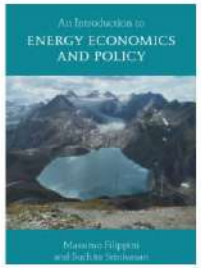
University of Tehran
School of Industrial Engineering

Energy Economics

Spring 2025

Course Description

- *Instructor:*
  - *Jalal Delaram*
  - *Website: https://jalaldelaram.github.io/web*
  - *Email: delaram@ut.ac.ir*
- *Class Time:*
  - *Sunday and Tuesday, 16:30 – 18:00*
- *References:*
  - *Class topics and transactions*
  - *Massimo Filippini, An Introduction to Energy Economics and Policy (2019)*



Chapter 1

Fundamentals

Overview

- *Integrates microeconomic theory, empirical analysis, and real-world case studies.*
- *Learning Objectives:*
  - *Analyze energy systems, market failures (e.g., externalities, behavioral anomalies).*
  - *Evaluate policy tools (taxes, subsidies, standards) and their equity implications.*
  - *Understand energy transition pathways (renewables, efficiency, electrification).*

What is Energy Economics?

- Economics is the study of how societies take decisions related to the production and consumption of goods and services to satisfy their needs in an efficient and sustainable manner, given scarce resources

- The application of economics to answer three questions:
  1. Which goods and services should be produced?,
  2. How should we produce these goods and services?, and
  3. For whom should these goods and services be produced?

What is Energy Economics?

- Energy economics is the application of the principles of economics to the study of how energy sources can be managed and used in an efficient and sustainable way to produce goods and energy services.

- Economic analysis of energy systems can be based on using ...
  - A microeconomic approach that studies the behaviour of individual agents such as consumers and firms, or
  - a macroeconomic approach that provides an analysis of the economic issues at the aggregate level of an economic system.

What is Energy Economics?

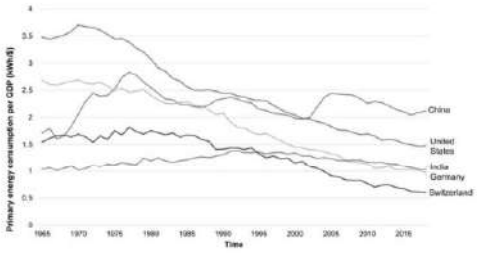
- If we now consider the energy sector, we can also identify three fundamental questions that we should answer in this sector:
  1. Which energy sources and energy services (such as heating, cooling, or lighting) should be produced?
  2. Which technologies and energy sources should be used to produce goods and energy services?
  3. For whom should the energy sources and services be produced?

The Role of Energy in Economic Systems

- The ultimate objective of any economic system is to enhance the well-being of both current and future generations of a society while taking into account the limits of natural resource availability as well as the Earth's constraints.
- Energy is a driver of economic growth
- Energy plays a crucial role as a production factor in several sectors, such as the industrial, transportation, services, and residential sectors

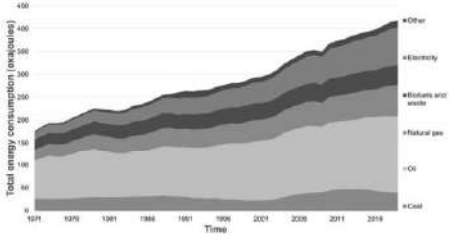
The Role of Energy in Economic Systems

- *While energy is an essential input in the production processes for goods and services, its role in contributing to production has generally declined over time.*
- *That is, reduced the total amount of energy consumed per unit of gross domestic product (GDP).*



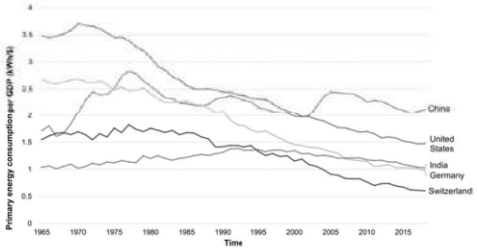
Global Energy Consumption Trends

- *Figure illustrates the trends in the total final energy consumption by source for the world.*
- *We observe a general reliance on the current energy systems on fossil fuels (coal, oil, and natural gas),*
- *A considerable share of the global electricity supply is also generated using fossil fuels.*
- *Energy consumption is steadily increasing.*
- *This development is largely driven by an increase in energy demand in the growing developing countries, whereas in industrialised countries, it has mostly been stable.*



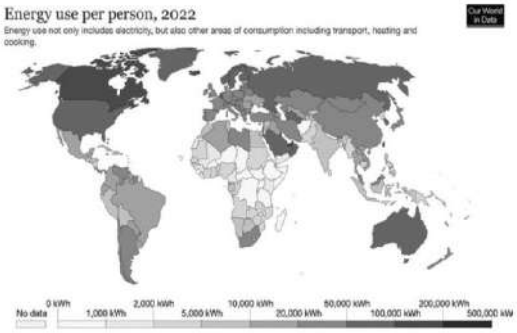
The Role of Energy in Economic Systems

- *We find that in general, energy intensity levels have declined over this period.*
- *This improvement does not imply, however, that the importance of energy has diminished; on the contrary, energy remains one of the main elements in promoting the well-being of all economic agents.*
- *This decline simply reflects technological gains over time, which have changed how societies use energy.*



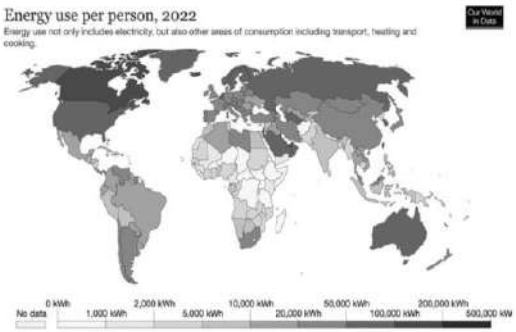
Global Energy Consumption Trends

- *Figure shows the total per capita energy consumption around the world, as of 2022.*
- *The value of this energy metric in several developed regions of the world, especially in the United States, Canada, Russia, Australia, Saudi Arabia, and the Nordic countries is much higher compared to that in the currently developing, or lower-income economies.*



Global Energy Consumption Trends

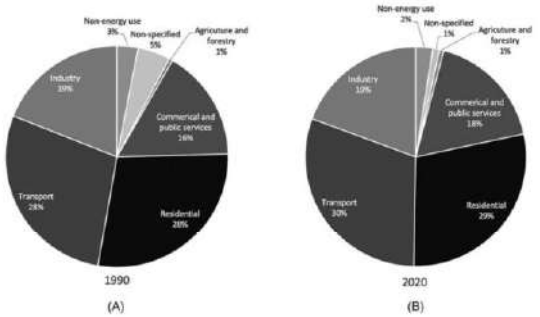
- *80% of global population uses <20% of energy.*



2/23/2025

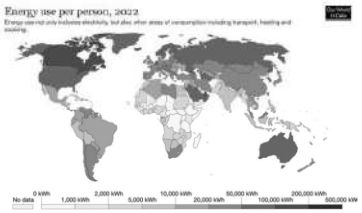
Who Uses Energy?

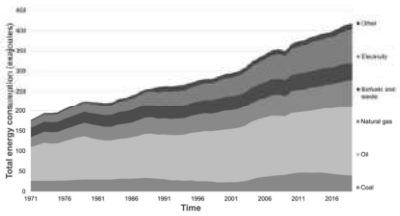
- *Industrialized Nations: Switzerland: Transport (30%) and residential (29%) dominate.*



Global Energy Consumption Trends

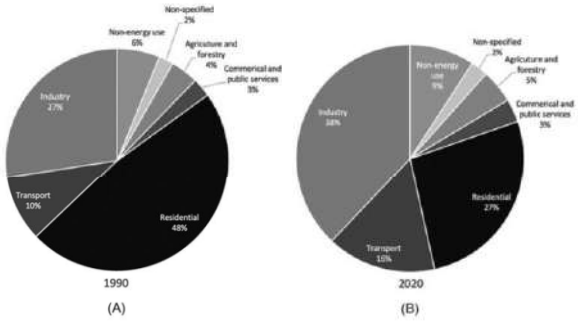
- *Emerging Trends:*
  - *Developing nations (India, Nigeria) drive future demand growth.*
  - *Industrialized nations plateau due to efficiency and population stabilization.*





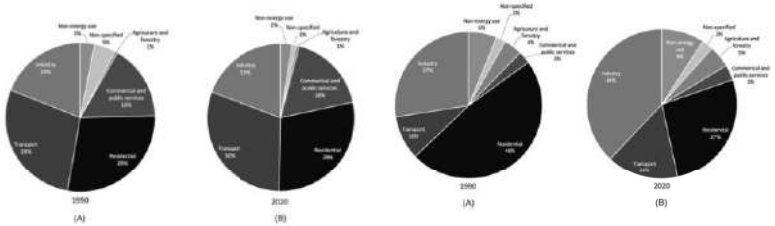
Who Uses Energy?

- *Developing Nations: India: Industry (38%) and residential (27%) lead.*



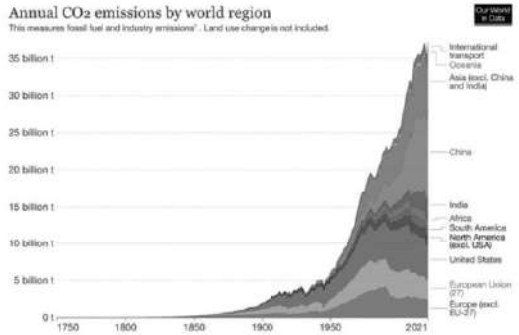
Who Uses Energy?

- *Transport demand in developing nations to surge (vehicle ownership, urbanization).*



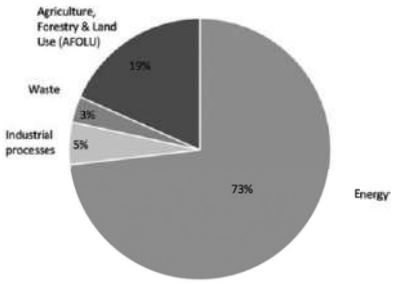
Greenhouse Gas Emissions

- *Historical CO_2 emissions (U.S. and EU cumulative vs. China's recent surge).*



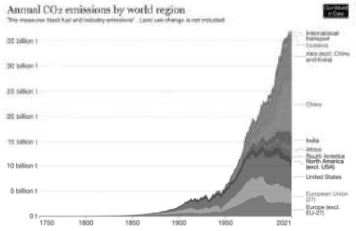
Greenhouse Gas Emissions

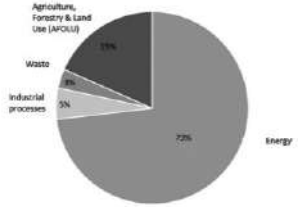
- *Energy sector = 73% of global GHG emissions.*



Equity Debate in Greenhouse Gas Emissions

- *Industrialized nations' historical responsibility vs. developing nations' growth needs.*





Problems with Current Energy Systems

- *Four Crises:*
  1. ***Environmental:*** *PM2.5 in Delhi (90 µg/m³ vs. WHO limit 5 µg/m³).*
  2. ***Non-Renewables:*** *Oil reserves concentrated in unstable regions (Middle East 48%).*
  3. ***Geopolitical Risks:*** *Ukraine war's impact on EU gas prices.*
  4. ***Inefficiency:*** *McKinsey study: U.S. could save $1.2 trillion via efficiency.*

The Energy Transition

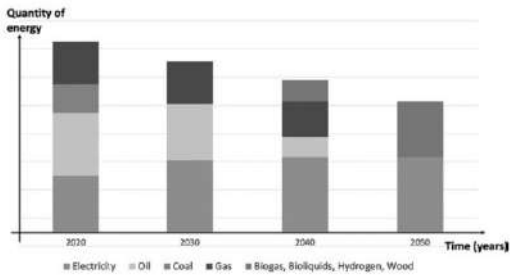
- *Through the energy transition, governments want to achieve an energy system dominated by electricity produced from renewable energy sources within the next two to three decades.*

The Energy Transition

- *Energy transition refers to a structural change in the current energy system with respect to supply and demand.*
- *On the supply side, the energy transition implies a shift away from traditional fossil fuels such as coal, oil, and gas towards more sustainable and renewable energy sources, such as solar energy, wind energy, and hydropower.*
- *On the demand side, the energy transition involves the adoption of energy-efficient technologies, investments in digitalisation to optimise energy consumption, as well as making changes to consumption behaviour.*

The Energy Transition

- *An illustration of a possible pathway of the transition of an energy system for a typical industrialised country from fossil fuels towards an energy system based on renewable energy sources and electricity produced using renewable energy.*
- *Starting from an energy system dominated by oil, gas, and coal, the transition results in an energy mix that is dominated by renewable energy sources such as biogas, hydrogen, biofuels, and wood and electricity produced from renewable energy sources.*



The Energy Transition

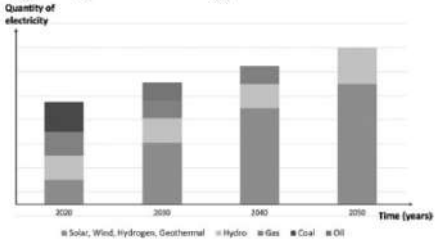
- *An important point to note regarding the energy transition is the relevant decrease in total energy consumption due to the adoption of more energy-efficient technologies and the electrification of the transport and heating sectors.*
- *This is likely to be the case for industrialised countries.*
- *In developing countries, we expect a similar transformation towards renewable energy sources and an increase in overall energy efficiency, but we also expect an increase, and not a decline, in total energy consumption.*
- *This increase will be driven mostly by economic growth and population increases.*

The Energy Transition

- *Generally, it is expected that the electrification of sectors such as transport and heating will increase the electricity demand.*
- *The energy transition implies that the suppliers will also increase electricity production, largely based on renewables.*
- *In order to reach a well-functioning electricity system relying mainly on renewable energy sources such as solar energy and wind energy, which are characterised by intermittence in production due to meteorological factors, it is essential to:*
  1. *have a well-developed, interconnected electricity distribution network that enables the flexible and dynamic management of demand and supply using digitalisation*
  2. *have a backup technology, such as gas-based power plants functioning with hydrogen, or technologies such as storage hydropower plants or large batteries that can be used during periods of supply shortages, which are mainly operated at the national level.*

The Energy Transition

- *Regarding the transformation of the electricity sector in industrialised countries illustrated Figure ...*
- *At the end of the transition process, the electricity production mix will be mainly based on hydropower, wind energy, solar energy, and geothermal energy.*
- *The electricity production mix is likely to be different across countries depending on their characteristics. We foresee this transformation taking place also in developing countries, although with a different path between 2030 and 2050*

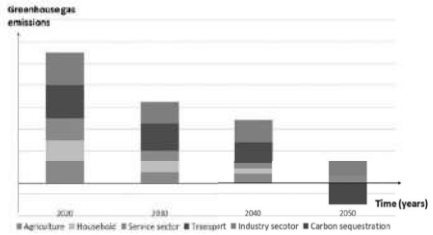


The Energy Transition

- *Some policymakers use the term 'energy transition' in combination with the term 'net zero'.*
- *This refers to a transition that is used to achieve an energy system characterised mainly by renewable energy sources, along with a small proportion of fossil fuel-based energy essential for sectors in which renewables cannot be employed.*
- *Since the energy transition also implies achieving climate neutrality, that is, an energy system that produces zero CO2 emissions, emissions from the sectors that still use fossil fuels must be captured and stored in dedicated repositories underground*

The Energy Transition

- *Figure illustrates the development of GHG emissions over time.*
- *Towards the end of the energy transition process, emissions are likely to be low, and, as discussed previously, they can be eliminated using carbon capture and sequestration technologies.*
- *For instance, emissions from industrial processes such as steel and cement production are likely to be captured from the production sites, and then transported and stored deep underground in geological formations*

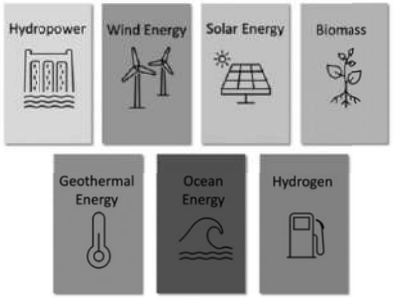


The Energy Transition

- *Generally, we distinguish between direct **benefits** and **co-benefits** of an energy transition.*
- *The direct benefits are obtained from the avoided negative climate change impacts, such as damages due to natural extreme events, agricultural yield losses, and adverse effects on labour productivity.*
- *Co-benefits result from the reduction of air pollution, greater biodiversity, enhanced water quality, and improved security of supply.*
- *It is, therefore, important to consider both costs and benefits (including these co-benefits) in all discussions about the energy transition, even though some benefits, such as the increase in air and water quality, as well as an increase in the security of supply, are not easy to estimate from an economic point of view.*

The Energy Transition

- *Type of renewable energy sources for the energy transition*



The Energy Transition

- *The energy transition is an extremely essential but also challenging goal for societies to achieve.*
- *To reach this goal, we need to continue to invest in research and development activities to further enhance the exploitation of renewable energy sources, increase the level of energy efficiency, and digitalise the electricity sector.*
- *To ensure that they reach this ambitious goal, governments around the world are trying to design and implement effective energy and climate policies.*