

What is changing?

Three simultaneous trends:

1. Massive electrification
2. More renewable generation
3. Increased system complexity

Examples: EV charging, heat pumps, solar power, battery storage, flexible demand, etc…

Yesterday

- few large generators
- predictable demand

Tomorrow

- millions of distributed assets
- highly dynamic system



UPPSALA
UNIVERSITET

Complexity is increasing (fast?)

The challenge of the future energy system might be less about producing electricity and more about coordinating it.

More unknown and varying factors at play. More dynamic reality.

Examples: weather uncertainty, distributed resources and market interactions

Gaining **situational awareness** is important.

Motivates why AI will likely be useful.



UPPSALA
UNIVERSITET

AI - The nature of the subject

A creative combination of **mathematics** and **programming** where the **use of data** is always at the centre.

Proposition 2 (Projection step)**.** If $(\widetilde{\boldsymbol{\beta}}, \tilde{t}) \in C$, the projection is the identity. On the other hand, if $(\widetilde{\boldsymbol{\beta}}, \tilde{t}) \notin C$, let us denote $\text{Proj}_C(\widetilde{\boldsymbol{\beta}}, \tilde{t}) = (\boldsymbol{\beta}^{\text{Proj}}, t^{\text{Proj}})$. We have that:

1. For $C = \{(\boldsymbol{\beta}, t) : \rho t \geq \delta \|\boldsymbol{\beta}\|_2\}$, then $t^{\text{Proj}} = \delta \frac{\rho \|\widetilde{\boldsymbol{\beta}}\|_2 + \delta \tilde{t}}{\delta^2 + \rho^2}$ and $\boldsymbol{\beta}^{\text{Proj}} = \frac{\rho t^{\text{Proj}}}{\delta \|\widetilde{\boldsymbol{\beta}}\|_2} \widetilde{\boldsymbol{\beta}}$.
2. Now, for $C = \{(\boldsymbol{\beta}, t) : \rho t \geq \delta \|\boldsymbol{\beta}\|_1\}$. Let $(\cdot)_+$ denote the operator $\max(\cdot, 0)$ and define λ as the solution to

$$\sum_{i=1}^{p} (|\widetilde{\beta}_i| - \delta\lambda)_+ = \tilde{t} + \rho\lambda, \qquad (5)$$

which exists and is unique for $\tilde{t} > 0$. Then, $t^{\text{Proj}} = \tilde{t} + \rho\lambda$ and $\beta_i^{\text{Proj}} = \text{sign}(\widetilde{\beta}_i)(|\widetilde{\beta}_i| - \delta\lambda)_+$.

```
# Shift scores back
scores = torch.cat([scores[...,(sz[0]+1)//2:,:], scores[...,:(sz[0]+1)//2,
scores = torch.cat([scores[...,:,(sz[1]+1)//2:], scores[...,:,:(sz[1]+1)//

# Find maximum
max_score1, max_disp1 = dcf.max2d(scores)
_, scale_ind = torch.max(max_score1, dim=0)
max_score1 = max_score1[scale_ind]
max_disp1 = max_disp1[scale_ind,...].float().cpu().view(-1)
target_disp1 = max_disp1 - self.output_sz // 2
translation_vec1 = target_disp1 * (self.img_support_sz / self.output_sz) *

if max_score1.item() < self.params.target_not_found_threshold:
    return translation_vec1, scale_ind, scores, 'not_found'

if self.output_window is not None and self.params.get('perform_hn_without_
    scores = scores_orig
```



UPPSALA UNIVERSITET

AI brings predictive capabilities and decision support

Generative AI produce text, images, code, etc.



Key capability of AI today: **recognize patterns**.

Patterns offer better **predictions** (situational awareness) which lead to **better decisions**.

These decisions can then be taken by humans or machines.

UPPSALA UNIVERSITET

AI brings decision support

All the governing equations are known

Some of the governing equations are known

None (or very few) of the governing equations are known

Combine predictions with system knowledge.

IA and think more about how to create systems that are easy to work with.

UPPSALA UNIVERSITET

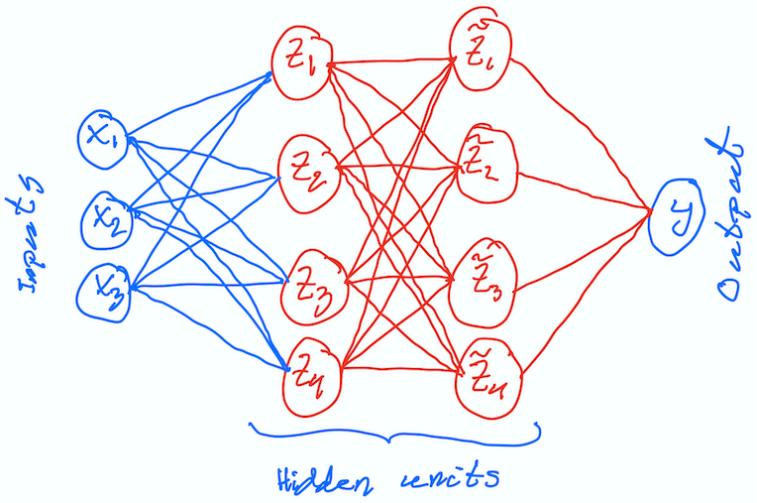
Deep learning

Works **extremely well** on **clearly defined** problems with **lots** of data.

Accounts for the vast majority of all progress and investment in AI/ML.

Has generated massive business potential. The mathematical model is 80 years old...

Need for new mathematics to understand why it works.



UPPSALA
UNIVERSITET

Examples of using AI in energy



UPPSALA
UNIVERSITET

Learning power grids

The challenge:

- Electricity demand changes continuously.
- Renewable generation is variable and distributed.
- Electrification adds millions of new loads such as EVs, heat pumps and batteries.

The complexity cannot be managed manually.

AI enables:

1. Demand forecasting
2. Grid monitoring
3. Control
4. …

Turn the power grid from a passive infrastructure into a **learning and adaptive system**.

UPPSALA UNIVERSITET

AI for Wind and Solar Power

The challenge:

- Solar power depends on clouds, weather, and season.
- Wind power depends on highly variable atmospheric conditions.
- Electricity supply and demand must be balanced continuously.

AI enables:

1. Better forecasting
2. Grid operation
3. Site design
4. …

Reduce variability to make it a more maneageable energy resource.



UPPSALA
UNIVERSITET

Fusion - deep RL operating the magnetic coils

The challenge:

- Fusion plasmas are very complex systems.
- Successful operation requires predicting and controlling billions of particles in real time.
- Traditional physics-based simulations can take hours or days.

AI enables:

1. Real-time plasma control
2. Surrogate models
3. Experiment optimization

AI does not replace physics. It complements physics by making prediction, control, and discovery faster.

Degrave, et al. **Magnetic control of tokamak plasmas through deep reinforcement learning.** *Nature* 602:414-419, 2022.



UPPSALA
UNIVERSITET

AI for science

Science advances when we develop new instruments (e.g. telescope, microscope) that help us observe, model, and understand the world.

AI is the latest such instrument.



UPPSALA
UNIVERSITET

AI for science – concrete energy examples

- **Batteries** (discover new battery materials, predict material properties before synthesis, reduce costly laboratory experiments)
- **Solar** (design more efficient PV materials, explore large material combinations)
- **Fusion** (learn from plasma simulations, predict instabilities and improve reactor control)
- **Climate** (faster climate and weather models, better understanding of renewable energy integration)

Self-driving labs offers an interesting trend of high relevance to energy.



UPPSALA
UNIVERSITET

Concluding

The energy transition is often described as going from fossil fuels to renewables.

The transition from static systems to **dynamic and learning systems** is **equally important**.

The best predictive performance is currently obtained from **highly flexible learning systems**.

IA and think more about how to create systems that are easy to work with.



UPPSALA
UNIVERSITET