Energy and Resource Economics (IKT3610)

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Lecture 1 (08 Oct 2020)

Introduction to Energy

- Energy economics is the branch of economics that analyzes energy markets.
- Electricity, being a form of energy, is contained in the field of energy economics. Thus, electricity economics is that part of energy economics that refers to electricity markets, namely, the modalities and features through which electricity is produced, sold and purchased.
- The nature and physics of electricity have specific characteristics that have to be clearly understood
- This will give a clear picture of the constraints that they pose to the way energy as well as electricity markets function

- In the following, we will explain what energy and electricity are and the nature of their relationship.
- I will also specify the characteristics of electricity as a type of energy and briefly consider the evolution of the set of appliances, tools and technical apparels that enable it to be exploited.

Basic Principles of Energy

- Energy is whatever enables a body to do work. Work, in the physical sense, is a displacement against a resistance.
- We thus have a possible definition of energy, as stated in Newton's second law of motion:

***Energy**: the capability to do work, i.e., a displacement against a resistance:*

$$E = F \cdot x$$

F is a force, measured in Newtons, and x is a displacement, measured in any unit measure of distance, such as meter.

Basic Principles of Energy

Therefore, E is measured in Newton-meters. It is also measured in joules, where one joule corresponds to one Newton-meter:

Joule: *the work done, or energy transferred, by an object when a force of one Newton displaces it for one meter.*

The definition refers to work done, or energy transferred.

Q: Where is that energy transferred?

Basic Principles of Energy

We have said that the energy that exerts a force does work.

Heat is energy that does not carry out work.

A force is the product of mass (m) and acceleration (a):

$$F = m \cdot a$$

Acceleration is the rate of change of velocity (v):

$$v = \frac{dx}{dt},$$

$$a = \frac{dv}{dt}.$$

where the unit measure of

-velocity is meters per second (or any other ratio of distance over time),

-acceleration is meters per second squared (it is simply the derivative of distance per time over the same unit measure of time).

Basic Principles of Energy

Therefore,

$$E = F \cdot x$$
$$E = m \cdot a \cdot x$$
$$E = m \cdot \frac{dv}{dt} \cdot x$$
$$E = m \cdot \frac{dv}{dx}\frac{dx}{dt} \cdot x$$
$$E = m \cdot v \cdot \frac{dv}{dx} \cdot x$$

The final equation shows that energy is the product of the linear momentum ($m \cdot v$), *i.e.*, the (linear) velocity that holds the mass, and the term $\frac{dv}{dx} \cdot x$, which represents the applied force that gives rise to the relative change in the velocity, for a given distance.

Basic Principles of Energy

Recall: A mass possesses two kinds of energy: potential energy and kinetic energy.

The first depends on the position of the mass, the latter on its motion.

The potential energy is given by the gravitational force, applied to a mass at a given height (h) above a given plane:

$$E_p = g \cdot m \cdot h$$

where g is the gravitational constant ($g \approx 9.81 m/s^2$ - *what does the unit look like?*)

Basic Principles of Energy

The kinetic energy associated with a linear motion depends on the mass and the velocity by means of the following equation:

$$E_K = \frac{1}{2} \cdot m \cdot v^2$$

Equation for the kinetic energy shows that linear momentum is the rate of change of kinetic energy with respect to velocity:

$$\frac{dE_K}{dv} = mv.$$

Basic Principles of Energy

From

$$E = m \cdot v \cdot \frac{dv}{dx} \cdot x$$

we can easily see the relationship between kinetic energy and work done:

$$W\ (or\ E) = \frac{dE_K}{dv}\frac{dv}{dx} \cdot x$$

$$W = \frac{dE_K}{dx} \cdot x$$

The work done, *i.e.,* the energy transferred, is just the change in the kinetic energy between any two locations (*i.e.,* for a given displacement).

Basic Principles of Energy

Both kinetic energy and potential energy satisfy the principle of conservation of energy stated in the first law of thermodynamics, *i.e.*; the internal energy of a system equals the work done by the system, and therefore total energy remains constant.

Heat goes from hot to cold bodies, thus establishing the irreversibility of energy transfer in natural processes, as stated in the second law of thermodynamics.

Basic Principles of Energy

Laws of thermodynamics:

- The first law of thermodynamics says that energy can neither be created nor destroyed – it can only be converted from one form to another.
  - The first law says that there is always 100% energy conservation whatever people do. Those seeking to promote 'energy conservation' actually want to encourage people to do the things that they do now but in ways that require less heat and/or less work, and therefore less energy conversion.
- The second law of thermodynamics is also known as 'the entropy law'. It says that heat flows spontaneously from a hotter to a colder body, and that heat cannot be transformed into work with 100% efficiency.
  - It follows that all conversions of energy from one form to another are less than 100% efficient.
- Entropy is the measure of a system's thermal energy per unit temperature that is unavailable for doing useful work. It is a measure of the spontaneous molecular disorder.

A Simple Experiment

- Please, stand up and drop your book to the ground. Then, take the book again, and continue to read it. Done?
- Well, what has happened? We suppose you heard some noise. Why? Where does the sound come from? Figure 1.1 works out the experiment from the energy point of view:

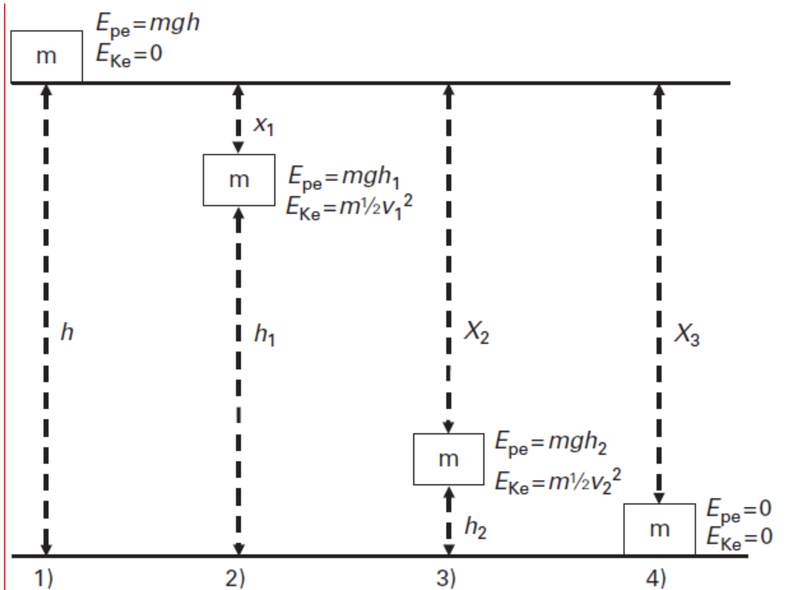


Figure 1.1 An example of energy associated to a mass m falling under gravity

A Simple Experiment

- At point 4, the book, after hitting the ground, has no more energy: there is obviously no kinetic energy (there is no velocity when the book lies on the ground), and no potential energy either, given that the ground is the datum plane (the height is zero).
- But the book has done work, i.e., there has been some energy that has displaced its mass through the distance x.
- Where has it gone? All the energy, i.e., the work done, which was accumulated in the change in the potential energy from zero (when the book was in your hand) to its maximum (right before it hit the ground) has been transferred to the system that contains the book (the room where you are doing your experiment) in several forms corresponding to different lengths of electromagnetic waves, namely, sound, heat, light, etc.
- This is why it is important to distinguish between work and residual heat.
- The energy transferred to the system cannot be recovered; it is somehow lost.

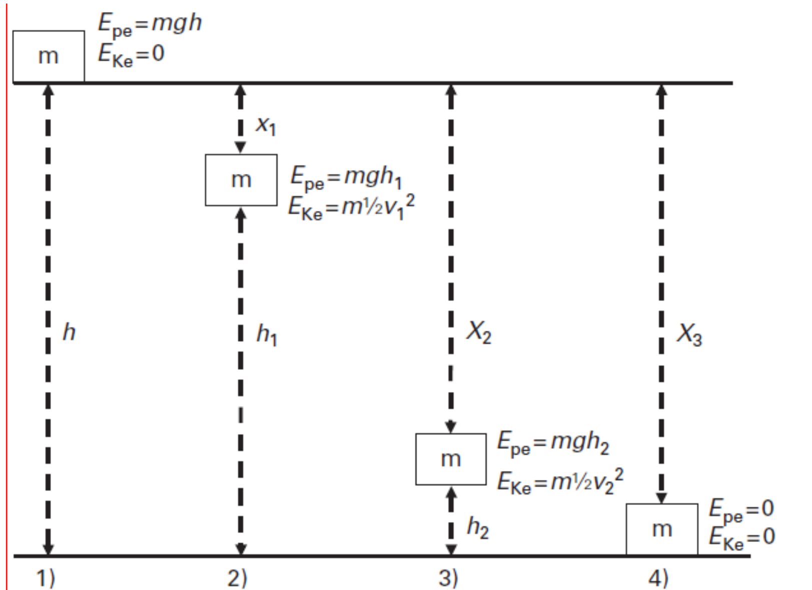


Figure 1.1 An example of energy associated to a mass *m* falling under gravity

Basic Principles of Energy

Change in entropy:

$$dS = dQ/T$$

S: entropy; Q: heat; and T: temperature (in degrees Kelvin)

$$S = \int dS = \int \frac{dQ}{T} = \frac{Q}{T}$$

Entropy is just the ratio of the heat over temperature.

The second law of thermodynamics simply states that: $dS \geq 0$

Basic Principles of Energy

- A machine, or a heat-work system, is defined by the energy that is used in it when doing work or that is added to it in order to perform the work. The consequence of the first law of thermodynamics applied to a heat-work system is that the energy of the machine corresponds to the difference between its initial and the final heat:

$$E = Q_L - Q_H$$

Q_H is the initial heat

Q_L is the final heat

- Heat goes from hot to cold bodies (second law of thermodynamics). Let's describe the heat transfer in an ideal machine by means of the so-called Carnot machine:

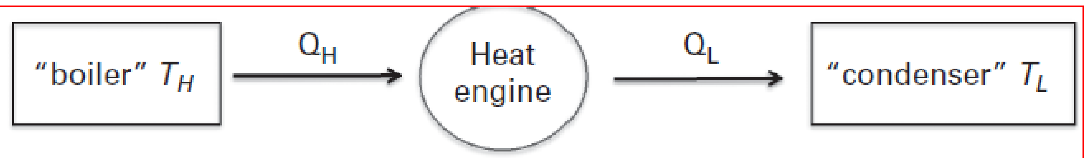


Figure 1.2 The ideal Carnot machine

Basic Principles of Energy

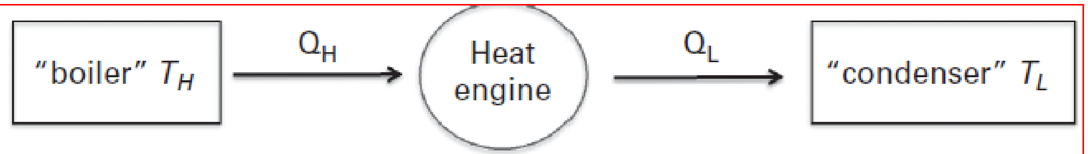


Figure 1.2 The ideal Carnot machine

Assume there is an original source of energy stored at temperature T_H. Call it the boiler. The original energy is Q_H. The machine carries out work in the engine; for instance, the steam that derives from the boiling water is used to rotate a turbine. The amount of energy is $E = Q_L - Q_H$ (< 0 because energy is extracted from the machine, not added to it). Then the temperature cools down, for instance the steam temperature is reduced to T_L (steam is condensed in the condenser, which could as well be the atmosphere where it is released into). Notice that entropy is reduced when the liquid flows from the boiler into the engine, since heat is subtracted from T_H, while it is increased when the hotter liquid (or steam) flows into the condenser, since heat is added to T_L

$$\cancel{S = \int dS}\ \mathrm{d}S = -S_H + S_L = \frac{Q_L}{T_L} - \frac{Q_H}{T_H}$$

where S_H is the entropy of the energy transfer from the boiler to the engine, while S_L is the entropy added to the system when energy is added to the condenser.

Basic Principles of Energy

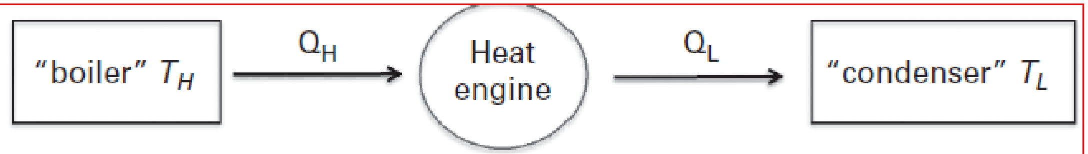


Figure 1.2 The ideal Carnot machine

$$dS = -S_H + S_L = \frac{Q_L}{T_L} - \frac{Q_H}{T_H}$$

Given that $dS \geq 0$, we have

$$\frac{Q_L}{T_L} - \frac{Q_H}{T_H} \geq 0$$

$$\frac{Q_L}{Q_H} \geq \frac{T_L}{T_H}$$

$$1 - \frac{Q_L}{Q_H} \geq 1 - \frac{T_L}{T_H}$$

Recall $E = Q_H - Q_L$

$$\frac{E}{Q_H} \geq 1 - \frac{T_L}{T_H}$$

- **Energy Efficiency**: the ratio of the energy output of a system over the energy input.

Primary Energy Sources and Energy Carriers

- Energy forms: mechanical, chemical, thermal, radiant, nuclear, electrical.
- Energy sources: coal, oil, gas, uranium, hydro, biomass, wind, solar, geothermal, ocean energy.

- Electrical energy is energy due to the movement of electrons induced by electromagnetic force

Primary Energy Sources and Energy Carriers

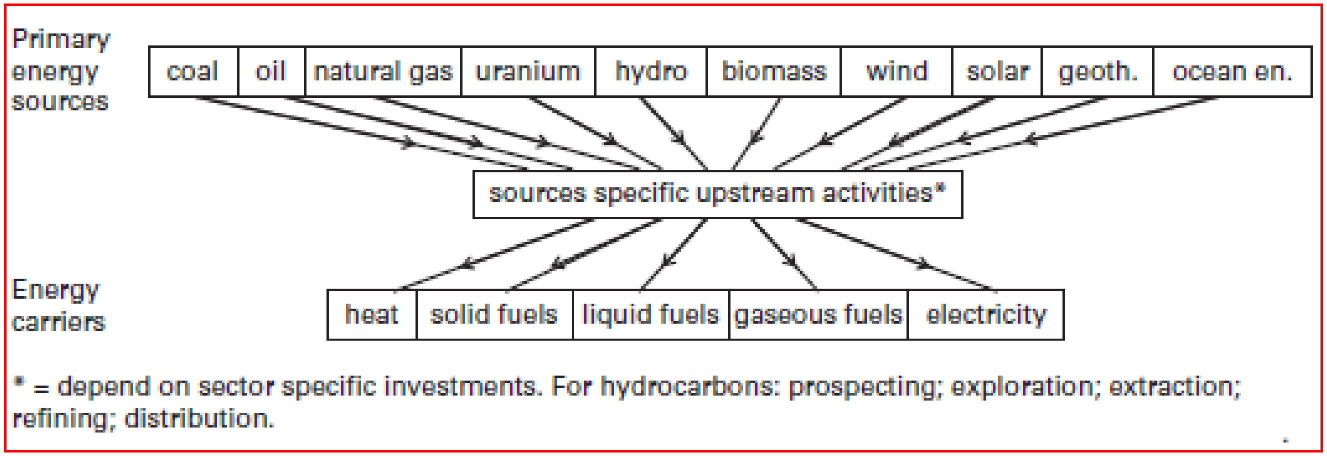
We can consider different levels of energy usage, either directly or through some transformation. In particular, it is useful to distinguish between primary energy sources and secondary energy sources, also called energy carriers:

Primary energy source: an energy source that can be directly used in some system.

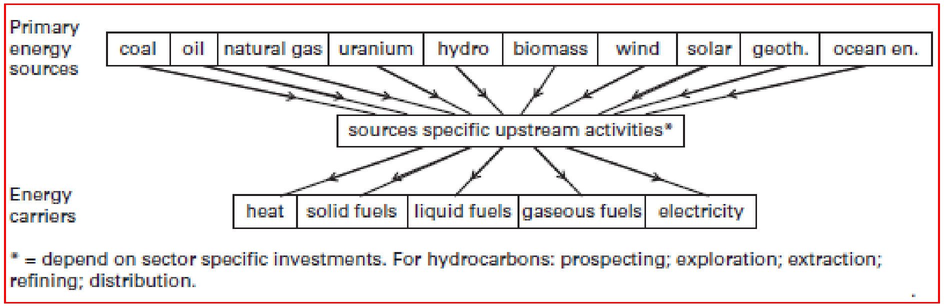
Energy carrier: an energy source that derives from the transformation of some primary energy source.

Primary Energy Sources and Energy Carriers

The energy carriers do not exist as energy sources, but are the product of the conversion of some primary energy source into some other form of energy.



Primary Energy Sources and Energy Carriers



From hydrocarbons we can obtain heat by burning coal, oil or gas, but also from biomass or geothermal energy.

Liquid fuels, such as gasoline or diesel, are derived from the refining of hydrocarbons, but also from coal (called Synfuel), natural gas or biomass.

Gaseous fuels come from the cultivation of gas fields, but also from the refining of other hydrocarbons or even from biomass.

Upstream activities: the economic activities that allow the usage of primary energy sources are called upstream activities.

Primary Energy Sources and Energy Carriers

Electricity, as an energy carrier, is obtained from the conversion of several primary energy sources.

These primary energy sources are transformed into fuels that are then further converted into electricity through power generation.

For instance, oil or coal can be burned to generate heat that is converted into electricity in thermal power plants, or the potential energy of water contained in a dam is converted into electricity exploiting the kinetic energy of water through hydropower production.

Note, however, that any energy conversion implies some loss of energy. Therefore, for the case of electricity, we must consider losses due to the efficiency rate of power production, as well as the losses due to the efficiency of the whole process of making electricity available to end consumers, called Electricity Supply Chain (ESC)

Energy Units and Energy Measures

We have already encountered the joule as the unit measure of energy.

Other possible unit measures for energy.

Some of them derive from the way the energy concepts were discovered and defined throughout history.

A first important equivalence is between joule and watt-second (Ws):

$$1\, Joule = 1\, watt \cdot second$$

- What is a watt-second? To understand this we have to explain the relationship between energy and power:

Power: the time rate of the work done by the energy:

$$P = \frac{dE}{dt}$$

Energy Units and Energy Measures

Power is an instantaneous (*timeless*) measure of the rate of conversion of energy, i.e., of doing work.

Therefore, power and energy are linearly related to the time:

$$E = p \cdot t$$

- The unit measure of power in International System of Units (SI) is the joule per second (J/s), called the watt (W).
- Using the second as the unit measure of time in SI, we have the equivalence $1\,Joule = 1\,watt/second$.

Energy Units and Energy Measures

There are other measures of power, such as the horsepower [HP], an old British power unit: 1 HP ≡ 745.7 W ≡ 0.7457 kW.

Table 1.1 Multiples in SI units

Factor	Name	Symbol
10^3	kilo	K
10^6	mega	M
10^9	giga	G
10^{12}	tera	T
10^{15}	peta	P

Energy Units and Energy Measures

It is possible to convert multiples of watt-second using the equivalences of times.

For instance, we know that there are 60 seconds in a minute, 3,600 seconds in an hour. Therefore, 3,600 watt-seconds correspond to a watt-hour.

Other unit measures for energy. Their purpose is to express the energy content of different primary energy sources using a common unit measure.

There exist several types of substances that we call coal, oil, gas, etc. depending on the different specific weight, sulfur content, caloric power, and so on.

These sources have been standardized with respect to the energy content, and then all primary sources but oil converted in fractions of energy with respect to the energy content of oil.

Tonne of Oil Equivalent (TOE): the amount of energy embedded in a standard tonne of oil.

Energy Units and Energy Measures

- It is also common to express the equivalence in terms of barrels of oil equivalent (BOE) rather than tonne. Taking into account that there are 158.987 liters in a barrel, using a standardized specific gravity of 0.88 (i.e. 1 l = 0.88 kg) we have a conversion of
- 1 BOE = 0.14 TOE. Obviously, for the oil itself the unit measure is rightly termed as just Tonne of Oil or Barrel of Oil.