Sustainable Energy Transitions at Uppsalas Universitet

Tomek Garbus

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1 Course Info

Literature: Dustin Mulvaney - *Sustainable Energy Transitions* (2021)

2 Chapter 1

Energy transitions are socio-technical processes that reshape the nature or patterns of use of energy resources and/or technologies.

A socio-ecological system describes human and Earth-system interactions as dynamic, interconnected, and co-produced by nature and society.

International frameworks to evaluate and manage social and environmental challenges:

- Convention of International Trade in Endangered Sepecies (CITES)
- Intergovernmental Panel on Climate Change (IPCC)
- Montreal Protocol to protect the ozone layer
- Agenda 21
- Sustainable Development Goals (SDG)

In the 70s, the concept of energy transition mostly referred to providing energy access to poor communities to increase their quality of life. It was also used then to refer to the growing need for coal resources in southwest USA. Today, the phrase *energy transition* refers to the move towards low-carbon economy.

Holocene - current geological epoch, refers to the last 12000 years. Contenders for the start of anthropocene epoch include the first major imprints on the atmosphere from fossil fuels – emissions of methande and carbon dioxide. Another candidate is the date that marks the start of atmospheric nuclear testing in early 50s.

International Energy Agency (IEA) (2010) suggests power demand will increase from 18 trillion watts in 2020 to somewhere between 25 and 30 trillion watts by 2050.

Starting in 2015,the world started to build more renewable energy than energy infrastructure to burn fossil energy.

Projections are trends taken into the future based on some existing trends or some BAU[1] scenario.

Forecasts are made by taking these projections and modifying them with assumptions about the future, such as new technologies or different rates of change.

[1] business as usual

Primary energy sources are the natural resources taken from the earth: coal, "wet" natural gas (wet because it contains water, methane, ethane, and other gases), petroleum, solar and wind power, uranium, and other direct sources of energy harvested.

Final fuel products and **energy carriers** are the energy sources that directly provide energy services.

Example final fuels: gasoline, "dry" natural gas (dry because it mostly contains methane), wood for a stove or campfire, hydrogen and electricty.

Example energy carriers: electricity, hydrogen, steam.

Corporate Social Responsibility (CSR) is an approach to sustainability that focuses on encouraging the private sector through voluntary standards, industry benchmarks to favour sustainable solutions under the pressure from investors and social and reputational pressure.

Wind, Water and Sunlight (WWS) strategies focus on replacing current energy systems with one run solely on electrification and renewables.

Hard and **soft** paths in energy transitions. Hard path refers to coal and nuclear power, while soft is led by renewables and appropriate technologies.

Aces of debates in energy transitions:

- apolitical
- democratic
- command and control
- global
- centralized
- private
- clean
- political
- technocratic
- market
- local
- decentralized
- public
- renewable

Political scientist Langdon Winner argued that some forms of energy production like nuclear energy rely on authoritarian forms of social organization to protect nuclear fuel and waste (Winner

1989). Uranium in the supply chain for nuclear fuel and plutonium in the waste (or some fuels) require militarization and heavy security as nuclear power plants because of vulnerability to meltdown accidents or occasional releases of low-level radiation. Winner argues that technologies are not neutral but can have inherent politics.

Rebound efect – when energy savings resulting from savings behaviour are just spent elsewhere on energy consuming activities. A classic example from this perspective is a driver who substitutes a vehicle with a fuel-efficient version, only to reap the benefits of its lower operating expenses to commute longer and more frequently.

2000-watt society is a notion for balancing basic human needs with overconsumption. 2000-watt of power is about 48 kWh energy per day.

Energy demand globally is still increasing.

World population in 1990 was 5.3 billion and annual elctricity consumption per person 2.07 MWh per person. By 2015, population was 5.3 billion and energy consumption 3.05 MWh.

China:

- 19% of world's population
- in 2013, 50% of world's coal consumption was China
- leads in wind power
- added a lot of solar (for 3 consecutive years added more then US in total through all years)

Giorgios Kallis is the leading thinker and writer on the question of de-growth. Degrowth thinkers look for steady-state energy systems and economies instead of fixating on increasing GDP.

Entropy laws mean that conversions of energy result in less useful work available with each conversion. This is why the laws of thermodynamics dictate that the end of the universe will be a cosmic heat death. The total amount of energy will be the same as it always has, but none of it will be available to do work.

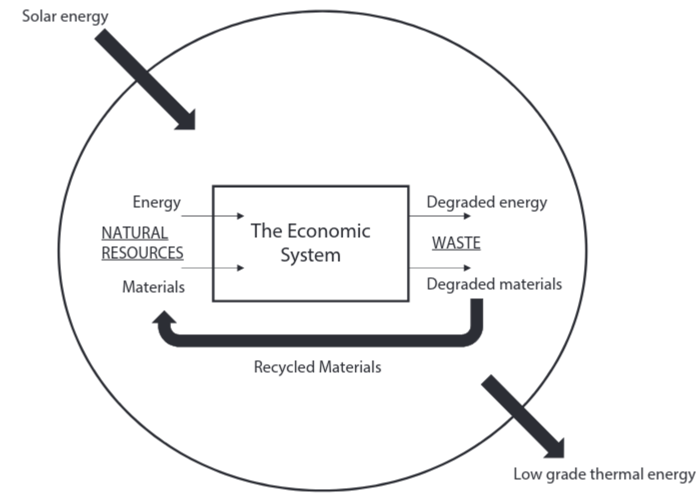

Fig. 1.2 Entropy and ecological economics

Eco-pragmatists argue in *The Eco-modernist manifesto* that the nuclear power is the only low-carbon energy technology capable of fully meeting the urgent response needed to climate change.

Wind, water, solar (WWS) strategy proposed by Jacobson and Delucchi, 2009, requires that all end users – heating, transportation, and so on – use electricity the primary energy carrier produced by various renewable energy sources, including wind, hydroelectric, and concentrated solar and photovoltaic power.

Jacobson's work on air quality also leads him to dismiss all biofuel technologies showing it is not possible to meet air quality standards burning ethanol because high levels of NO_x are produced with combustion of ethanol-gasoline blends due to high level of nitrogen in air.

The first WWS paper proposed seven ways to architect and develop a worldwide renewable energy system so that it will reliably satisfy demand and not have a large amount of capacity that is rarely used.

- interconnect geographically dispersed naturally variable energy sources (e.g. wind, solar, wave, tidal...)
- use a non-variable energy source, such as hydroelectric power, to temporarily fill gaps between demand and wind or solar generation
- use "smart" demand-response management to shift flexible loads to better match the availability of WWS power
- store electric power, at the site of generation, for later use
- over-size WWS peak generation capacity to minimize the times when available WWS power is less than demand and to provide spare power to produce hydrogen for flexible transportation and heat uses
- store electric power in electric-vehicle batteries
- forecast the weather to plan for energy supply needs better

The problem of **intermittency**: ensuring that there is enough power throughout the year, across the season and even dealing with year-to-year variability, providing power when the wind stops blowing and after sunset. Energy storage, heat sinks, demand response technologies and load-following generators like hydropower are therefore critical to making the WWS strategy work.

Critiques of "electrify everything" approach:

- electricity is the highest quality energy carrier, when many energy applications are only for low-quality heat
- elecrtifying everything may be overdoing it, producing higher quality energy than is needed.
- the WWS approach to 100% renewables also overlooks opportunities to acquire renewable energy from waste resources (e.g. some landfill, dairy, or waste treatment biogas)

But if renewables are cheap and abundant enough, overbuilding renewables may not be a bad thing.

Clack et al. 2017, paper criticising WWS, the key criticism is that the model underlying the WWS strategies failed to appropriately accountfor the real-time ramping up needed to correct intermittency issues from 100% renewables load.

Balancing authorities operate on top of electricity grids and their role is to plan the movement of energy to ensure the grid operates smoothly. There are 38 balancing authorities in the US (as of 2018) and many more globally and they help coordinate electricity sales between the nodes in the system.

Duck curve refers to a graph of effective load, or demand, of electrical energy, and it has a distinctive dip, resembling the belly of a duck, during midday hours when solar power resources are operating at full or near full capacity, reducing the need for fossil fuel generators. The general idea is to flatten this curve by pushing some of the solar power generated at midday to the evening to reduce the evening ramp up of fossil fuel generators via energy storage or peak displacement.

Microgrids:

- utilize usage information to balance demand and supply
- have energy storage, which makes them suitable for wind and solar
- decentralized, which leads to increased resilience
- advanced technologies which can predict weather conditions and plan ahead
- can function independently even when the grid goes down
- may help to serve remote communities which are too distant to connect to the main grid
- in California they may be a solution to the catastrophic wildfires
- there were ideas of utilizing blockchain technologies like Bitcoin to create a decentralized network of energy buyers and sellers to enable buying small amounts of energy at low cost. However, Bitcoin the most popular of these currencies, requires a lot of energy to produce (*mine*).

Energiewende in Germany:

- translates to *energy transformation*
- initially led by large wind firms, later by large PV producers
- the latte fallacy – the idea that the extra cost of energy would be about the cost of latte coffee a day. These low costs never materialized and instead the energy system cross-subsidised[2] some of the customers.

For many eco-socialists, natural capitalism suffers this fatal flaw of not being capable of a response to undermining its own resource base.

The **Socio-technical systems approach** to understanding social and technological change emphasizes the interactions and new social orders that give rise to new relationships between humans, each other, and their technical devices. Energy transition scholar Frank Geels describes how "new system innovations not only involve new technological artefacts, but also new markets, user practices, regulations, infrastructures, and cultural meanings".

2.1 Keep it in the ground

Article *Rolling stone* by Bill McKibben (2012) shows how much carbon that companies carry on their ledgers as value to shareholders, which they estimate to be 2795 gigatons (Gt) of carbon from coal, oil, and natural gas reserves if the fossil fuel reserves were burned.

Climate scientists suggest tat only 20% could be safely burned (565 Gt). The remaining 80% of fossil fuel reserves is referred to as unburnable carbon.

Many oil and gas company valuations are based on holding assets that are considered by climate scientists to be unburnable carbon or potential stranded assets, leading to some speculating about a carbon bubble (Lucas 2016).

The Yasuní-ITT Initiative in Ecuador was an unsuccessful organized effort to pay the country to keep one billion barrels of oil away from development (Sovacool & Scarpaci 2016). Similar efforts in the US have focused on protecting federal lands from fossil fuel development (Center for Biological Diversity 2015).

There should be no more investments in fossil fuels infrastructure. This has been formalized as the **divestment movement**.

2.2 Demand-side strategies

Warm showers and cold beer

Focus on satisfying the end user's demands, for example through energy efficiency or swapping grid for renewable energy.

2.3 Just transition

Sacrifice zones are areas poisoned or destroyed for the supposed greater good of economic progress.

Embodied energy injustices by supply-chain step:

Extraction:

- Forcible displacement
- Slow violence
- Human rights violations
- Public health impacts
- Ecosystem service loss

Processing:

- GHG emissions
- Stress, anxiety, fear at aproximate socio-environmental disruption

Transport:

- Disproportionate environmental contamination
- Uneven livelihood disruption

Site of combustion/production: hidden or ignored embodied energy injustices

Disposal:

- hazardous waste risks

Three pillars of energy justice for deep decarbonization strategies:

- pursuing energy strategies that ensure access to energy for those who don't have it

[2] Cross subsidization is the practice of charging higher prices to one type of consumers to artificially lower prices for another group.

- justice for those who work within and are affected by the fossil fuel economy, such as those living near power plants and industrial facilities, sometimes called fence-line communities
- to manage the potential impacts from pursuing decarbonisation and climate justice, meaning any impacts that might arise from renewable energy or climate adaptation

3 Chapter 2: Fundamentals of Energy Science

3.1 Units and examples

As a fundamental law of the universe, **energy is always conserved**.

Energy is a discrete quantity, power is a flow rate quantity.

Energy is the amount of power over time, measured in joules (J)[3].

Power is amount of energy released over specific time, like a joule per second (1 watt)[4].

TNT equivalent is $4.184 \times 10^9 J$. Nuclear explosions are measured in megatons, officially designated to be 1 million tons of TNT equivalent.

1 Btu (British thermal unit) is the amount of energy contained in a single match stick, equal to 1055J. 1 quad is 1 quadrillion Btu.

Lightbulbs: one 100-watt incandescent light bulb can be replaced with 8-watt to 12-watt LED bulb to emit same amount of light.

A flat-panel television screen uses the order of magnitude of 100 watts. Phone charger uses around 10 watts. A hair-dryer or microwave uses up to 1000 watts. An electic car uses over 7000 watts and electric hot water heater nearly 5000 watts.

Power is the rate flow of energy. It is an amount of instantaneous energy flow. This means that power has the unit dimension of time. A watt is also described as 1 joule per second.

Horsepower: 1 hp = 745.7 watts.

3.2 Methane

Hydrocarbons such as methane (CH_4) and propane (C_3H_8) when reacted with oxygen (O_2) produce carbon dioxide (CO_2) and water (H_2O). Methane can be produced by fossil or biogenic sources. Methane in the form of dry natural gas is used to heat homes and power fuel cells. It is generated with a mix of fossil natural gas and biogenic sources in landfills due to the decomposition of organic materials. Similarly, wastewater treatment facilities, dairies, and other animal food systems can be sources of methane generation. Because methane is a potent GHG, each molecule releases about 25 times more GHG pollution, so many mitigation strategies aim to convert CH_4 to CO_2.

[3] 1 newton is the force that accelerates 1 kg at one meter per square second. $1N = \frac{kg \cdot m}{s^2}$.
1 joule is equal to the amount of work done when the force of one newton displaces a mass through a distance of one metre in the direction of that force. $1J = N \cdot m = \frac{kg \cdot m^2}{s^2}$

[4] $W = \frac{J}{s} = \frac{kg \cdot m^2}{s^3}$

Stoichiometrically, methane combustion produces carbon dioxide, water, and heat.

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ + heat

3.3 Ethanol

Combustion of ethanol is an exothermic reaction and yields heat, water and CO_2.

$C_2H_5OH \rightarrow 2CO_2 + 3H_2O$ + heat

Ethanol is a biofuel produced mainly of corn and sugarcane, often blended with gasoline.

3.4 Eletricity

The force of charge separation is represented as $F = \frac{kqQ}{r^2}$ where:

- k is the electric constant
- q and Q are charges of the two objects
- r is the distance between the objects

The key relationship to remember with electricity is that electric fields cause magnetic fields, and vice versa: magnetic fields produce electric currents. These magnetic and electric fields are present in fluxes that operate perpendicular to each other and in a direction according to the right-hand rule. In other words, the rotation of the magnetic field's flow of force moves counterclockwise to the direction of electric current flow.

Voltage measure electrical potential.

$1V = \frac{1J}{1C}$

Electric current is the flow of electricity through a conductor. Electric current produces a magnetic field perpendicular to the direction the current is moving in loops that travel according to the right-hand rule.

Ampere's law: electric fields produce magnetic fields and magnetic fields produce electric fields.

3.5 Laws of thermodynamics

Entropy is the measure of the amount of energy no longer capable of conversion into work.

The first law of thermodynamics – the energy law – states that the total content of the universe is contant.

The second law of thermodynamics – the entropy law – states that the total entropy is increasing.

3.6 Exercises

3.6.1 Convert 210 kWh into joules

$756 \cdot 10^6$J

3.6.2 How many kWh are there in 101000Btu?

29.5986

3.6.3 Convert 150 kilocalories into giga-joules (GJ)

$150kcal = 150k \cdot 4184J = 0.0006276GJ$

3.6.4 Ten gallons of gasoline contains how much energy (MJ)?

10 gallons gasoline $\times \frac{121.3MJ}{1 \text{ gallon gasoline}} = 1213MJ$

3.6.5 The US used approximately 102 quads of energy in 2018. Convert this to (a) TWh (terawatt-hours) and (b) EJ (exajoules)

Quadrillon $= 10^{15}$

$1kWh = 3600000J$

(a) 102quads $\times \frac{293TWh}{1\text{quad}} = 29886TWh$

Exajoule $= 10^{18}J$

(b) $102 \cdot 10^{15} \cdot 1055J = 107.61EJ$

3.6.6 A household uses about 6721 kWh per year. What is the annual energy consumption of an average household expressed in (a) tons of coal equivalent (tce)? (b) ton of oil equivalent (toe)?

(a) $6721kWh \times \frac{1\text{tce}}{8141\text{kWh}} = 0.83$tce

(b) 0.57toe

Exergy refers to the amount of useful energy available to do work relative to the system. While energy cannot be created or destroyed, exergy can be destroyed because it is a measure of energy's potential and degradation.

3.7 Photon science

For 4.4 billion years, our sun has generated photons as it balances the pressure of its weight from gravity against the outward push of energy release from the fusion of hydrogen. The tremendous weight of the sun's gravity momentarily produces a hydrogen isotope with an extra proton—two overall. When the atom relaxes back to the more common hydrogen with only one proton, it releases the energy in the form of light. The loss of the temporary proton accelerates a charge, which is where electromagnetic radiation from our sun originates.

The power from the sun is 3×10^{26} watts or $1.360W$ per square meter. Aout 10^{17} watts is used by humans on Earth.

The energy of a photon is represented as (E). Plank's constant (f) and the speed of light (c) are variables in the determination of energy, which ranges depending on the wavelight (λ) of light. $E = hf = \frac{hc}{\lambda}$

3.8 GHG

The ratio of carbon to hydrogen in fuels affects the amount of GHG emmissions associated with each unit of energy from fossil fuels. For methane, this ratio is the at 1:4. This is why natural gas emits fewer GHGs per unit energy than coal where the ratio of carbon to hydrogen is about 2:1, depending on the grade of coal. Most petroleum has a aratio of about 1:2.

4 Chapter 4: Fossil Fuels

We can think of useful energy in the forms of stocks and flows. Stocks of energy and natural resources can be drawn down, while flows of energy and natural resources are constantly replenishing.

A total of 90% of air pollution – nitrogen oxides, sulfur oxides, particulate matter, heavy metals like lead, and volatile organic compounds – is caused by combustion according to US EPA.

Ozone in the upper reaches of the atmosphere blocks otherwis harmful ultra-violet light. But at ground level it is a lung irritant and can cause significant heart and lung damage.

Chemistry of the breakdown of nitrogen oxides to ozone:

- **Nitric oxide, primary pollutant**: $N_2 + O_2$ + high temperatures $\rightarrow$ 2NO
- **Nitrogen dioxide**: 2 NO + $O_2 \rightarrow 2\ NO_2$
- **NO_x + oxygen radical**: NO_2 + higher energy sunlight $\rightarrow$ NO + O
- **Ground-level ozone**: O + $O_2 \rightarrow O_3$