Scientific Machine Learning for IA solutions in the era of Energy Transition

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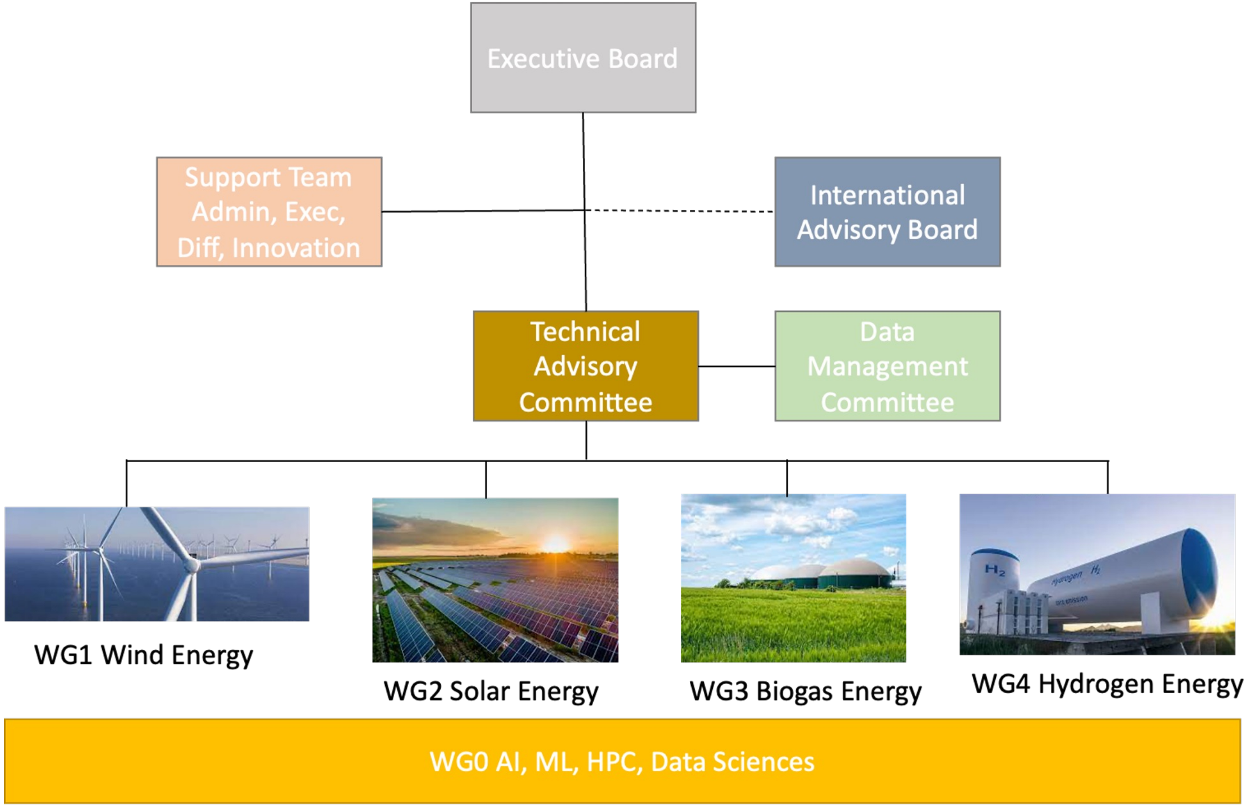
Center of Excellence in Artificial Intelligence for Renewable Energy



Center Partners: BR Science & Tech

COPPE UFRJ

Laboratório Nacional de Computação Científica
UNIDADE DE PESQUISA DO MCTI

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PTI
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Centro de Energias Renováveis
Center of Renewable Energy

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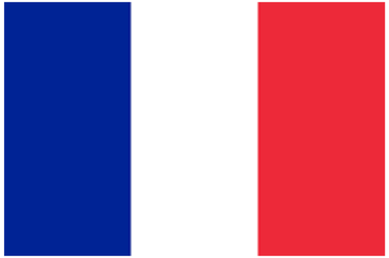
International Center’s Partners



Center Mission & Vision

Our mission: Advance and deploy AI tools and processes for the energy transition towards renewables and sustainability

Our vision: Consolidate, in five years, the first multidisciplinary platform of excellence in artificial intelligence geared to empower Brazil´s leadership in renewable energies

Similar Initiatives: NSF AI Institute for Dynamic Systems, NSF AI Institute for Foundations of Machine Learning, both dedicated to *Scientific Machine Learning*

CEAIRE’s Leadership

Alvaro Coutinho, CNPq 1A
CE&S, UFRJ

Frederic Valentin, CNPq 1B,
Appl Math, LNCC

Andre Novotny, CNPq 1B
Optimization, LNCC

Gerson Zaverucha, CNPq 1D
CS-AI, UFRJ

Fernando Rochinha, CNPq 1A
Mech Engng, UFRJ

Doris Veleda CNPq 2
REC, UFPE

Argimiro Secchi, CNPq 1B
Chem Engng, UFRJ

Suzana Kahn, IPCC Nobel
Prize, 2007, Green Fund, UFRJ

Center Innovation Initiatives

UFRJ Tech Park

HALLIBURTON

SENAI CETIQT

Schlumberger

SIEMENS

Partners Tech Parks

serratec
Parque Tecnológico Região Serrana

PTI
Parque Tecnológico
Itaipu

Other Innovation Partners

Advanced negotiations

BR PETROBRAS

TotalEnergies

Initial negotiations

equinor

ExxonMobil

Scientific Challenges

Long term challenges:

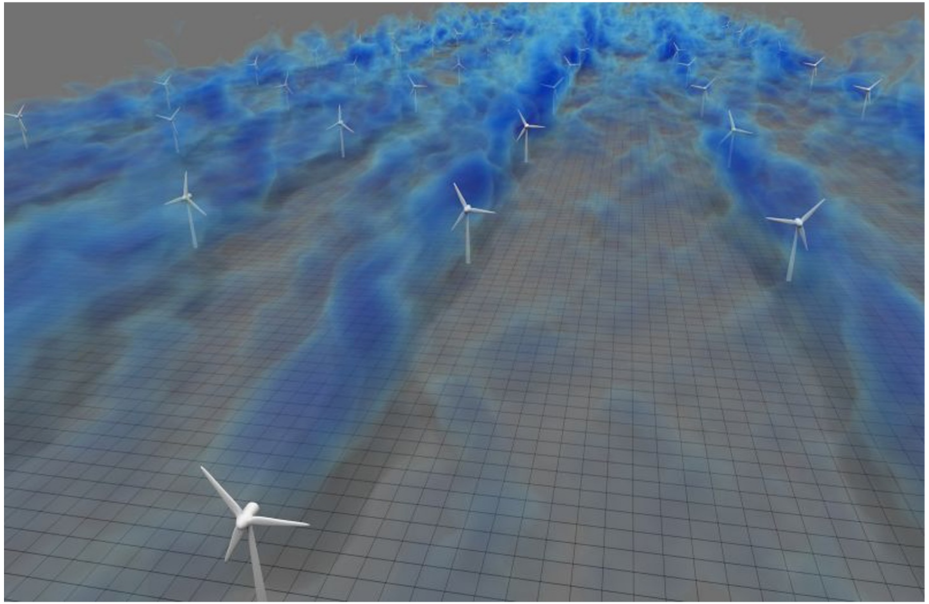
1. Promote systemic innovation that brings together digitalization, decentralization, and electrification in the renewable energy sector
2. Explore relevant applications and benefits of artificial intelligence for forecast and operation in the wind, solar, biomass, and hydrogen renewable energies
3. Contribute to decrease uncertainties on green hydrogen applications
4. Contribute to environmentally, socially, and economically sustainable biomass energy production
5. Help Brazil meet the United Nations Sustainable Development Goals and the climate goals of the Paris Agreement
6. Contribute to training of qualified human resources capable of advancing the use of artificial intelligence for development of contemporary technologies in renewable energy

Wake steering optimization problem under uncertainties

Wake effects in large wind farms are critical because they can lead to **significant power production losses** as they represent large zones of intense turbulence and low velocity, when compared to the free streaming air interaction with the turbulent flow

Frequently, wake effects are not considered as the adopted control strategies rely on the maximization of the power generation of each turbine, by aligning its axe with the incoming wind, which lead to overall sub-optimal performance

A control strategy that has been receiving attention in recent years is **yaw-based wake steering**, where the rotors of upstream turbines are intentionally misaligned, deflecting wakes away from downstream turbines



R.J.A.M. Stevens, D.F. Gayme, and C. Meneveau, Large eddy simulation studies of the effects of alignment and wind farm length, JRSE 6, 023105 (2014)

Wake steering optimization problem under uncertainties

Computational costs associated with solving an optimization problem under uncertainties can become prohibitive, specially if an expensive high-fidelity model for the wake flow is used

Machine Learning (ML) algorithms and models have been increasingly applied to simulate the farm internal flow complexity, and to design and control, enabling robust predictions using data produced by the fusion of high and low fidelity simulations with field measurements

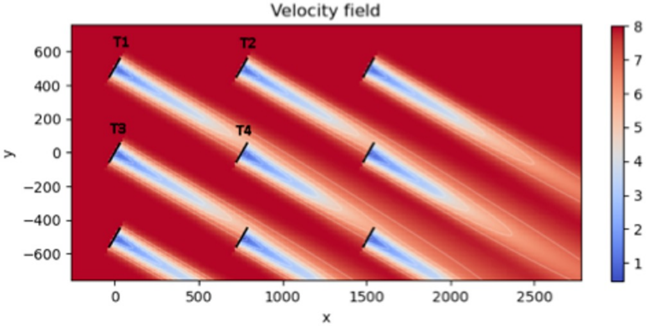
DNN, GP, FCNNs, Deep Convolutional Conditional GANs are examples of strategies to generate ML surrogates to reduce overall costs of sampling strategies (Monte Carlo method)

Probabilistic Learning on Manifolds (PLoM) method is for Wake Steering Optimization under Uncertainty[1]

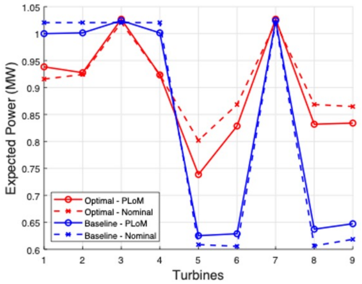
PLoM can be seen as a **supervised machine learning method**

PLoM enables analyzing wake steering optimization considering the variability of the wind conditions in the form of **uncertainties**

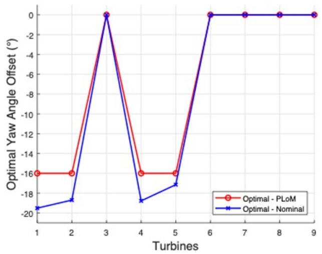
UQ analysis with PLoM are **much faster** than MC methods



Wind farm layout with nine wind turbines with the wind coming from the lateral direction



Power of each wind turbine



Optimal yaw angle offsets

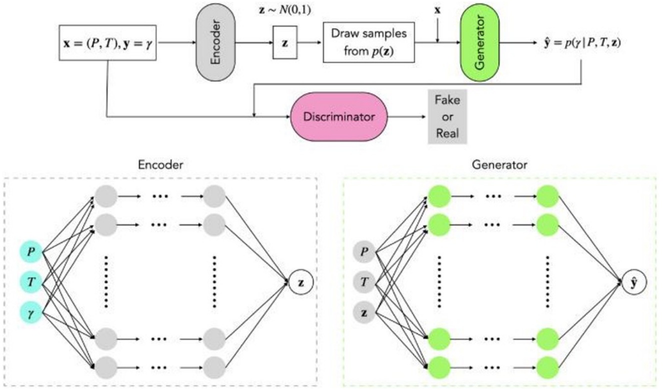
[1]Almeida & Rochinha, A Probabilistic Learning Approach Applied to the Optimization of Wake Steering in Wind Farms, Journal of Computing and Information Science in Engineering, 2022

Decarbonization and Sustainability - Efficient Fuels

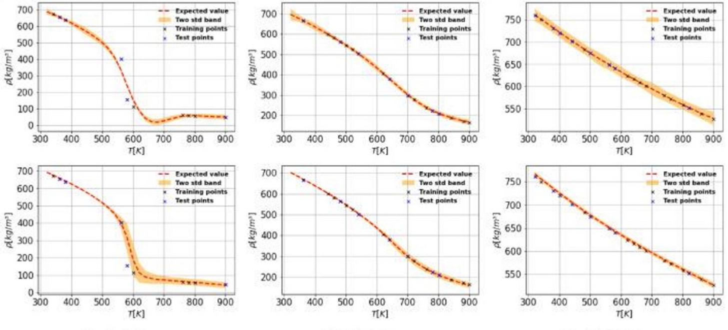
Biofuels operating at extreme conditions (super critical) are believed to be good alternatives to fossil fuels and might represent a substantial decrease in carbon emissions.

Biofuels performance is not well characterized and due to costs and complexity, computational models are considered important tools

Phsysichocemical properties (needed for simulations) of such fuels are not well understood, what could be circumvented with the intensive use of Molecular Dynamics models, **which is not feasible due to computational complexity**, but this can be alleviated by using Machine Learning Techniques.



Schematic view of the conditional generative model

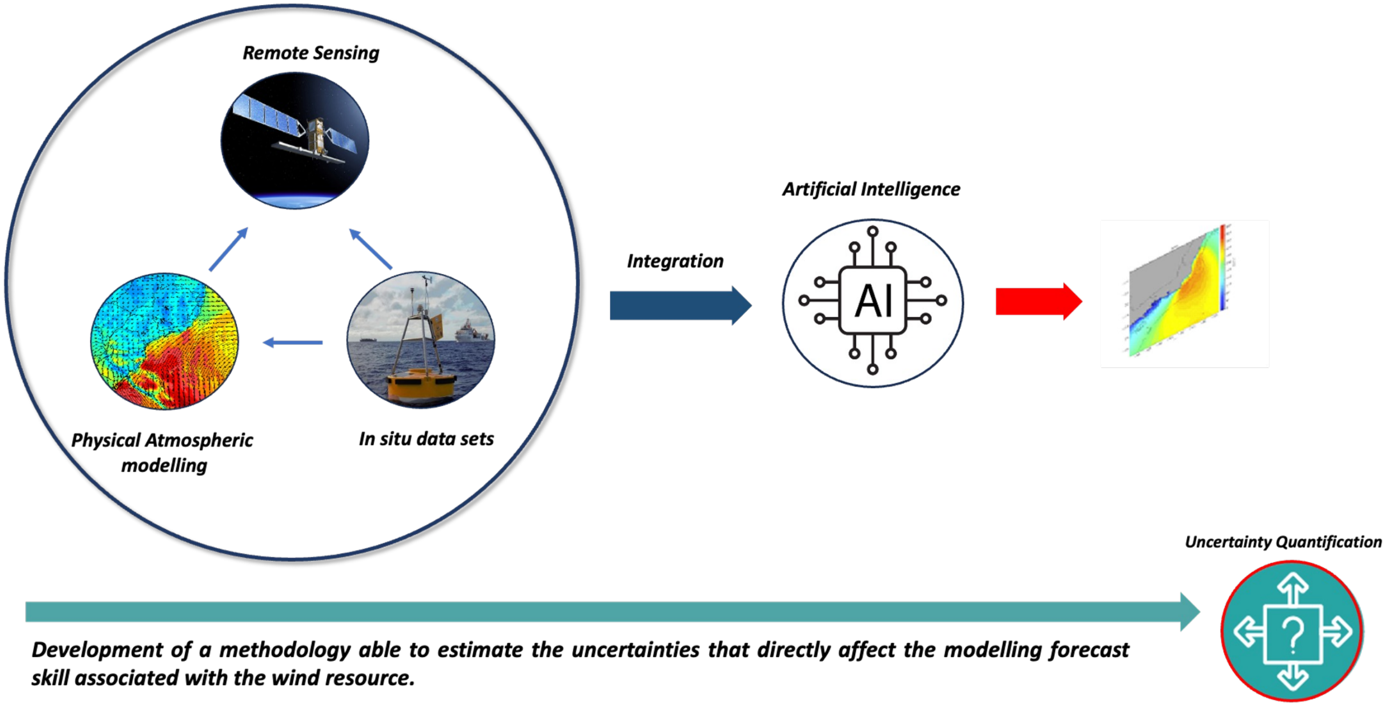


(a) 3 MPa (b) 10 MPa (c) 100 MPa

n-Octane predictions with the GP (top) and probabilistic conditional generative models (bottom) at the pressures 3, 10, and 100 MPa

Rodolfo SM Freitas, Ágatha PF Lima, Cheng Chen, Fernando A Rochinha, Daniel Mira, Xi Jiang. Towards predicting liquid fuel physicochemical properties using molecular dynamics guided machine learning models. Fuel, 2022.

Development of Methodology for estimating offshore wind energy potential based on the integration of Artificial Intelligence, Regional Atmospheric Physical Modelling and Remote Sensing Images



TotalEnergies

Developing and Implementing Neural Operators for Multiscale Modeling of Three Phase Flow in Porous Media

Exploring and leveraging different Machine Learning models and tools (DNN, NOs) to build efficient computational solutions to handle the design and implementation of efficient simulators for field scale three-phase black oil flows

Particular emphasis is placed on deep understanding the impact of subsurface uncertainties in the predictions employing a probabilistic perspective

Applications in CCS and reservoir management

ExxonMobil

What links (from AI perspective) such applications?

The previous renewable energy applications (and many more) are very different in their nature but they share some common ground:

- **Complex multi-physics, multi-scale** characteristics difficult to be captured and simulated with well established techniques.
- **Rare events** are to be detected within risk analysis
- **Uncertainties** are to be taking into account (raising the complexity and dimensionality of the mathematical underlying problems).

Non-conventional approaches are in need. Machine Learning and Artificial Intelligence are supposed to play a key role, but:

> **DATA is scarse and noisy**, and, in many situations, expensive to be acquired (the small data regime in contrast with the big data era).
>
> Combining consolidated (physics based) knowledge with ML and AI is the way to go …

CEAIRES's Main Results

Consolidate an interdisciplinary Center capable of producing innovative methodological advances and technological solutions involving digital transformation and AI techniques in the area of renewable energies **in line with several initiatives** in Europe and USA

Enable **advanced forecast** in wind and solar energy by AI

Improve power generation using wind, solar, biomass and hydrogen

Continuous education in the use of artificial intelligence in renewable energy applications

Generate an **innovation ecosystem** in advanced digital technologies for renewables

Contribute to **improve the Brazilian clean energy production** and meet the Paris Agreement climate goals