Generative AI for Distribution Systems Planning

PW Conference 2024

Assistant Prof. Pedro P. Vergara
Intelligent Electrical Power Grids (IEPG)

TU Delft

Content

- Contextualization
    - Congestion in distribution systems
- Generative AI for DS Planning
- Case Study: Increasing solar (PV) panels adoption

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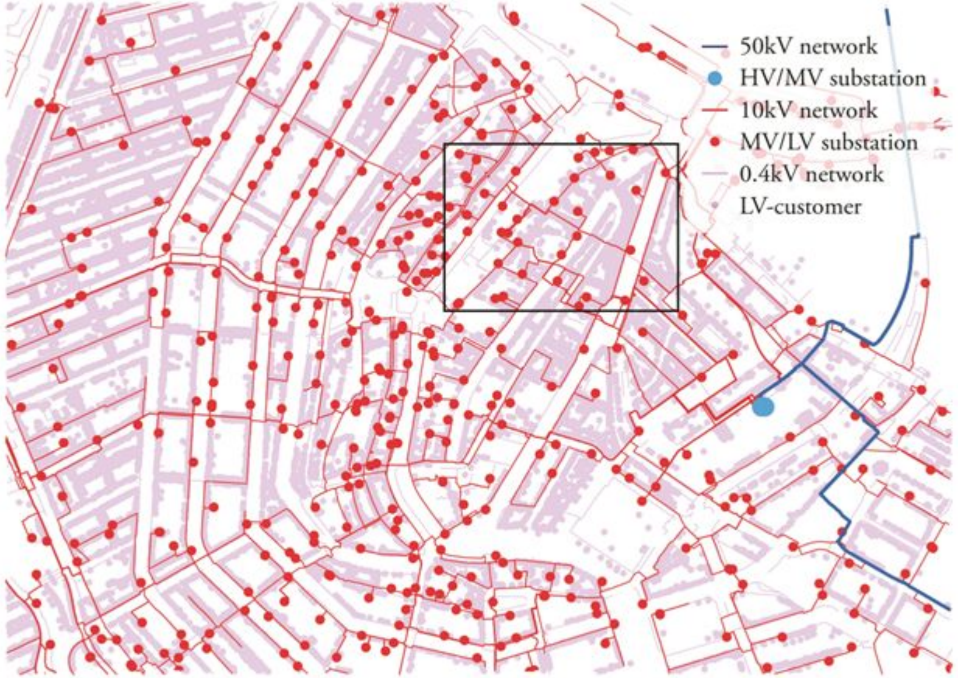
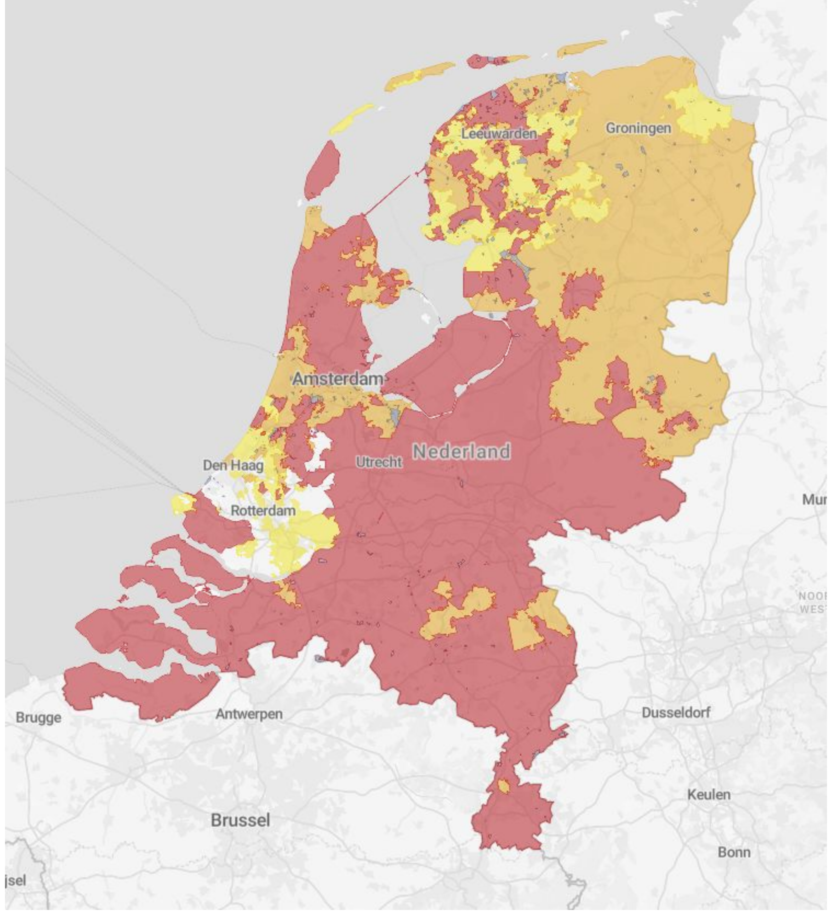
Contextualization

Congestion in Distribution Systems

Large numbers of energy resources (EVs, electric heat pumps) are creating *congestion*.

There is no capacity left in the distribution system for new customers to be connected.

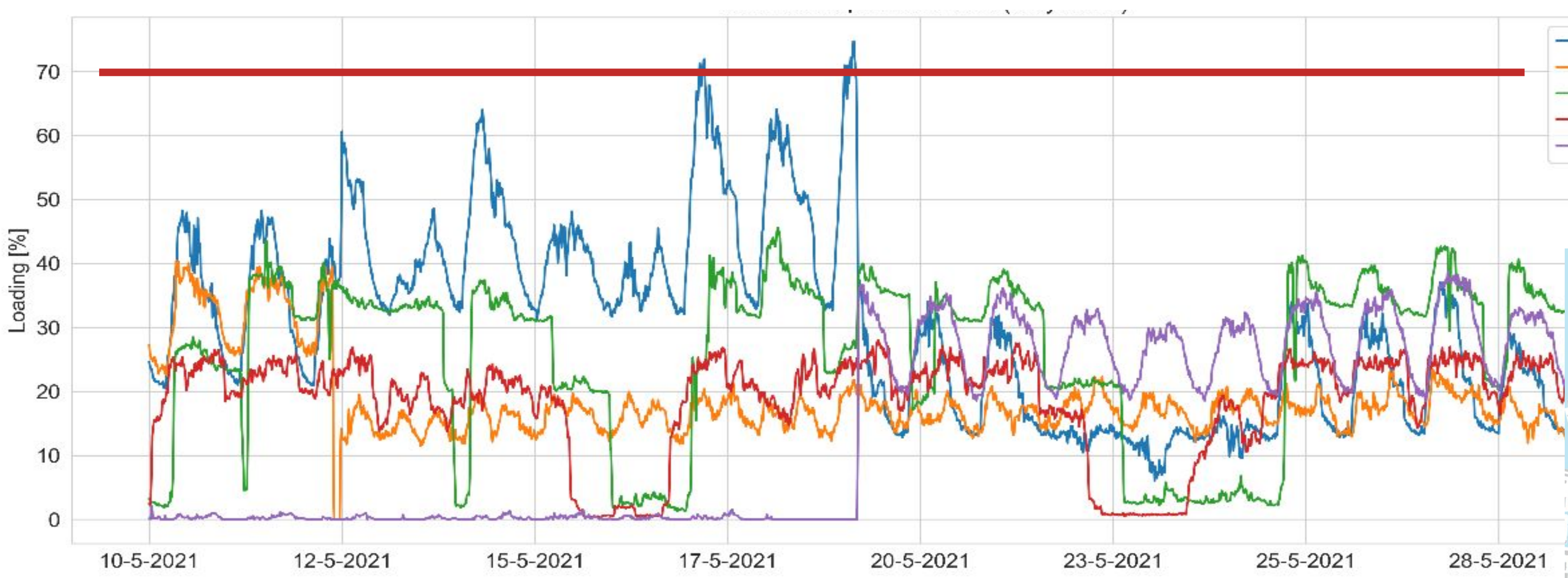




https://capaciteitskaart.netbeheernederland.nl/

Congestion in Distribution Systems

How exactly *congestion* looks like?



Buiksloterham, Amsterdam

Distribution system infrastructure operating at its *maximum (physical) capacity*.

No capacity available during short periods of the year.

We need to quantify it!

Generative AI

Generative AI

Generative AI is the term used for ML models that have the ability to produce new and unique content, including text, images, audio, and videos.

This makes generative AI a valuable tool across various industries, such as gaming, entertainment, and product design.

An excellent feature of these models is the opportunity to **condition** their outputs.

How can we make use of such tools for electricity infrastructure planning?

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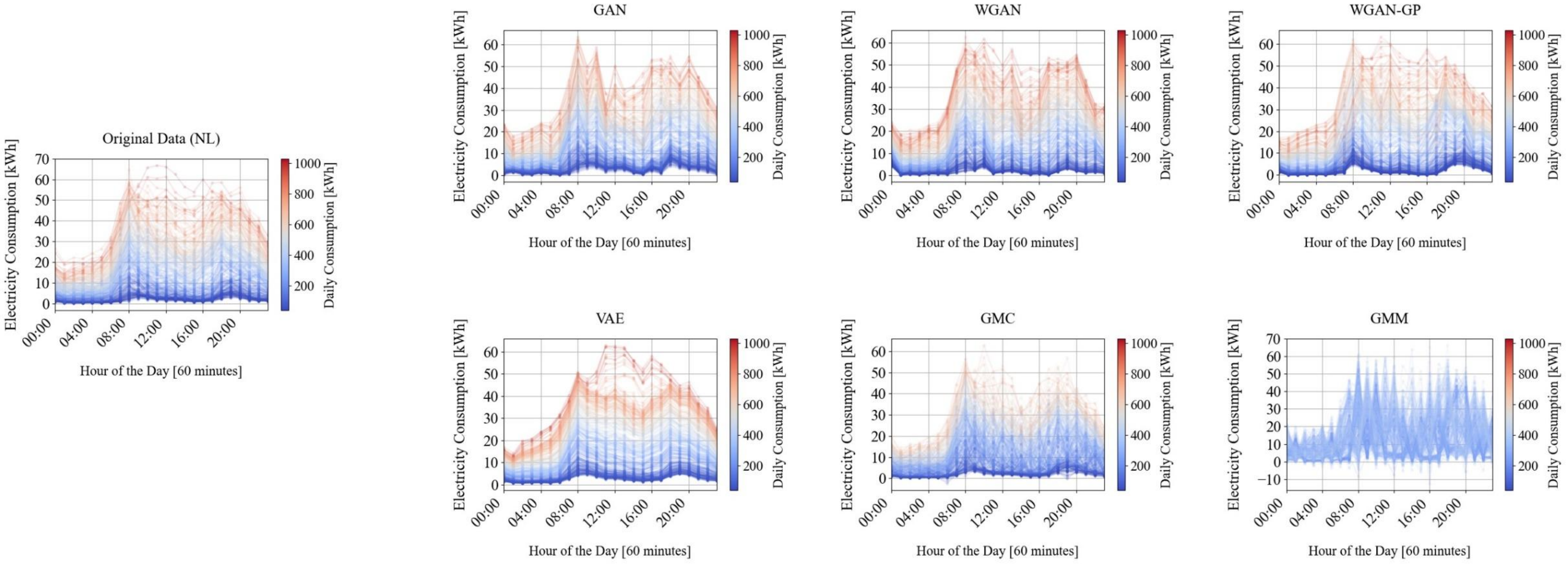
Jonathan Ho, et. at., Denoising Diffusion Probabilistic Models (DDPM), NeurIPS, 2020.

Generative AI: Time-series energy data generation

Large number of models available, with multiple architectures and features. Some more simple, other more complex.

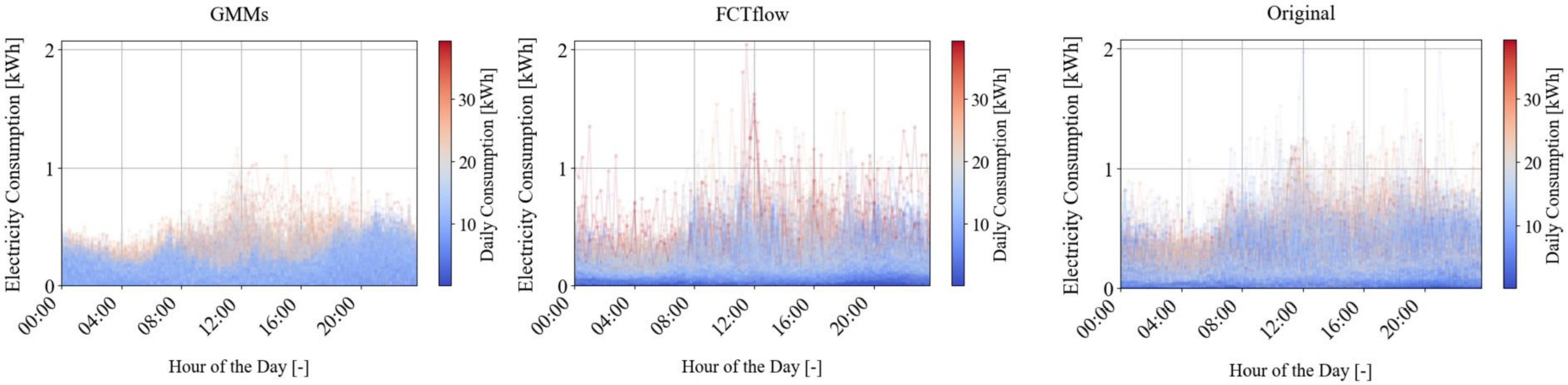


Depending on the type of data (features), we must select the correct model.

W. Xia, P. P. Vergara, et. at. “Comparative Assessment of Generative Models for Transformer- and Consumer-Level Load Profiles Generation”, Sustainable Energy, Grids, and Networks, 2024.

E. M. S. Duque, P. P. Vergara, P. H. Nguyen, A. van der Molen and J. G. Slootweg, "Conditional Multivariate Elliptical Copulas to Model Residential Load Profiles From Smart Meter Data," in IEEE Transactions on Smart Grid, vol. 12, no. 5, pp. 4280-4294, Sept. 2021.

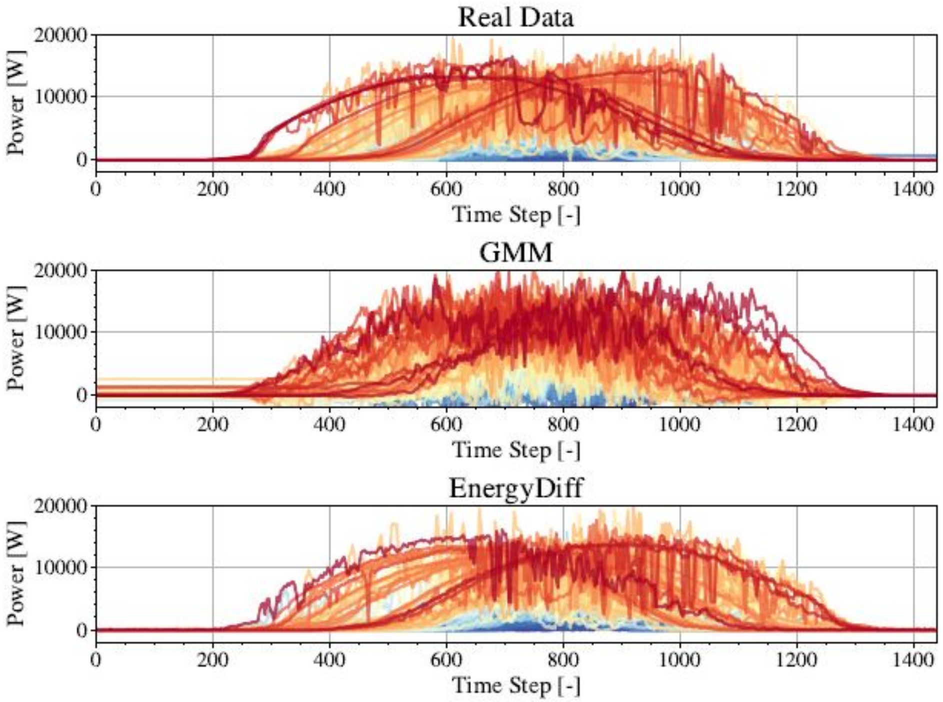
Proposed Flow-Based Model for Time-Series Demand Generation



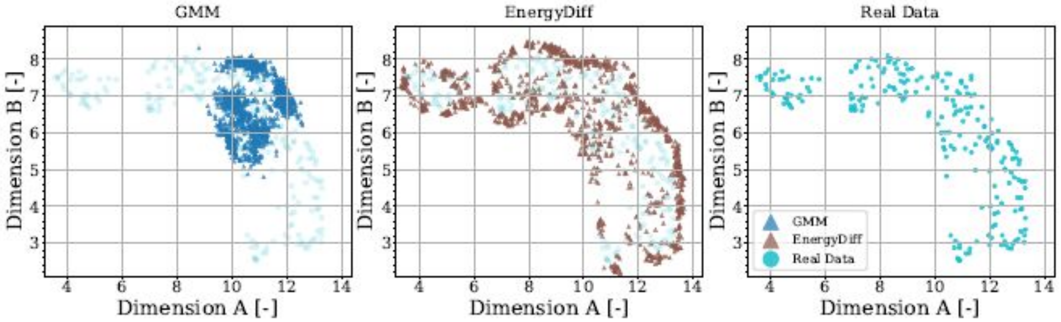
FCPFlow outperforms other models in several metrics, this suggest superiority in capturing both temporal correlation and fitting distribution shape.

W. Xia, C. Wang, P. Palensky, P. P. Vergara, “Flow-Based Model for Conditional and Probabilistic Electricity Consumption Profile Generation and Prediction” submitted to the IEEE Transactions on Smart Grid, 2024. Pre-print: https://arxiv.org/abs/2405.02180

EnergyDiff for Time-Series PV Data Generation



PV data: GMM sample data are overly noisy and contain negative values.



Visualization of a sample of the generated data using only two dimensions. GMM is not capable of generalizing well.

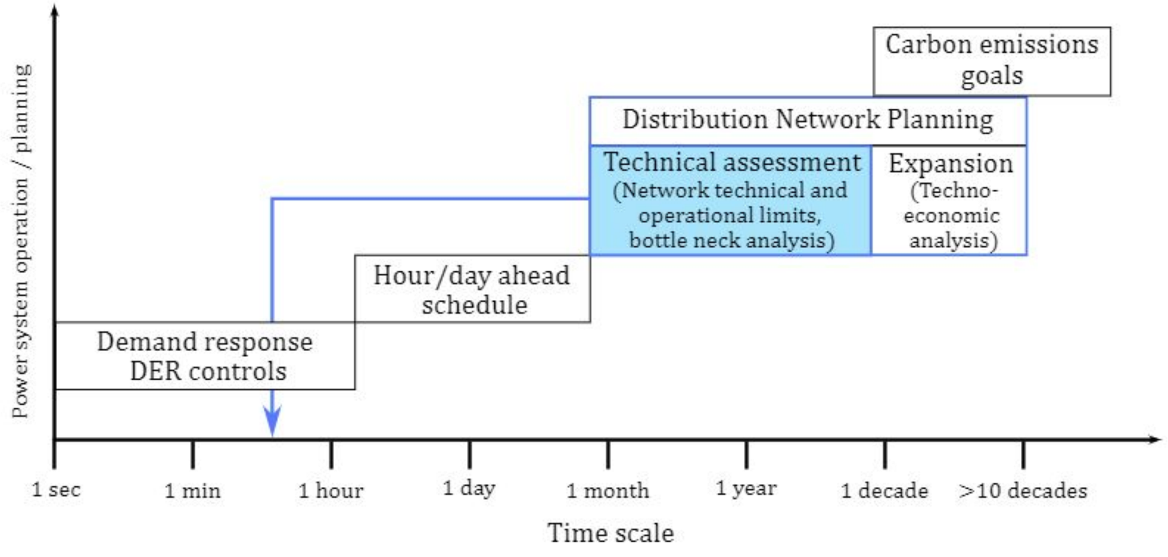
N. Lin, P. Palensky, P. P. Vergara, “EnergyDiff: Universal Time-Series Energy Data Generation using Diffusion Models”, submitted to the IEEE Transactions on Smart Grid, 2024. Pre-print: https://arxiv.org/abs/2407.13538

Case Study: Increasing Solar (PV) Panels Adoption

Distribution Systems Planning

We aim to develop a framework that allows grid operators to make risk-informed decisions before committing to network reinforcement.

Is it available enough *solar (PV) panels hosting capacity* or is it network reinforcement needed?



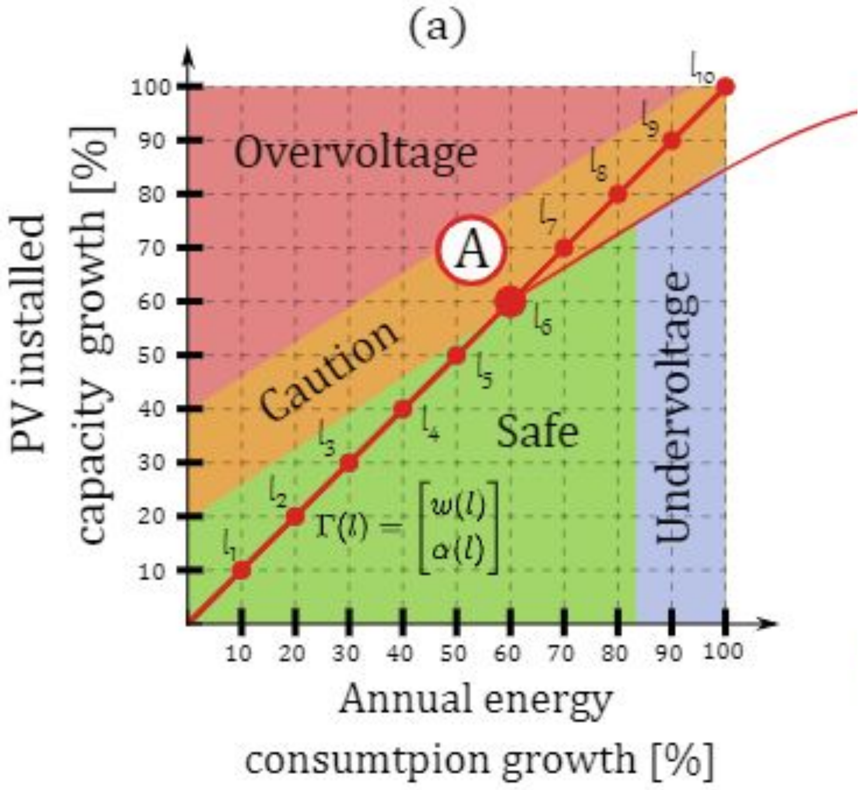
E. M. S. Duque, J. S. Giraldo, P. P. Vergara, P. H. Nguyen, A. v. d. Molen and J. G. Slootweg, "Risk-Aware Operating Regions for PV-Rich Distribution Networks Considering Irradiance Variability," in IEEE Transactions on Sustainable Energy, vol. 14, no. 4, pp. 2092-2108, Oct. 2023.

Electricity Infrastructure Planning

Consumption and PV generation modelling.

- **Conditioned** to future load growth.
- PV generation conditioned to the irradiance profile.

Technical issues: Overvoltage (high solar PV generation), undervoltage (high demand consumption)



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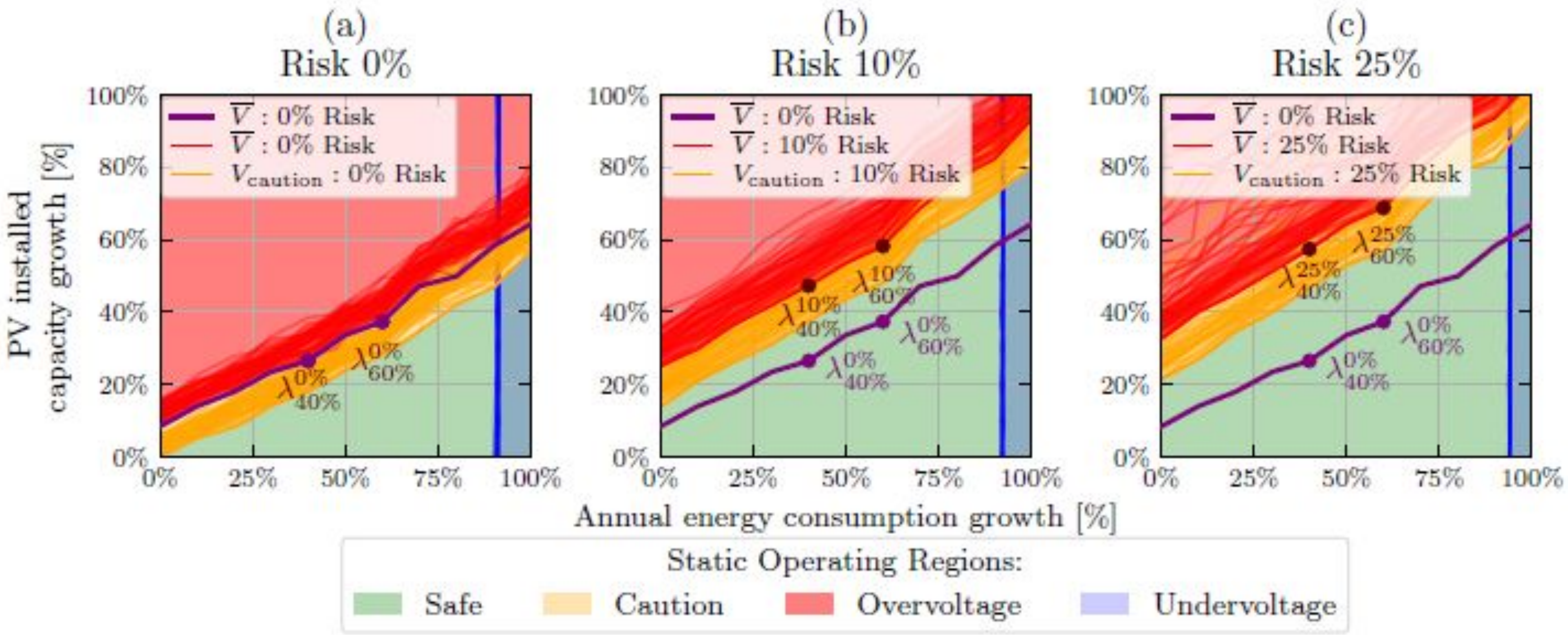
Critical Static Operating Regions and Nomograns

Example: At 40% annual energy growth: (Risk, PV capacity limit): (0%,26.5%) to (5%, 42.3%).

15% more capacity with only 5 % risk increase.

Planning considering (and quantifying) risk allow a better use of the current infrastructure.



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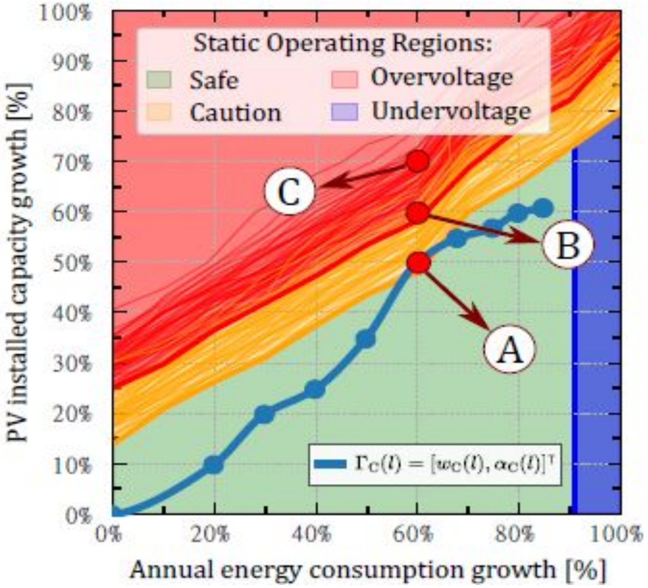
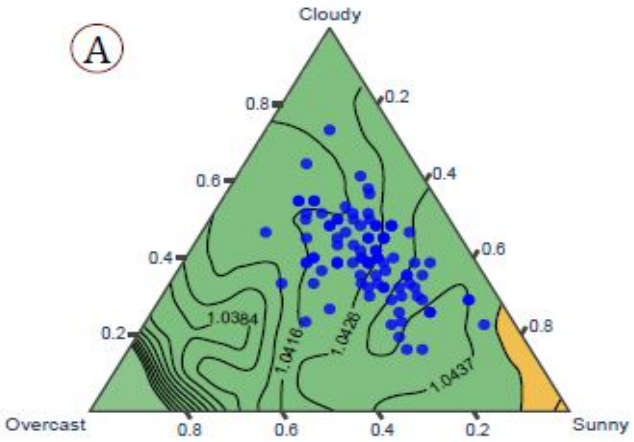
Critical Static Operating Regions and Nomograns

Of course, grid operators dislike taking risks. *We can assess such risk further*.

If the system is allowed to operate at the caution-safe border (Point A). How much risk is involved?





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Conclusions

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- Generative AI models can help overcoming the lack of (smart meter) energy data due to privacy constraints.

- Planning considering accurate (generation, consumption) data modelling allows reducing uncertainty when allowing risk.

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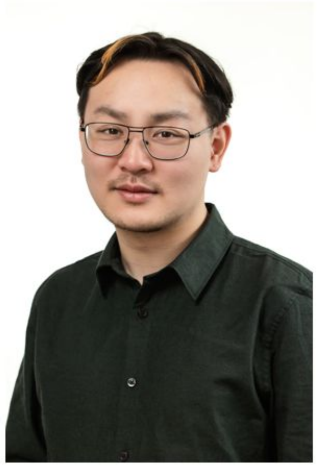
Dr. Pedro P. Vergara
P.P.VergaraBarrios@tudelft.nl
https://www.pedropvergara.nl

PedroPVergara.nl

Generative AI for Distribution Systems Planning and Operation

Content available thanks to the hard work of Weijie, Nan and Mauricio.

Weijei Xia
PhD Researcher
W.Xia@tudelft.nl



Nan Lin
PhD Researcher
N.Lin@tudelft.nl

E. M. Salazar Duque
PhD Researcher and Developer
mauricio.salazar-duque@enexis.nl

ALIGN4 energy

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Thank you for your attention.

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