INSTITUT FÜR
ENERGIETECHNIK UND
THERMODYNAMIK
Institute for Energy Systems and Thermodynamics

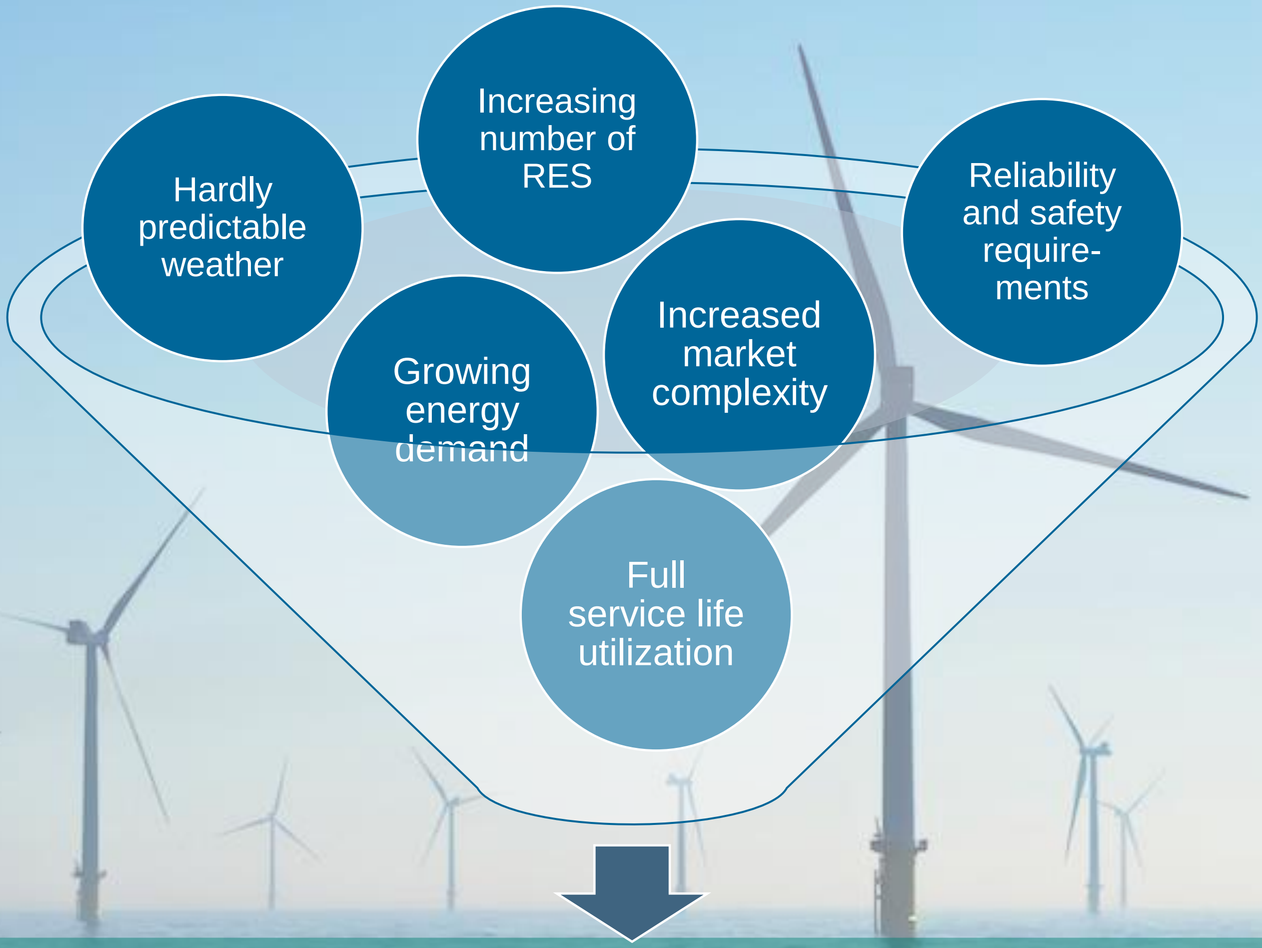
WESC 2023
23 - 26 MAY | GLASGOW, UK

Using Reinforcement Learning to Optimize Operational Strategies for Wind Energy Systems

Carlotta Tubeuf
Institute of Energy Systems and Thermodynamics, TU Wien

May 26, 2023

Motivation



Long term profit maximization through the optimal operating strategy

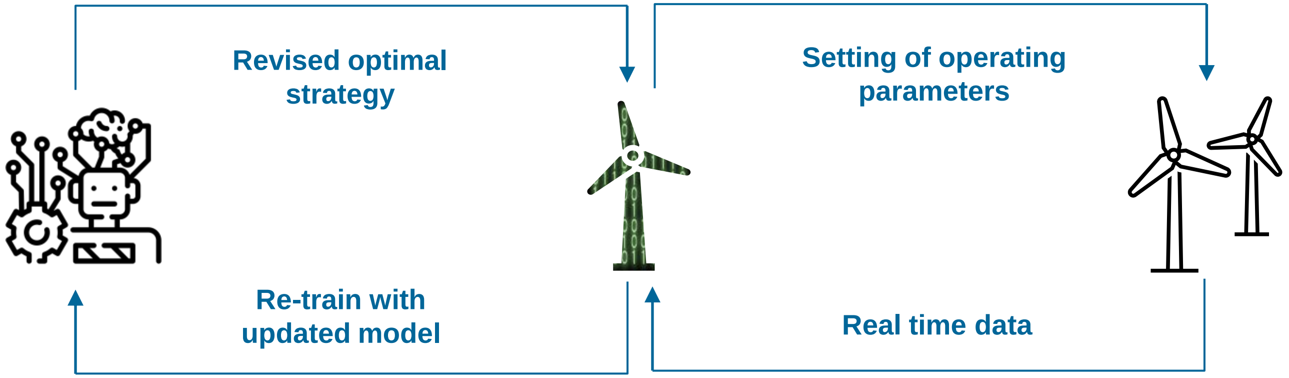
PHOTO BY NICHOLAS DOHERTY ON UNSPLASH

Introduction

Advanced optimization methods are needed to find optimal operating strategies for wind energy systems

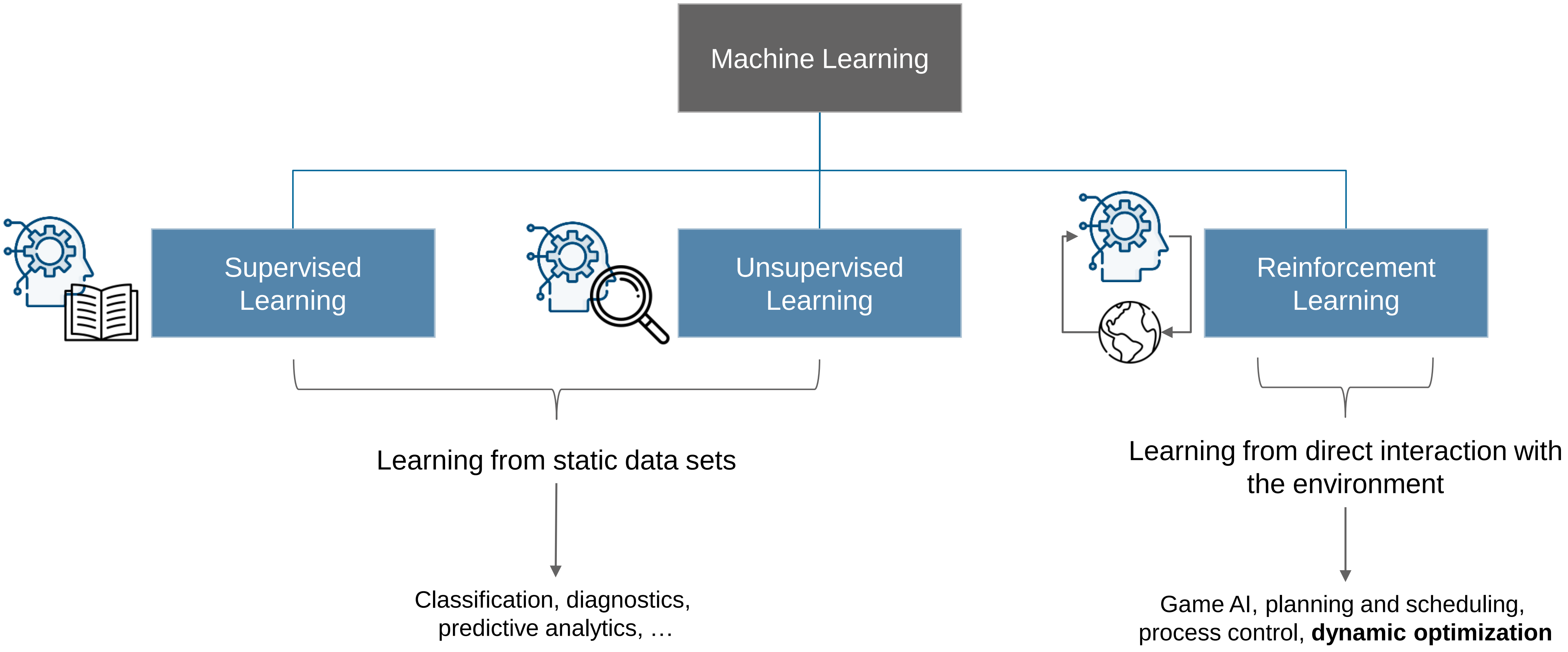
→ **Reinforcement learning** for operational planning

- Potential to handle highly complex environments with multiple objectives
- Optimal solution can be found without prior knowledge
- In combination with a digital twin platform, RL can learn continuously, adapt the operating strategy and interact with the real wind turbine



IMAGES: FLATICON.COM

Reinforcement learning

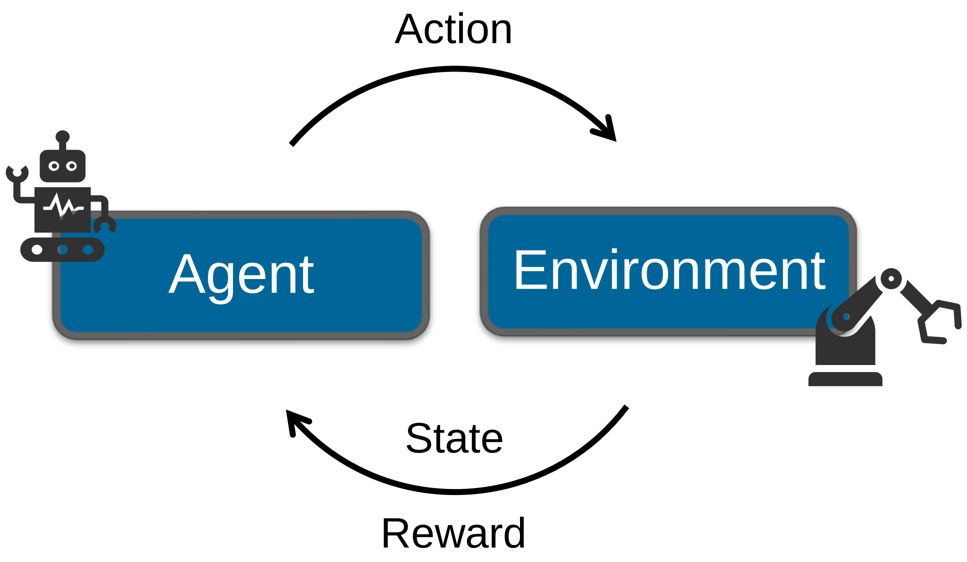


IMAGES: FLATICON.COM

J. H. LEE, ET AL., "MACHINE LEARNING: OVERVIEW OF THE RECENT PROGRESSES AND IMPLICATIONS FOR THE PROCESS SYSTEMS ENGINEERING FIELD," *COMPUT. CHEM. ENG.* 114 (2018): 111–121.

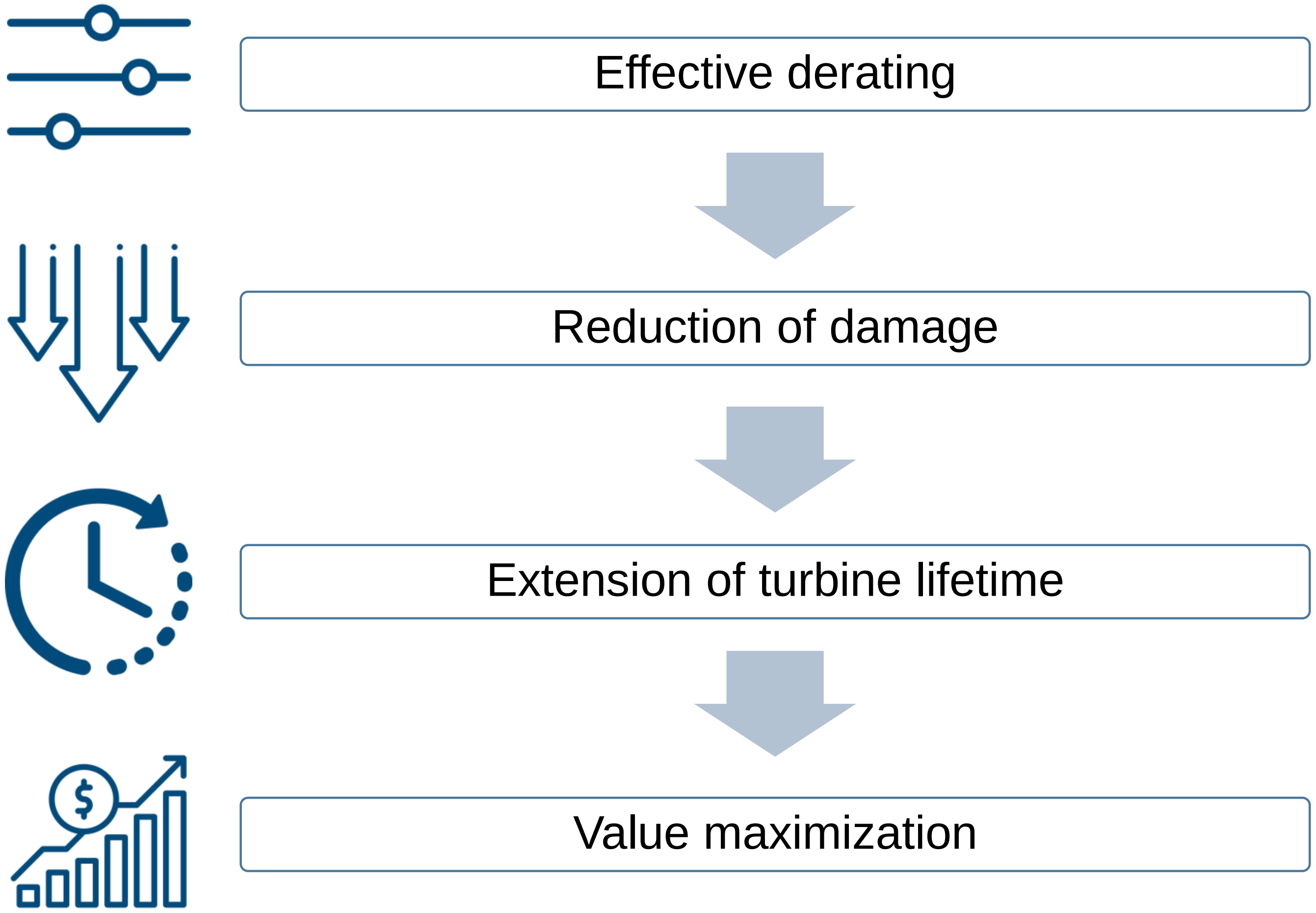
Reinforcement learning

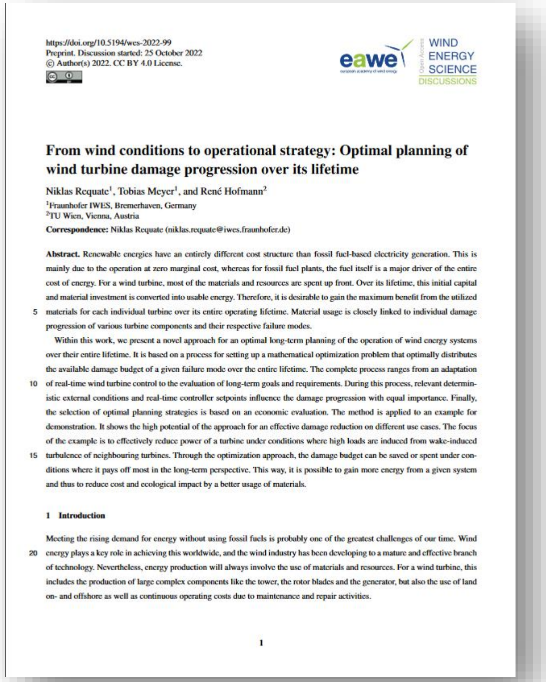
- Reinforcement learning **agent** takes an **action** that leads to a change in the **environment**
- The **policy** defines how the agent behaves in a given situation
- Goal = finding the optimal policy that maximizes the **cumulative reward** by directly interacting with the environment



R. S. SUTTON, ET AL., REINFORCEMENT LEARNING: AN INTRODUCTION, SECOND EDITION. CAMBRIDGE, MASSACHUSETTS; LONDON, ENGLAND: THE MIT PRESS (2018).

Proof of concept





https://doi.org/10.5194/wes-2022-99
Preprint. Discussion started: 25 October 2022
© Author(s) 2022. CC BY 4.0 License.

WIND ENERGY SCIENCE DISCUSSIONS

From wind conditions to operational strategy: Optimal planning of wind turbine damage progression over its lifetime

Niklas Requate[1], Tobias Meyer[1], and René Hofmann[2]
[1]Fraunhofer IWES, Bremerhaven, Germany
[2]TU Wien, Vienna, Austria
Correspondence: Niklas Requate (niklas.requate@iwes.fraunhofer.de)

Abstract. Renewable energies have an entirely different cost structure than fossil fuel-based electricity generation. This is mainly due to the operation at zero marginal cost, whereas for fossil fuel plants, the fuel itself is a major driver of the entire cost of energy. For a wind turbine, most of the materials and resources are spent up front. Over its lifetime, this initial capital and material investment is converted into usable energy. Therefore, it is desirable to gain the maximum benefit from the utilized materials for each individual turbine over its entire operating lifetime. Material usage is closely linked to individual damage progression of various turbine components and their respective failure modes.

Within this work, we present a novel approach for an optimal long-term planning of the operation of wind energy systems over their entire lifetime. It is based on a process for setting up a mathematical optimization problem that optimally distributes the available damage budget of a given failure mode over the entire lifetime. The complete process ranges from an adaptation of real-time wind turbine control to the evaluation of long-term goals and requirements. During this process, relevant deterministic external conditions and real-time controller setpoints influence the damage progression with equal importance. Finally, the selection of optimal planning strategies is based on an economic evaluation. The method is applied to an example for demonstration. It shows the high potential of the approach for an effective damage reduction on different use cases. The focus of the example is to effectively reduce power of a turbine under conditions where high loads are induced from wake-induced turbulence of neighbouring turbines. Through the optimization approach, the damage budget can be saved or spent under conditions where it pays off most in the long-term perspective. This way, it is possible to gain more energy from a given system and thus to reduce cost and ecological impact by a better usage of materials.

1 Introduction

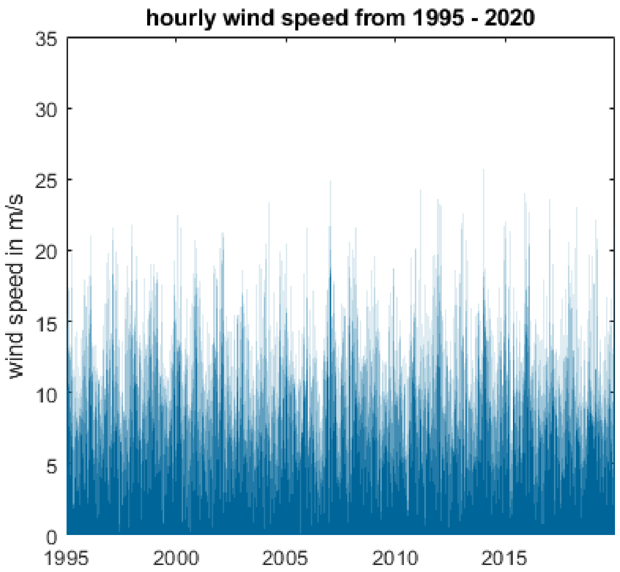
Meeting the rising demand for energy without using fossil fuels is probably one of the greatest challenges of our time. Wind energy plays a key role in achieving this worldwide, and the wind industry has been developing to a mature and effective branch of technology. Nevertheless, energy production will always involve the use of materials and resources. For a wind turbine, this includes the production of large complex components like the tower, the rotor blades and the generator, but also the use of land on- and offshore as well as continuous operating costs due to maintenance and repair activities.

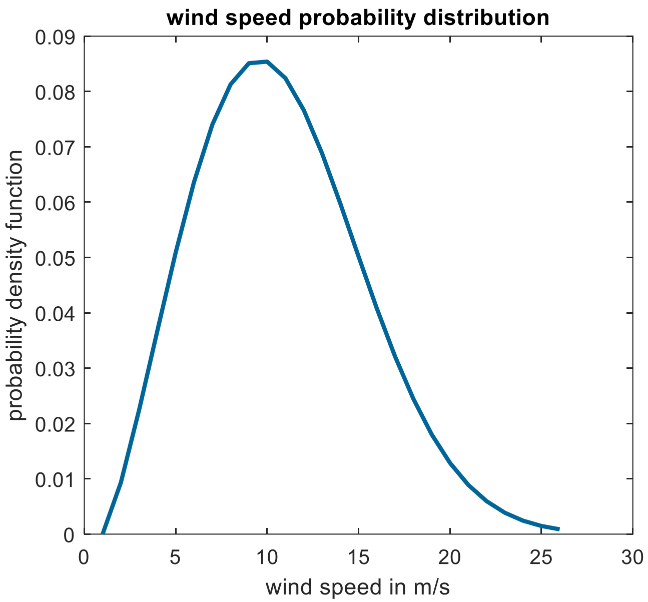
1

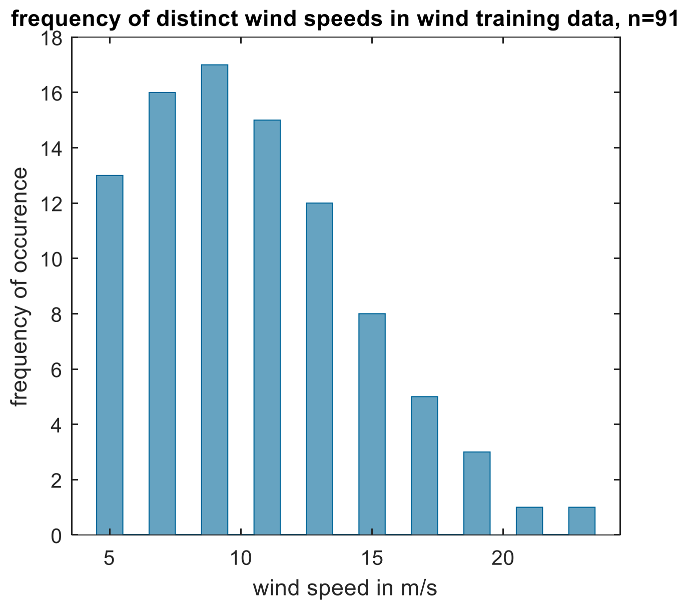
N. REQUATE, T. MEYER, UND R. HOFMANN, „FROM WIND CONDITIONS TO OPERATIONAL STRATEGY: OPTIMAL PLANNING OF WIND TURBINE DAMAGE PROGRESSION OVER ITS LIFETIME“ [UNDER REVIEW], *WIND ENERGY SCIENCE DISCUSSIONS*, S. 1–51, OKT. 2022, DOI: 10.5194/WES-2022-99.

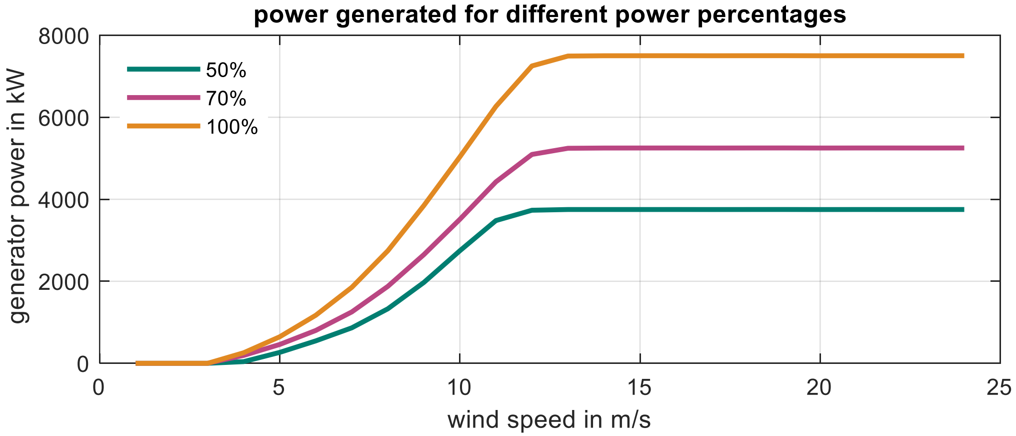
IMAGES: FLATICON.COM

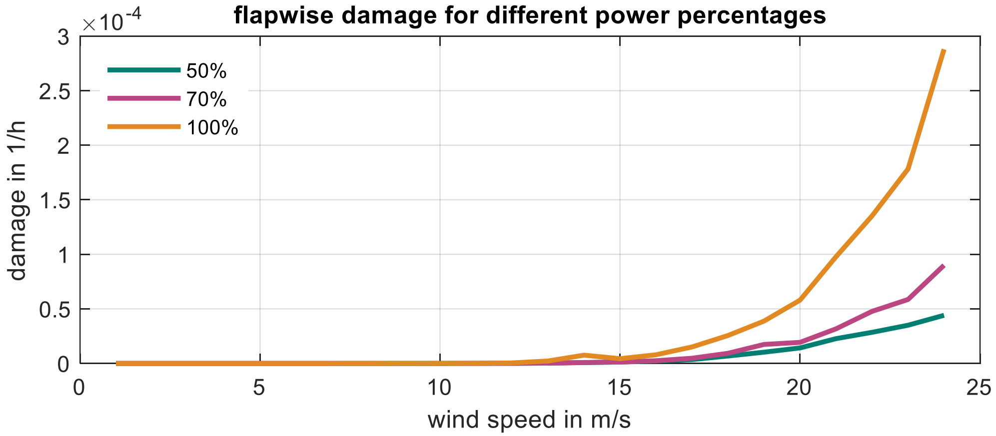
Calculation environment





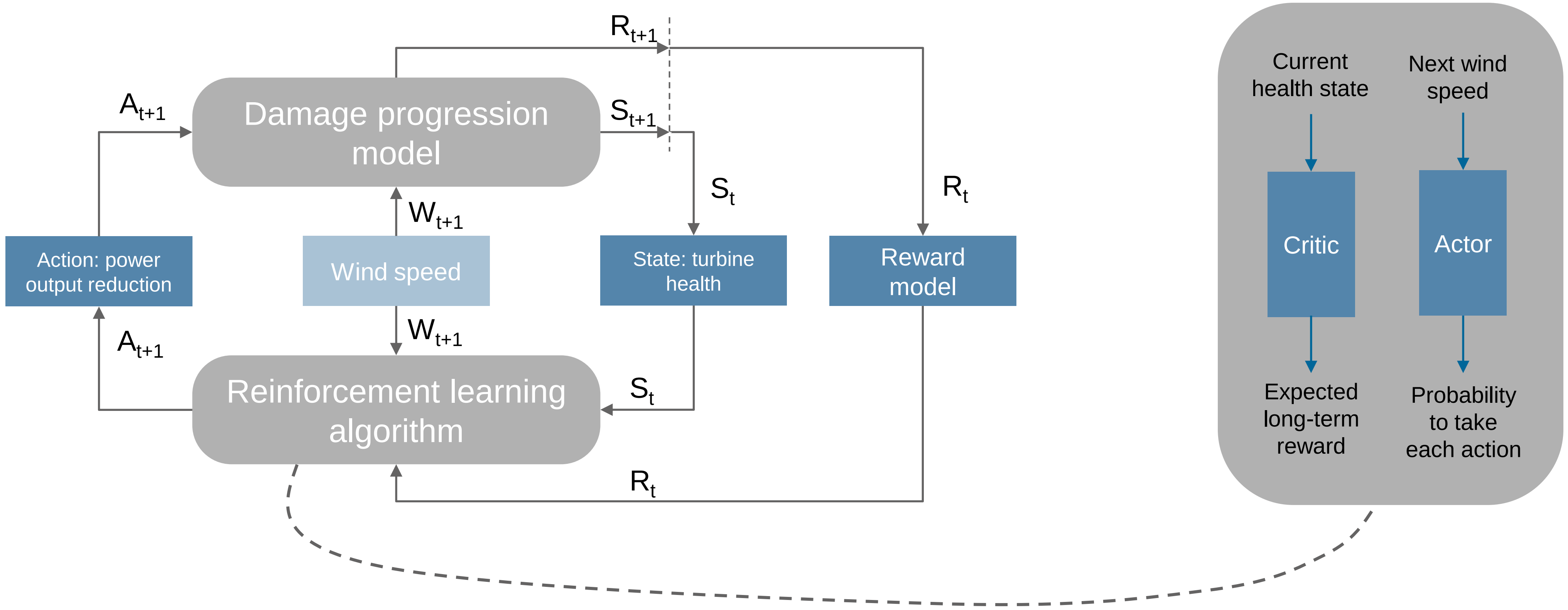






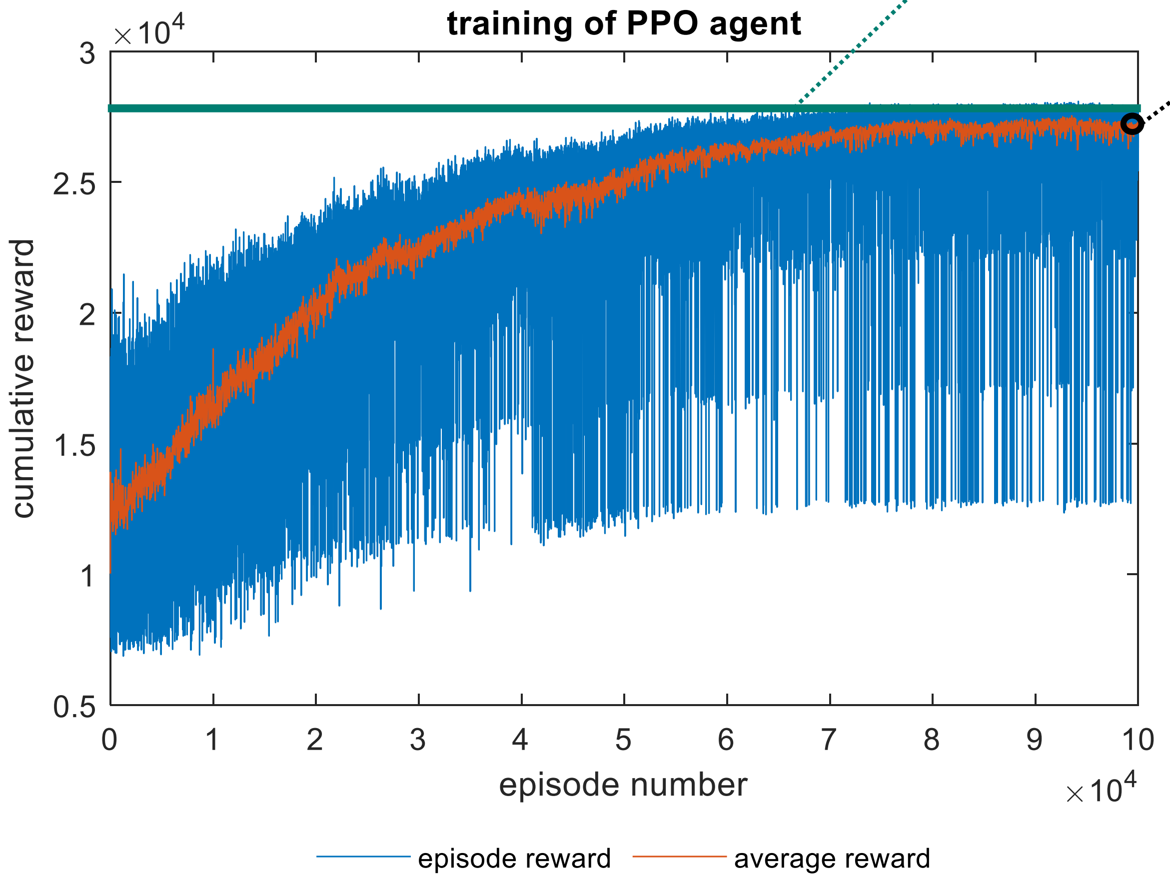
RL problem formulation

- Proximal Policy Optimization (PPO) reinforcement learning method
- Uses a value function critic and a stochastic policy actor

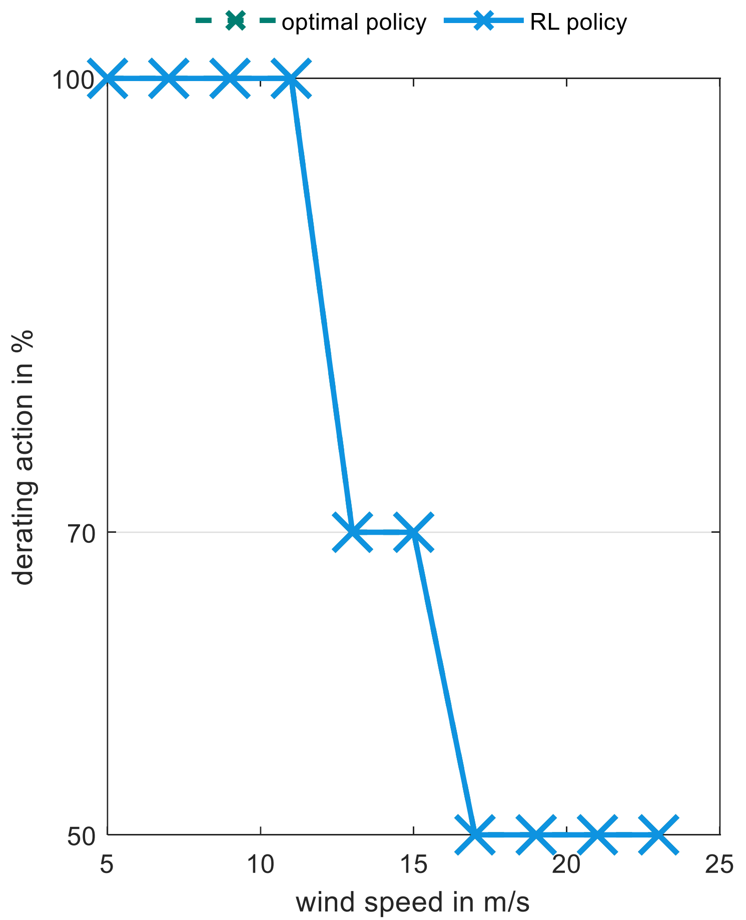


Training progress

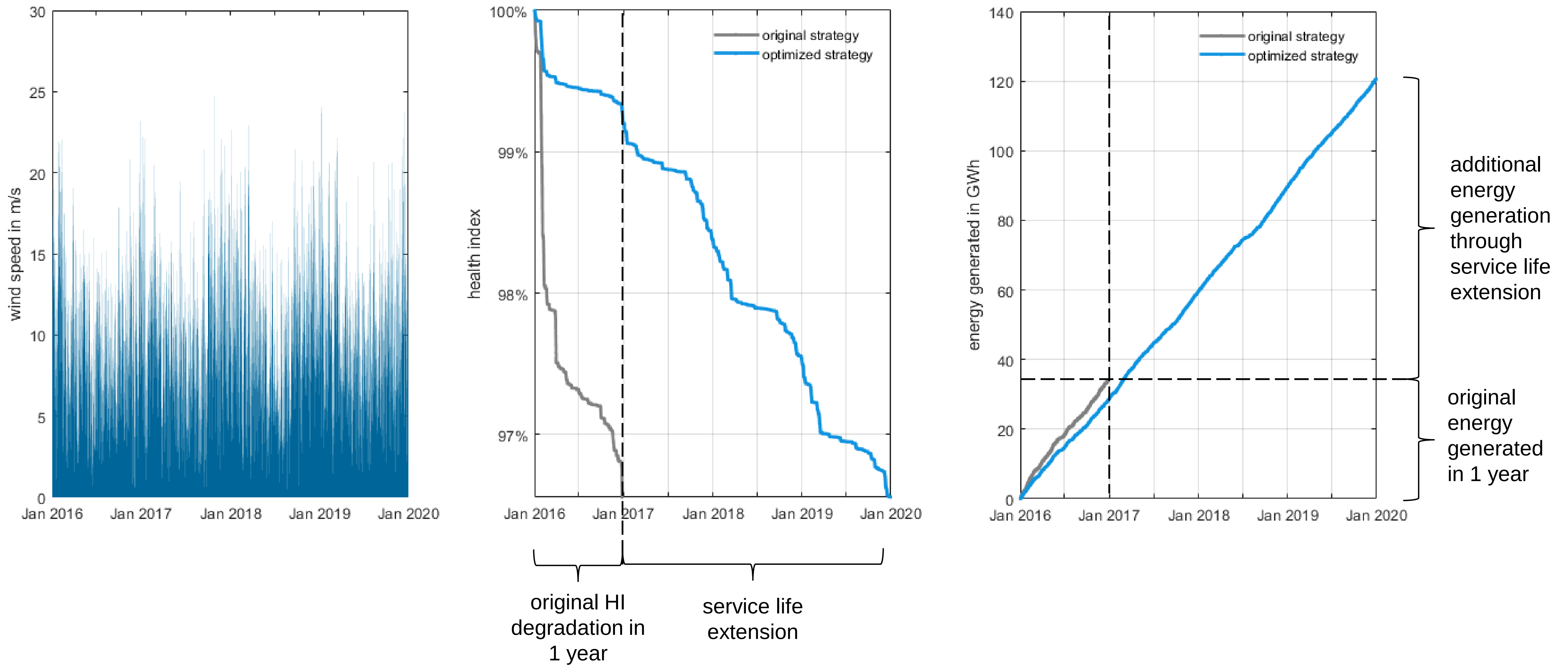
Optimal reward = 2.8 * 10^4



RL policy after 100 000 training episodes



Value maximization through service life extension

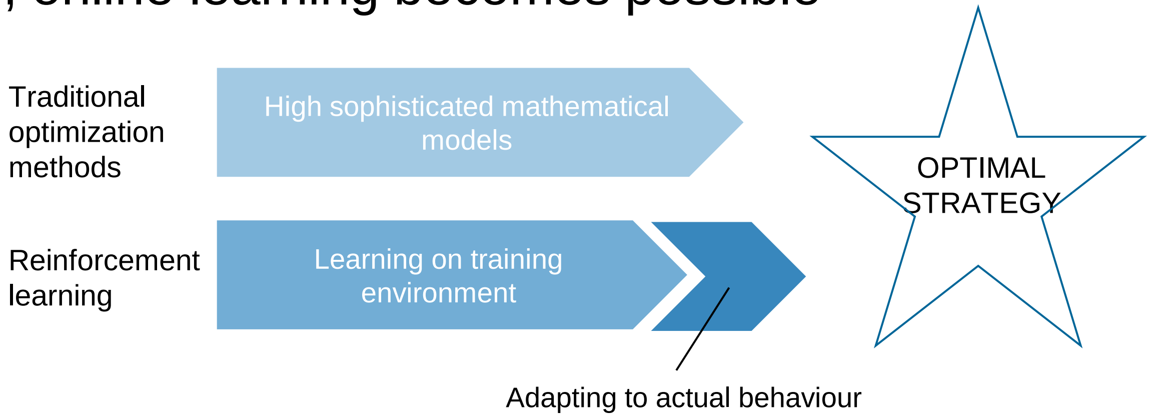


Summary

- Many factors need to be considered when searching for the **optimal operating strategy** for wind energy systems
- **Reinforcement learning** is a promising method that can handle **complex environments**
- The influence of wind makes the problem **highly stochastic** → actor-critic reinforcement learning algorithms are probably best suitable for problems in wind energy
- RL agent is able to find the same optimal strategy as Requate et al. without any prior knowledge
- With Reinforcement Learning, the same conclusion can be drawn as with mathematical optimization: **Effective derating can lead to value maximization through lifetime extension**

Discussion

- Mathematical modelling and optimization will always be necessary to formulate training environments, but RL holds great potential for larger action and state spaces
- Through a digital twin platform, online learning becomes possible



- Future research will use deep reinforcement learning to handle more complex environments:
  - Considering further influences on the damage progression
  - Considering market prices when feeding energy into the grid
  - Considering targeted maintenance periods
  - Etc.

INSTITUT FÜR
ENERGIETECHNIK UND
THERMODYNAMIK
Institute for Energy Systems and Thermodynamics

Carlotta TUBEUF
PhD student at research unit industrial energy systems
carlotta.tubeuf@tuwien.ac.at | ORCiD: 0000-0001-9452-7812

Dr. Felix BIRKELBACH
PostDoc researcher at research unit industrial energy systems
felix.birkelbach@tuwien.ac.at | ORCiD: 0000-0003-4928-6209

Prof. Dr. René HOFMANN
Head of institute of energy systems and thermodynamics
rene.hofmann@tuwien.ac.at | ORCiD: 0000-0001-6580-4913