UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

COURSE SYLLABUS

Advanced Technologies for Renewable Energy Concepts

2627-2-F7603Q012-F7603Q01201

Aims

This course aims to provide students with an advanced understanding of the physics behind renewable energy technologies, emphasizing the role of physical models and artificial intelligence (AI) in energy system optimization. Building on the concepts introduced in Physical Bases for Modern Energies, the course explores cutting-edge developments in renewable energy, including solar, wind, hydro, and hybrid systems, with a focus on integration strategies for Net Zero Energy Buildings (NZEB).
A key aspect of the course is the combination of physical models and AI-based approaches to improve energy forecasting, system design, and operational efficiency. The course is structured in two main parts:

1. Theoretical lectures (32 hours, in-person) ? Fundamental physical principles governing energy technologies.
2. Online applied sessions (16 hours, remote) ? Hands-on experience with energy system simulations, AI-driven forecasting, and economic evaluations using RETScreen and Python-based tools.

By the end of the course, students will be able to:

- Critically analyze advanced energy technologies from a physics-based perspective.
- Integrate AI-driven models with physical models for energy forecasting and system optimization.
- Evaluate the feasibility and sustainability of different renewable energy systems.
- Design hybrid energy systems combining solar, wind, and storage solutions for NZEB applications.

Contents

- Overview of Renewable Energy Technologies: A brief recall of solar, wind, hydro, and hybrid systems, emphasizing their role in Net Zero applications.

- Key Photovoltaic Innovations: Review of recent advancements in multi-junction, perovskite, and bifacial solar technologies for system integration.

- Solar Thermal and Storage Solutions: Discussion of CSP and thermal storage strategies relevant to Net Zero design.
- Wind and Marine Energy for Net Zero: Summary of offshore wind, floating turbines, and marine energy technologies with a focus on integration potential.
- Energy Storage and System Optimization: Examination of battery technologies, hydrogen storage, and supercapacitors in the context of Net Zero energy management.
- Integration of Renewable Energy Systems: Smart grids, hybrid systems, energy balancing.
- Physics-Based Predictive Modeling: Application of fundamental physics principles to develop predictive models for energy systems.
- Net Zero Energy Buildings (NZEB): Energy modeling for residential, school, and industrial applications.
- AI and Energy Optimization: Machine learning for energy forecasting, hybrid modeling approaches.

Simulation Tools for Energy Planning: RETScreen for economic evaluation, Python for AI-driven analysis.

Case Studies and Practical Applications: Real-world projects integrating physics and AI models.

Detailed program

Part 1: Theoretical Foundations (In-person, 32 hours)

Introduction to Energy Technologies for Net Zero (2h)

- Overview of Net Zero goals, energy demand trends, and integration challenges.
- Brief recap of key physical principles from Physical Bases for Modern Energies (only as needed).

Technologies for Renewable Energy Systems (6h)

- High-efficiency photovoltaic technologies: multi-junction, perovskite, bifacial panels.
- Advances in CSP and thermal energy storage for large-scale applications.

Wind and Marine Energy in Integrated Systems (6h)

- Floating wind and offshore wind integration challenges.
- Marine energy (wave, tidal): role in hybrid renewable systems.

Energy Storage and System Balancing (6h)

- Battery technologies: innovations and applications in energy grids.
- Hydrogen as an energy carrier: feasibility and integration in Net Zero strategies.

Integrating Renewable Energy into Smart Systems (6h)

- Energy grids, hybrid energy configurations, demand-response.

- Optimization of distributed generation and storage using AI-assisted models.

Predictive Modeling and Simulation for Net Zero Systems (4h)

- Bridging physics-based models with AI for energy forecasting.
- Practical aspects of integrating renewable energy technologies into real-world applications.

Part 2: Online Applications & Simulations (Remote, 16 hours)

AI and Predictive Energy Models (4h, Python-based)

- Application of machine learning and deep learning for energy forecasting.
- Hybrid approaches: combining AI models with physics-based simulations.

Simulation and Economic Feasibility with RETScreen (4h)

- Economic modeling of Net Zero energy projects.
- Scenario analysis for different energy configurations.

Hybrid Modeling for Net Zero Systems (4h, Case Study)

- Developing a predictive model integrating physics and AI.
- Case study: optimizing energy management in a Net Zero building.

Final Project & Discussion (4h)

- Students create a custom simulation combining physical principles and AI techniques.
- Presentation and discussion of results, highlighting practical implications.

Prerequisites

Physics: Classical Mechanics, Thermodynamics, Electricity and Magnetism.

Mathematics: Single and Multivariable Calculus, Differential Equations.

Basic Programming Skills (Python preferred, but not mandatory).

Basic Knowledge of Renewable Energy Systems (from Physical Bases for Modern Energies).

Teaching form

6 CFUs (48 hours total):

- 32 hours of in-person theoretical lectures (Delivered Didactics - DE).
- 16 hours of online applied sessions, including case studies and simulations (Remote Didactics - RDE).

Case studies and discussions on advanced sustainable energy technologies.

Reading and analysis of scientific papers on energy innovation.

Joint discussions with the Socio-Political Aspects of Modern Energy Plants module.

Textbook and teaching resource

J. Tester et al. Sustainable Energy: Choosing Among Options

D. MacKay Sustainable Energy – Without the Hot Air

C. B. Vining Thermoelectric: Basic Principles and New Materials Developments

Lecture slides, notes, and additional scientific articles provided on the e-learning platform.

Semester

First semester

Assessment method

The final examination consists of an oral exam, with a grade ranging from 18 to 30/30. The exam will evaluate the student's ability to critically analyze and connect different energy technologies, considering their physical, economic, and societal aspects.

Assessment criteria:

1. Knowledge and understanding of advanced energy technologies.
2. Ability to connect different physics-based concepts and integrate economic and policy aspects.
3. Autonomy of analysis and judgment in evaluating sustainability and efficiency.
4. Proper use of scientific and technical terminology in energy discussions.

Office hours

Available by appointment via email.

Sustainable Development Goals

AFFORDABLE AND CLEAN ENERGY | INDUSTRY, INNOVATION AND INFRASTRUCTURE | SUSTAINABLE CITIES AND COMMUNITIES | CLIMATE ACTION