Sustainable Energy Transitions at Uppsalas Universitet

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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.

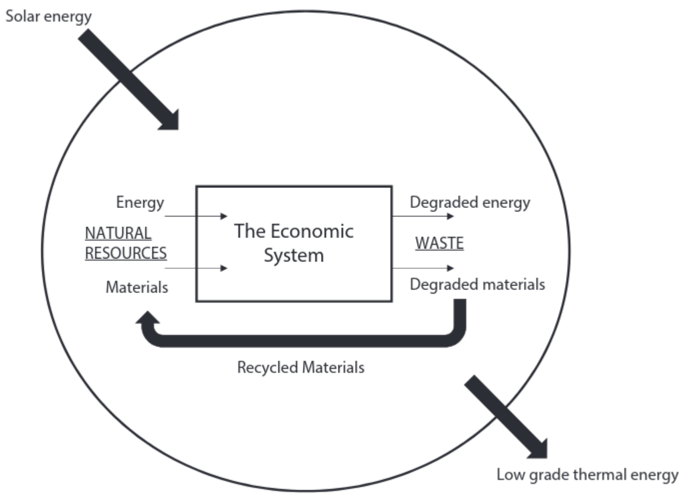

Fig. 1.2 Entropy and ecological economics

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.

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O + \text{heat}$

3.3 Ethanol

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

$C_2H_5OH \rightarrow 2CO_2 + 3H_2O + \text{heat}$

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

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 $\times \frac{293TWh}{\text{1quad}} = 29886TWh$

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

(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 3: Energy and the Social Sciences

4.1 Environmental Justice

The term came into widespread use in the 1980s to describe the uneven distribution of environmental burdens and public health harms.

Locations of incinerators, toxic waste disposal facilities, regional "cancer alleys" and an increased exposure to air pollutants are disproportionately found in low-income or minority communities.

Environmental justice – the idea that no social group, communities, or individuals should bear disproportional environmental or pollution burdens.

4.2 Energy poverty

Energy poverty is defined as not having access to modern energy sources, or not being able to pay for those energy-related expenses.

The regions of the world with highest levels of energy poverty are:

- sub-Saharan Africa
- Latin America
- China
- India

Globally, 1 of 5 people in the world have no access to electricity.

In Africa, excluding Egypt and South Africa, 1 of 5 people DO have access to electricity.

China has seen the most rapid movement out of energy poverty due to great success with rural electrification.

Indicators of energy poverty:

- whether there is access to electricity
- type of cooking fuels, for example relying on wood, charcoal and/or dung for cooking constitutes poverty

IEA's definition of energy poverty: *inability to cook with modern cooking fuels and the lack of a bare minimum of electric lighting to read or for other household and productive activities at sunset*

Other definitions of basic energy needs:

- Swiss 2000-watt society: electricity consumption of 50-100 kWh per person per year
- UN Advisory Group on Energy and Climate Change: 50-100 kg of oil equivalent or modern fuel per person per year

Energy comes in different qualities, electricity is considered the highest quality.

Inefficient burning of solid fuels on an open fire or traditional stove indoors creates a dangerous cocktail of pollutants (CO_2, small particles, nitrogen oxides, benzene, butadiene, formaldehyde, polyaromatic hydrocarbons and others).

4.3 Resource curse

Also referred to as Dutch disease.

Resource curse – the apparent contradiction that some communities become over-reliant on an extractive natural resource and that social systems are unable to ensure the community benefits from these riches.

Nigeria has huge petroleum wealth that is lost through circuits of poor policy decisions, corruption, and inequality.

4.4 Behavior and energy

7% of energy use could be reduced from behavioral changes alone.

Studies were made advocating in two groups for energy savings. One group received information about efficiency and their personal savings, while the other got information about the collective good of reduced air pollution. The second one had a stronger behavioral response.

Neighboorhood effect for the adoption of rooftop residiential solar energy.

Jevons paradox: *If the quantity of coal used in a blast-furnace, for instance, be diminished in comparison with the yield, the profits of the trade will increase, new capital will be attracted, the price of pig-iron will fall, but the demand for it increase; and eventually the greater number of furnaces will more than make up for the diminished consumption of each.*

Rebound effect: this idea asserts that gains in energy efficiency are not always realized because of other systematic effects. For example, savings from fuel economy improvements can lead to increased driving. Or, more efficient heating could lead people to keep their homes warmer in the winer. A similar concept called the Khazzoom-Brookes postulate.

According to a study by EC, air-conditioning has a possible rebound up to 50%, with an average of 25%.

4.5 Theories of Social Change: Ecological Modernication and Social Movements

Collaborative approaches:

- policy-level interventions

Adversarial approaches:

- protests
- lawsuits
- boycotts

4.6 Political ecology

In political ecology, discourse analysis is used to identify how environmental problems become naturalized or deemed inevitable.

4.6.1 A rhetorical model for environmental discourse and its political discourse

Ethos: relies on the reputation of the speaker and the appeal to character, regulatory discourse. Example: *Scientists agree that the products of biotechnology present no new risks*

Pathos: relies on how emotions are evoked, poetic discourse, nature as spirit, evokes values. Example: *anti-genetic engineering activists are causing people to starve in Africa*

Logos: relies on how persuasive a case is made, appeals to fact and reason. Example: *food security depends on advances in plant breeding. Biotechnology is the most important new plant breeding tool. We need to utilize biotechnology to improve food security*

4.7 Global Production Networks (GPN)

The GPN framework is used to answer various research questions from understanding colonialism, patterns of economic development, and global governance to the socio-ecological transformation of natural resources into commodities and implications for labor.

In research that uses the concept of GPNs, there is a tendency to focus on the behavior of multinational actors and institutions.

Global value chains: this concept aims to capture the activities that give rise to global production systems. Firms construct value over space through sourcing and contracting arrangements, and this approach aims to understand how these activities are organized and governed. Value is added across the supply chain as materials move from raw materials to finished products.

Filieres: A French concept that seeks to explore the chain of activities related to the production of raw materials into final export products. Research on Filieres usually follow the commodity beyond its useful life, as opposed to other analyses, which may stop at the factory gate/site of production.

4.8 Social acceptance of energy systems

There have also been several lawsuits in Western US directed at solar developers by Native Americans over burial grounds and sacred sites (Mulvaney 2019).

Pasqualetti 2001:

- More participatory approaches yield better results than the decide-announce-defend strategy.
- *Several studies of the social gap in support of wind farms suggest concerns about loss of property value. The first round of wind turbine installations can lower home values because of the visual impact, but over time, these prices recover, as new wind farms become part of a landscape or location; so research even shows wind farms can have a positive effect on the housing price*

4.9 Science and Technology Studies (STS)

STS explores questions that help us understand energy transitions because of engagements with expert knowledge production and public participation.

The STS term **socio-technical imaginaries** is an approach to examining energy futures. Social norms and values are reflected in or shaped by scientific knowledge. Any sustainable energy strategy will have to be sensitive to the context and geographies specific to energy transitions. **Reflexivity** is a term used to describe careful reflection and adaptation in policy design to pay attention to how outcomes of energy transitions are developing.

5 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**: $O + O_2 \rightarrow O_3$

5.1 Coal

Creation of coal:

- processes started during carboniferous period 360 to 286 Myr
- vegetation and other sources of carbon are sedimented upon, starved of oxygen, and decay under pressure, at high heat, and over time, to form coal
- from cellulose and lignin in plants
- youngest form is **peat**, produced from compression of sedimentary layers of rock, soil and sand
- brown coal forms from peat given more time, heat and pressure
- most brown coal comes from Quaternary period starting 2 Myr ago

Energy Density – a metric that represents a quantity of energy per unit area of unit volume.

Coal mining:

- 7.3 Bt globally per year
- China 2300 Mt
- India 708 Mt
- US 672 Mt
- Australia 503 Mt
- Indonesia 461 Mt

Over 90% of coal is used in the electricity sector.

China's plans imply that it will have consumed about 50% of global coal ever produced.

3 of the most fatal coal mine disasters were caused by firedamp – an explosive mix of methane (CH_4), coal dust, and hydrogen sulfide (H_2S).

In total, 60% of PM is from coal, 45% of SO_2, 30% of NO_x and 80% of mercury.

Mercury is a contaminant found in coal and after combustion is deposited in the environment.

Carbon capture and storage (CCS): many CCS technologies require converting coal into syngas – synthetic gas – that comprises hydrogen, carbon monoxide and carbon dioxide. The reaction to produce syngas is:

Coal(mostly carbon, hydrogen) + $O_2 + H_2O \rightarrow H_2 + CO$

5.2 Natural gas (fossil gas)

Mainly methane, often referred to "dry" natural gas. "Wet" natural gas is the collection of hydrocarbons extracted from the Earth, including water, ethane, propane, butane, methane and impurities.

5.3 Petroleum (crude oil)

Final products: gasoline and diesel. The word *petroleum* refers to the primary energy resource extracted from Earth.

Despite strong climate action and renewable energy adoption, oil consumption is expected to increase to 123 million barrels per day by the year 2025.

One pivotal player in global oil production is the Organization of the Petroleum Exporting Countries (OPEC). The cartel operates by ensuring that prices and production outputs are set to achieve favorable outcomes for members. Saudi Arabia is what oil economy experts call a swing producer. This means they can swing production in short notice because of significant amount of oil production capacity. But recent years have seen some diminishment in the power of OPEC and the rise of the US and natural gas industries over petroleum ones.

The 1969 Union Oil spill from a platform near Santa Barbara, California, is considered to have catalyzed the US government into setting up the Environmental Protection Agency (EPA) as well as passing Clean Air Act and Clean Water Act.

5.4 Tar sands, oil sands

- 75% of tar sands are in Alberta, Canada
- combinations of sand, clay, water and bitumen
- bitumen is a hydrocarbon and can be used for any kind of oil or gasoline
- 14% more GHG then conventional oil

6 Chapter 5: Nuclear and renewables

6.1 Nuclear

The global nuclear plant fleet is 450 reactors producing around 11% of global electricity.

Long opposition was caused by linking nuclear power to nuclear winter post-nuclear war stories.

Nuclear energy is a result of splitting uranium 235, an isotope found in rock at about 2–3% of uranium, depending on the origin of the ore. Most of the balance is non-fissile uranium, U-238. Each split uranium 235 atom releases heat, atomic fragments, and one or two neutrons can cause other uranium 235 atoms to also split. A consistent rate of radioactive decay of uranium 235 occurs in the core of a nuclear plant. This heat is used to make steam, turn a turbine, and spin a generator. The reactor core is kept cool usually by circulating water in the tower. Passively cooled power plants, which are not yet commercially in operation, propose using gravity, density, or some other physical process to ensure that cores of reactors are kept cool without the need for an external energy source. Most nuclear power plants are either boiling water reactors or pressured water reactors. The major difference is in how the heat is transferred in the process of making steam.

Top two producers of uranium ore are Canada and Australia.

6.2 Wind

Power $= 0.5 \times \rho \times C \times v^3 \times A_{\text{Sweep}}$

- V^3: meters per second – doubling of the wind results in eight-fold increase in power
- $\rho = 1.2 kg \cdot m^{-3}$ (kilograms per cubic meter)
- A_S: m^2 – area swept by the blade
- C – efficiency coefficient depending on the turbine, usually between 0.4 and 0.5

Environmental toil: kills birds and bats.

6.3 Solar

PV problems:

- require raw materials extracted from mines
- during installation, there can be impacts to ecosystems when utility-scale solar energy (USSE) projects are sited near wildlands or in sites that interfere with ecosystem processes

PV modules generate electric current by the photovoltaic effect, where incoming photons push electrons across a voltage. While there are numerous other technologies that are colloquially called solar power technologies, all non-PV solar technologies utilize the thermal energy from the sun to heat liquids to produce hot water or to generate steam. PV modules utilize photons to generate direct current and do not require moving parts or steam like these other solar powered technologies.

A **photovoltaic module** is a device comprised of several photovoltaic cells that is the principal unit of a photovoltaic array. A photovoltaic module's size is roughly 1 square meter.

Types of PV technologies:

- **crystalline silicon** (90% market share)
  - mono-crystalline (10-20% more efficient)
  - multi-crystalline
- **think films**

Net metering is a simple model where prosumers generate their own electricity, and only pay for what they import from the grid. In times of excess, they can also export energy back to the grid for credit. Since the Energy Policy Act of 2005, every public electrical utility is required to offer net metering.

PV modules are the only renewable electricity source that can be readily integrated into the built environment and atop residential and commercial spaces and non-industrial zones.

6.4 Hydropower

Today, the world's hydropower production is dominated by China, Canada, and Brazil, with China producing 1,064 TWh.

Hydropower can change stream flows, increase turbidity, displace or lock-in habitats, change fish migration patterns, degrade wilderness resources, and increase erosion and landslides.

6.5 Biofuels, biogases

Biofuels are any organic matter available on a renewable or recurring basis. This includes agricultural crops and trees; wood and wood wastes and residues; plants (including aquatic plants); grasses; residues; fibers; and animal wastes, municipal wastes, and other waste materials.

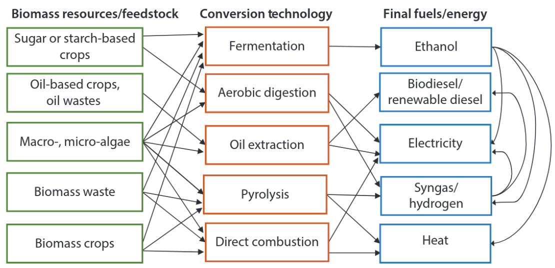

Fig. 5.15 Different platforms for biofuels to energy

Energy crops are high-yield production crop species. These are higher energy content but more expensive to produce because they require more inputs. They can roughly be divided into sugar crops, grains, and oil seed crops.

6.6 Geothermal

7 Chapter 6: Sustainable Energy Indicators

7.1 Industrial ecology

Industrial ecology is a metaphor used to describe industrial systems that do not create waste because processes use waste as inputs to other industrial processes.

Commoner's four laws of ecology:

- everything must go somewhere
- everything is interconnected
- nature knows best
- there are no free lunches in nature

7.2 Sustainability indicators

Corporate Social Responsibility (CSR) has been increasing (a large portion of Fortune 500 companies report sustainability indicators to their shareholders and the public).

Global Reporting Initiative (GRI)

Indicators:

- air quality emissions
- water use and disposal
- greenhouse gases
- nitrogen effluents
- hundreds of others

7.3 Carbon footprints

A **carbon footprint** is a GHG inventory for an individual, product or organization.

ISO 14046 – international standard for conducting carbon footprints.

The global range for personal carbon footprints varies from 1 to 100 metric tons annually, and there are probably more severe high-use cases.

7.4 Life-Cycle Assessment (LCA)

The Coca-Cola Company set the standard for LCA in 1969 with a study to characterize the resource and energy dimensions of glass versus aluminum containers. Eventually, this led to European Commission issuing a Liquid Food Container Directive in 1985. The International Standards Origination (ISO) 14000 has developed a standardized LCA methodology.

Attributional LCA inventories all materials and assigns them emissions.

Consequential LCA further asks what are the consequences of producing that product or passing a policy.

Arguably, the weakest aspect of using LCA in policy is the subjective elements of the process throughout LCA—judgments about what to include, exclude, and how to measure. But it is the interpretation phase that is often most challenging because it relies on understanding the systems and how to put the LCA findings into context.

7.5 Energy Return On Investment (EROI)

7.6 Energy Payback Time (EPT)

EPT is meant to illustrate how long the energy investments in a renewable energy take to pay off the initial or life-cycle energy investments.

The EPT for PV can range from six months as is claimed by some major photovoltaic manufacturers like First Solar to two and three years for crystalline silicon.

GHG emissions from the lifecycle of the PV system (g CO_2e): $\text{GHGs} = W/(n \times pr \times I \times LT \times A)$

- I irridation (kWh per square meter per year)
- n: conversion efficiency
- PR: performance ratio
- LT: lifetime (years)
- A: area of the module (m^2)

7.7 Water footprints

Blue water footprint estimates the volume of surface and groundwater withdrawn, consumed or removed from the hydrologic cycle to produce a product. It most accurately represents the amount of water used.

Gray water footprint is an indicator of water pollution, and it is defined as the amount of water required to assimilate water pollution to an acceptable threshold or standard.

Dilution factor $= \frac{\text{Contamination concentration}}{\text{Water quality threshold}}$

Grey water footprint $= \frac{\text{Water disposed} \times \text{dilution factor}}{\text{Natural gas production}}$

Green water footprint is the evaporative flow from the land surface. Green water footprints apply mostly to products produced in agriculture or forestry.

8 Chapter 7: Low-Carbon Electricity Systems

8.1 The electricity grid system

- natural monopolies
- jurisdictions grant utilities the right to entire markets
- in the past many utilities owned both power plants and systems of wires
- today there are competitive markets for electricity generation

A **grid** is a collection of components and devices that transmit, distribute, and deliver electricity, including the transmission wires and towers, distribution wires and towers, substations, transformers, meters, and other essential parts, sometimes including the power generators, companies, and workers.

Grid:

- power plants generate alternating current (AC) electricity
- transformers step up electricity to higher voltage such as
  - 100kV
  - 230000V
  - 345000V
  - 440000V
  - 500000V
  - 750000V
- moving electricity at lower voltage would require very thick wires
- voltage is "push" or "pressure" of electricity energy

- most (but not all) high-voltage transmission lines deliver AC current
- unlike DC, AC can have multiple taps
- once power reaches a distribution substation, it is stepped down to several hundred volts and carried on power poles
- most outlets are 110-220V

Social discount rate is a measure of how much less valuable money is to an investor over time.

US electrical grid:

- divided into 3 sections
  - Western US: Western Interconnection (WECC)
  - Texas: Electric Reliability Council of Texas (ERCOT)
  - East, Midwest and South: Eastern Interconnection

8.2 Levelized Cost of Electricity (LCOE)

- standard economic metric representing the cost of electricity
- allows for comparing electricity sources with varying capacity factors
- the main drivers of LCOE calculations are:
  - capital costs
  - fuel costs
  - annualized operating and maintanance costs
  - financing
  - capital recovery factor based on specified discount rate and power plant life

Levelized cost of electricity (LCOE) is the cost of delivering electricity over some time period. It is commonly measured as cost per unit energy (US$ per kWh).

LCOE framework is also used to describe any avoided social and environmental costs, social costs of carbon, avoided criteria air pollutant emissions, and reduced utility regulatory compliance costs.

Swanson's effect suggests that doubling production results in 20% decrease in costs.

8.3 Power density

Power density:

- describes how much power can be obtained from an energy source per unit land or space.
- describes power flux per unit of horizontal surface
- some units used to express power density include some amount of energy (joule, calorie, btu, kWh) per unit weight (gram, pound, ton) or volume (cubic centimeter, cubic decimeter, cubic meter).
- helpful to provide a sense of whether specific energy resources can be matched to power some area, facility, or place.
- nuclear and fossil fuels are the most dense sources.
- of the renewables, solar power is the most energy dense, sometimes also hydropower.
- lower densities have wind and geothermal power.
- biofuels have the lowest density.

Energy density:

- useful metric for various technologies with different capacity factors
- common metrics include kWh/m^2
- sometimes with solar, it is reported as energy per unit energy installed (kWh/kW)

8.4 Designing electricity systems for flexibility

- flexibility in both energy generation and demand will be needed
- due to intermittency associated with renewables
- wind power is raised to its cube for generating energy
- nuclear and coal power plants are slow and expensive to shut down
- **duck curve** of energy demand

Jim Lazar (2014) "Teaching the Duck to Fly" 10 strategies for long-term sustainability of variable energy sources:

1. target efficiency to hours of the day when load ramps up
2. orient solar panels to the west
3. substitute solar thermal with a few hours of storage in place of some projected PV generation
4. implement standards that allow the grid operator to manage electric water heating loads to shave peaks
5. require new air conditioner to include two hours of thermal storage
6. retire inflexible generating plants with high off-peak must-run requirements
7. concentrate utility demand charges into the "ramping hours" to enable price-induced changes in load
8. deploy electrical energy storage in targeted locations
9. implement aggressive demand-response programs
10. use interregional power transactions to take advantage of diversity in loads and resources

8.5 Energy storage and integrated resource planning

- key challenge to solving the duck curve
- for electricity, the most common form of energy storage is pumped storage which stores gravitational potential energy as water is pumped uphill
- Li-on batteries get cheaper

- EV batteries may be repurposed as stationary energy storage

8.6 Smart grids, internet of things, artificial intelligence

- DR: demand-response programs
- they fall into 2 categories: incentive-based and price-based

9 Chapter 8: Low-carbon mobility

9.1 Transportation in 2020 is powered mostly by petroleum

- petroleum is easy to store and transport
- fuels from petroleum have very high energy density
- they include diesel, petrol (gasoline in US), kerosene, jet fuel, liqueified petroleum gas

The future of mobility will be driven by new technologies that will facilitate

1. automation of driving and transport systems through advances in artificial intelligence;
2. electrification of automobility, which will make the translation of energy into wheel motion more efficient;
3. decarbonization of transport by using more people-powered transport (walking and biking) and less carbon-intensive fuels, such as solar-powered electricity for EVs, hydrogen generated from clean energy, and biofuels.

Why US consumes excessive amounts of oil products:

- inefficient fuel fleet
- absence of more efficient diesel cars
- complete absence of high-velocity trains

Paths to decarbonizing transport focus on:

- driving less, more biking, avoided travel, walking
- replace combustion engines with electric vehicles
- decarbonize energy sources that power vehicles

9.2 Electric vehicles

- more than 90% of criteria air pollutants are created from combustion
- the full life-cycle economic cost of a vehicle is its cost plus the cost of fueling it over some determined time
- li-ion batteries are used in all sorts of electronics so EVs benefit from the attention of all industries
- these batteries do not contain a lot of lithium as a percentage of the total battery
- Tesla, Nissan and GM use lithium manganese oxide batteries
- Toyota uses lithium nickel cobalt oxide
- BYD uses lithium iron phosphate

Challenges for EVs:

- charging stations – finding places for them in the cities or homes with driveways
- range anxiety

9.3 Well-to-wheel analysis

- LCA is useful to compare emissions from vehicles and fuels in the transportation sector
- well-to-wheel (WTW) analysis is specific LCA framework to understanding environmental impacts of fuel and vehicle combustion
- the findings of this kind of research usually show that the fuel yields the highest impact in vehicle's lifeycle
- for comparison of different fuels, well-to-tank (WTT) is usually used

9.4 Hydrogen fuel cells

- hydrogen is the most common element in the universe (about 75%)
- hydrogen gas is rare on Earth, usually bound to other chemicals
- very energy dense
- very volatile and risks explosion
- **green hydrogen** typically refers to the hydrogen produced by hydrolysis powered by renewable energy[5]
- hydrogen is an energy carrier, but not primary energy source
- **hydrogen fuel cell** – a device that converts hydrogen and oxygen into water and produces electricity
- most hydrogen today is from steam reforming from natural gas

9.5 Ethanol

- most biofuel supply is sugar- and starch-based platforms for liquid biofuels
- almost one third of US corn produce went to ethanol production in 2016
- **energy content** of the selected liquid fuels:
  - gasoline: 125k Btu/gallon
  - ethanol: 84k Btu/gallon
  - compressed natural gas: 106 k Btu/gallon
  - propane: 91k Btu/gallon
- low EROI
- food vs fuel debates
- water quality and quantity issues are large impacts from producing biofuels

[5]Hydrolysis is a chemical reaction in which a molecule of water breaks or more chemical bonds

- nitrogen pollution since farmers overuse cheap fertilizers to maximize crops

9.6 Biodiesel and renewable diesel

- different liquid fuels

9.7 Low-carbon drop-in fuels

9.8 Vehicle-to-grid storage

9.9 Autonomous vehicles

9.10 Public transportation

9.11 Urban planning for walking and biking

9.12 Decarbonizing aviation, long-range travel, flying less

10 Chapter 9: Low carbon industries and the built environment

10.1 Energy efficiency and green building

- nearly 40% of natural resources extracted from the Earth end up in buildings
- industries use about a third of overall energy
- housing affordability crisis in many parts of the world
- greening up the city sometimes results in gentrification: pushing poor communities out for the sake of middle class
- heating, ventilation and air-conditioning (HVAC) systems use over 50% of buildings' energy and 20% total consumption in US
- closing the loop on material flows and transitioning to a circular economy could have major implications for natural resource use
- a **negawatt** is a term coined by Amory Lovins which describes an avoided amount of power
  - when a 100-watt lightbulb is replaced with the same lumen LED but at 20 watts, it results in 80 negawatts
- one of recent improvements is in heat pumps for residential heating applications
  - some heat pumps are air-to-air, finding heat in the outdoors on a cold day and delivering it indoors
  - geothermal heat pumps are ground-to-air, meaning they find warm air in the ground and deliver it indoors
  - heat pumps can also heat water (air-to-water heat pumps, they take heat from the outside and deliver it to water)
  - air-to-water heat pump can be used to heat a home or building with hydronic or radiant floors
  - as heat pumps replace oil and gas for heat applications, the sector will incur GHG benefits and savings
- challenge with greening the buildings: turnover of inventory is very slow
- **The Rosenfeld Effect**
  - total per capita electricity use has stayed relatively flat in California in the last 4 decades while it has risen sharply in US as a whole
  - this is often credited to physicist Art Rosenfeld's influence on California energy policy
  - Rosenfeld started championing energy efficiency in the early 1970s as a cost-effective strategy to save energy resources and reduce customer energy bills

10.2 Water and wastewater infrastructure

- a major energy use and source of GHGs in any municipality or community is related to the provision of drinking water and the disposal of wastewater
- GHGs wastewater treatment is equal to those from aviation and container shipping (all 3 represent about 1% of total emissions)
- global sanitation is a major challenge with billions lacking access to basic sanitation and clean drinking water
- wastewater emissions can contain the GHG methane as well
- this is because anaerobic decomposition of organic matter takes place in sewers, also called as methanogenesis
- since methane is more potent GHG than CO_2, it is an opportunity to mititage some GHG emissions while generating heat or electricity on-site
- **methanogenesis** is a metabolic pathway where microorganisms anaerobically digest organic material and produce methane

10.3 Cement production

- cement is the second most substance on Earth after water
- the main input for cement is limestone, along with calcium and silicon
- supply chains for cement begin at limestone quarries, in addition to sand
- the technique most commonly used to produce cement in kilns is not only energy intensive but also emits CO_2 by chemical reaction
- each ton of cement results in about a ton of CO_2
- cement is estimated to account for 6% of overall GHG emissions
- the following stoichiometry produces CO_2 emissions:
- $CaCO_2 + \text{Heat} \rightarrow CaO + CO_2$
- short-term changes to cement productions that could reduce emissions:
  - fuel switching to less carbon-intensive fuels

  - material substitution: calcium sulfoaluminates and calcium silicates are two most critical materials to reduce the emission-causing clinker materials
  - other air pollutants from cement production include persistent organic pollutants, dioxins, heavy metals, sulfur dioxide, and particulate matter
- growth of cement is still slated to continue to rise in the coming decades
- cement kiln dust is a widely accepted occupational hazard

10.4 Major alloys and metals: steel, copper, aluminium

- mining industries and their associated smelting activities are significant contributors to many environmental problems including:
  - GHGs
  - water and air quality impairing emissions
  - land-use change
- iron- and steel-making are about 5% of global GHGs
- every ton of steel results in 1.6-3.1 tons of CO_2 equivalent
- this is due to coking process
- some fundamental processes cannot change
- but some companies are mostly relying on renewable electricity purchased off-site, coupled with wind and hydropower
- circular economy approaches:
  - recycled materials for metals can reduce the environmental burden
  - closing this loop decreases energy and GHGs compared to virgin metals, mostly steel, copper, aluminium
  - semiconductor metal recovery reduces environmental burdens of PVs
  - recycling metals is getting more complicated as different kinds of metals are brought together where historically materials were homogenous
  - copper contamination from electric components in cars is complicating steel recycling
  - increased plastic composites also complicate this picture
  - recycled aluminium can reduce energy use by almost tenfold compared to making it from bauxite

10.5 Chemical industries

- chemical industry is responsible for 10% of global GHGs emissions
- about two-thirds of overall energy use in indudstry is used by manufacturers using high temperature heat such as in making plastics and ammonia
- many chemical industries rely on steam and super-heated steam for heating reactor vessels and other tasks
- ammonia could also be used as a fuel directly, or cracked, for its hydrogen
- many feedstocks used in chemical industries are purchased from oil and gas industries
- chemical industries also often buy raw materials from petroleum companies
  - one example is ethane, which is separated by a cracker

11 Chapter 10: Sustainable And Just Energy Strategies

Agriculture contributes around 25% GHG emissions, out of which 80% is from animal agriculture.

Livestock production accounts for 70% of agricultural land and 30% of total land.

Another 25% GHG emissions are from electricity and heat.

The **food-energy-water nexus** is a phrase used to describe the biophysical, natural, social, and behavioral processes that are interconnected by food, energy, and water.

FEW systems can be physical, natural, biological, or social and behavioral processes.

Photovoltaic (PV) systems displace thermoelectric power generation, which consumes roughly 39% of freshwater withdrawals in the US.

Freshwater use for producing food and fiber constitutes roughly 70% of the freshwater used in agriculture.

Global meat production rose to 350 million tons in 2014 from 78 million tons in 1961.

37% of global methane is from cattle.

Methane has 23-25 times heat trapping ability of that of CO_2.

Livestock also contribute 64% of ammonia emissions, which contribute to acid rain and acidification of land and waterways. Cattle and livestock are water-intensive also, requiring over 900 liters of water to produce a gallon of milk, and while 1.3 billion tons of grains are consumed by farm animals each year, nearly all of it is fed to cattle.

Extended producer respon- sibility (EPR) is one means to lessen the impacts of end-of-life (EOL) management problems with products after they outlive their useful life.

11.1 Techno-ecological synergies

Example: agrovoltaics: rice grown under a canopy of photovoltaics

Example types of solar techno-ecological synergies:

- installations over previously disturbed land
- over water
- as distributed energy generators
- in agroecological systems

- distributed throughout the electricity grid

Floatovoltaics are photovoltaics integrated with materials that allow them to float and be installed in lakes, reservoirs, wastewater treatment ponds, ocean bays, and other marine waterways.

Benefits of agrivoltaics:

- managed and native pollinators
- increased water use efficiency
- soil erosion prevention
- can alter microclimatic conditions to keep the PV systems cooler and make them operate more efficiently

Benefits of floatovoltaics:

- reducing algae growth
- preventing water loss from evaporation

Benefits of built-up systems (PV on rooftops):

- insulating buildings
- cooling buildings
- energy savings

11.2 Moving forward on an energy transition towards decarbonization

12 Community acceptability and the energy transition: a citizens' perspective

Breffní Lennon, Niall P. Dunphy, Estibaliz Sanvicente

12.1 Introduction

The current shift to RES is different from energy transitions of the past due to diversity of drivers leading it:

- climate change
- growing awareness of energy-related inequalities
- social and behavioural transformations
- questioning historical narratives
- challenging accepted understandings of democracy and economics

In contrast, past transformations were mostly driven by exploitation of new energy resource.

Social dimension is of equal importance to that of technology.

This paper explores how local people can contribute to the energy transition through more meaningful and engaged process.

12.2 Background

Energy democracy movement emphasises justice and equality being integral to the current energy transition.

How can local communities become empowered to drive project development and meaningfully engage in the low-carbon energy transitions?

Information gaps, information deficits is a term describing the assumption that by simply providing appropriate amounts of information, citizens will respond accordingly and refine their behaviours.

Strenghtening democratic legitimacy can help increase social acceptability of RES adoption.

The paper presents perspectives of citizens from 6 communities in France, Ireland, Italy, Spain and UK.

Historically, cooperative movement has a track record of helping local communities access the start-up capital needed to create businesses and jobs.

Energy democracy narratives offer an alternative to neoliberal modes of capitalism and challenge the assumption of unlimited growth.

Scholars call for:

- more nuanced approaches that move beyond the accept/reject dichotomy
- adherence to three overarching principles of effectiveness, efficiency and legitimacy
- establishment of new change alliances
- overseeing a fairer distribution of the benefits of change
- using market mechanisms to facilitate all stakeholders in the transition

12.3 RES configurations for social/community acceptability

Most commonly cited motivations against renewable energy deployment:

- high local costs compared to perceived local benefits
- inappropriate scale of development
- limited citizen involvement in local energy planning
- additionally, for large-scale projects such as wind-farms:
  - detrimental effects to human health
  - biodiversity loss
  - landscape degradation
  - negative impacts on tourism and property prices

Opposition is often attributed to NIMBYism through oversimplified and perhaps lazy analyses.

When people know little about the technology, acceptance may mostly depend on trust in actors, as demonstrated by the case of gasifier project in Devon (p.4).

The participants of the study wanted a far greater say in shaping the transition to a low-carbon economy, but the opportunities for a meaningful engagement were low.

Perceived unfairness can result in protests, damanged relationships and divided communities and that perceptions of unfairness are exacerbated when winners and losers are created within the community (cited from Gross[37]).

Deployment of renewable energy projects requires business models which:

- deliver sufficient financial return
- minimize and mitigate impacts
- provide for equitable distribution of financial and other benefits among (affected) community members

Satisficing is a term mixing words *satisfy* and *suffice* and denotes meeting an acceptability threshold without necessariliy maximizing any specific objective.

12.4 Research design and methodology

Citizen jury is a deliberative democracy technique that is being used to engage citizens on a range of research topics including health care. Also known as citizens' assembly.

12.5 PBM 1: an energy purchasing cooperative

A group of local people established a cooperative with open membership to all residents and microbusinesses in the area. Ownership is vested directly in the coop's members, each contributing equally to the capital through membership subscription.

The cooperative deals directly with the energy supply company (ESCO). It also helps the more financially vulnerable members pay their costs.

This approach involves a minimal number of key stakeholders.

12.6 PBM 2: a commercial wind farm project

Members of a local community approach a commercial wind company to develop a wind farm in their area.

They establish Community Development Association (CDA). Members of the CDA set up a local company to oversee the planning application and any community-oriented incentive schemes, a common practice in a number of EU member states. The new company is a subsidiary of the commercial wind company.

Electricity produced from the wind farm is fed directly into the national grid at a fixed rate, under the national Feed-In-Tariff (FIT) scheme.

CDA sub-committee and landowners (hosting the wind turbines) end up having the most local control in this type of project.

Most participants see the majority of the profits from this type of project leaving the local area to be accumulated by individuals at national or international level.

12.7 PBM 3: a locally owned (hydropower) renewable energy project

A community cooperative established a subsidiary company to develop a hydro-electric scheme on a local water-course which flows into a designated national park.

The key goal is to provide community members with electricity at reduced rates.

A portion of the annual income is put into projects that benefit the wider community, such as free home insulation and zero-interest loans.

The scheme generates enough electricity annually to power over 300 homes with a projected income of several million euros over a projected 20-year period.

This project scored highly on all measures except extra-local wealth-generating capacity.

Potential shortcomings:

- geographically specific
- technically challenging
- reliance on government support

12.8 PBM 4: a farmer-owned biogas cooperative partnered with a district heating cooperative

Two groups come together:

- the first one wants to turn animal waste into biogas production
- the second wants to install a combined heat and power (CHP) plant to generate electricity and provide district heating to local residents

In the beginning the two groups establish separate cooperatives. The first uses pig slurry to produce methange gas. This biogas is then received by the second coop that runs the CHP plant supplying heat to local consumers.

Caveats with regard to community participation:

- biogas producers face regulatory and social challenges compared to the natural gas rivals
- local resistance to a biogas facility

12.9 PBM 5: municipalities, universities, schools and hospitals (MUSH) energy producer

The mayor of a municipality established a local community-owned project with an objective of increasing the uptake of renewable energy in the area through the installation of RES systems on public-owned buildings.

The MUSH coop decided to invest in solar photovoltaic (PV) arrays mounted on the roofs of two public education institutions and a hospital.

Electricity produced from each PV plant is used onsite with any excess electricity being fed directly back to the national grid.

Income from the sale of electricity is fed into other projects such as insulation upgrades in schools and hospitals, decreasing the energy demand of these buildings by over 40%.

12.10 PBM 6: an environmental finance service

A group of local landowners implements proven nature-based business models that prioritise the restoration of self-sustaining ecosystems that originally existed in the area.

With help from an NGO they secure loans from a European investment bank focusing on nature-based business creation and additional backing from a European capital financing facility also engaged in this area.

The project involves a series of educational programmes for landowners and local residents, as well as other technical, financial and promotional supports that encourage active rewilding of land no longer in active agricultural use.

Besides rewilding efforts, micro-power generation and energy configurations that have the minimal environmental impact.

The group secures a national grant.

13 Wicked energy transition?

Johann Köppel, Sustainable Energy Transition

What characterizes wicked problems:

- There is no definitive formulation. Definition of the problem is part of the problem.
- No stopping rule – actors stop their actions at their discretion.
- Resolutions are not true-or-false but good-or-bad (or better-or-worse).
- There is no immediate and ultimate test for a solution of the problem.
- Every resolution of a wicked problem is one-shot operation; there is no opportunity to learn by trial-and-error, every attempt counts significantly.
- Don't have an exhaustively describable set of potential solutions, not a set of well-defined operations to be incorporated.
- They are essentially unique.
- Every wicked problem is a symptom of another problem.
- The existence of a wicked problem can be explained in multiple ways. The choice of explanation determines the nature of the solution.
- The planner has no right to be wrong. Planners are liable for the consequences of their actions.

14 Complex Societal Problems

Dorien J. DeTombe, 2002

14.1 Introduction

14.1.1 The problem handling process

Each phase of the process should be carefully reflected, discussed and guided.

The first subcycle: **defining the problem**:

- becoming aware of the problem and building mental image
- extending the mental idea by hearing, talking, thinking, reading about the problem
- putting the problem on the agenda and deciding to handle it
- forming the problem handling team and starting to analyze it
- gathering data, exchanging knowledge, and forming hypotheses about the problem
- formulating the conceptual model of the problem

The second subcycle: **changing the problem**:

- constructing the empirical model and the desired goal
- defining the handling space
- constructing and evaluating scenarios
- suggesting interventions
- implementing interventions
- evaluating interventions

14.2 What are complex societal problems?

Examples:

- transportation problems
- environmental problems
- urban planning problems
- healthcare problems
- water problems
- Internet problems
- they are seldom really solved

Characteristics of CSP:

- uncertain what the problem looks like
- limited knowledge and data
- governmental or continental scale
- many cultures involved with different traditions of problem handling
- group of actors involved changes during the process
- power and emotions of different actors
- often caused by greed, war, corruption, indifference and/or huge private profit
- political agendas at play

There is also a tendency to privatize the benefits of the problems and to socialize the costs.

14.3 The COMPRAM method

DeTombe, 1994

Summary:

- democratic, transparent and structured
- problems are solved cooperatively by diverse teams under the problem owner and coordinator
- the actors should be involved in the problem solving from the very beginning
- the process should take 6-12 months
- interventions, in order to be effective, have to be integrated

14.3.1 The 6 steps of COMPRAM

- analyze and describe the problem by a team of neutral content experts
- analyze and describe the problem by different teams of actors
- find interventions by experts and actors together
- anticipate the societal reactions
- implement the interventions
- evaluate the changes

Handling CSP requires 3 elements: knowledge, power and emotions.

14.3.2 The seven-layer model

It is meant to help integrate and understand knowledge from various disciplines.

Layers:

- normal verbal language layers:
  - description of the problem
  - definition concepts and phenomena
  - theories hypotheses assumptions experience intuition
- visual language of the mental model
  - knowledge islands
  - semantic model
  - casual model
- mathematical language of the simulation model
  - system dynamic simulation model

The framework avoids the term "solving" the problem because CSP are rarely really solved. Instead it talks of "changing" the problem.

15 Accelerating the energy transition through innovation: Chapter 1

15.1 New global developments that affect the energy sector

- The Paris Agreement
  - objective: keep the global avg temperature rise "well below 2° and try to limit this to 1.5°.
- United Nations' Sustainable Development Goal number 7
  - ensure universal access to modern energy by 2030
  - double the rate of energy efficiency improvement by 2030
  - significantly accelerate deployment of renewable energy
- in 2015, the share of renewables in primary energy supply was about 16% and the share of renewables in electricity generation was 24%
- over the last 5 years, the cost of solar PV has fallen by 80% and the cost of wind by 30%
- taller wind turbines can reach better quality wind resources
- EVs use a third of the energy and accelerate faster than conventional cars

15.2 What is energy transition?

- IFET states the central role of accelerated deployment of energy efficiency and renewable energy technologies

15.3 What is innovation?

- technology breakthroughs that provide renewable solutions to sectors where at present no cost-effective alternatives to conventional energy technologies exist
- improvements to the existing renewable technologies, which reduce cost and stimuate deployment
- new business models and engagement of new actors across energy systems, allowing for a profitable scale-up of renewable technologies
- new types of financing that reduce cost and enhance access to funds
- enabling policy and regulatory innovations that provide incentives for market access and growth

15.4 Status of the energy transition

Energy sector innovation cycle:

1. technology push
2. research
3. development
4. demonstration
5. market development
6. commercial diffusion

7. market pull

- limiting climate change to below 2° implies a reduction of energy related CO_2 emissions of nearly 70% rom 2015 levels
- globally more than 32 Gt of energy-related CO_2 were emitted in 2015
- these emissions need to fall to 9.5 Gt by 2050 to limit warming to 2°
- energy efficiency measures and renewable energy will according to REmap and IRENA deliver about 90% of the emissions reductions needed to decarbonise the global energy system
- the world is underinvesting in innovation

16 Innovation in business models

- Oxford dictionary defines *innovate* as to "make changes in something established, especially by introducing new methods, ideas or products"
- change vs innovation: change does not need desirability or intentionality, final result of change can be positive or negative
- creativity vs innovation: creativity is a key part, first step of innovation
- invention vs innovation: invention is the process of creating something novel, while innovation is the introduction of the invention in a market or society

Ten types of innovation framework provides a way to identify new business opportunities and develop viable innovative models. It is structured into three categories: configuration, offering and experience:

- configuration
  - profit model
  - network
  - structure
  - process
- offering
  - product performance
  - product system
- experience
  - service
  - channel
  - brand
  - customer engagement