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.

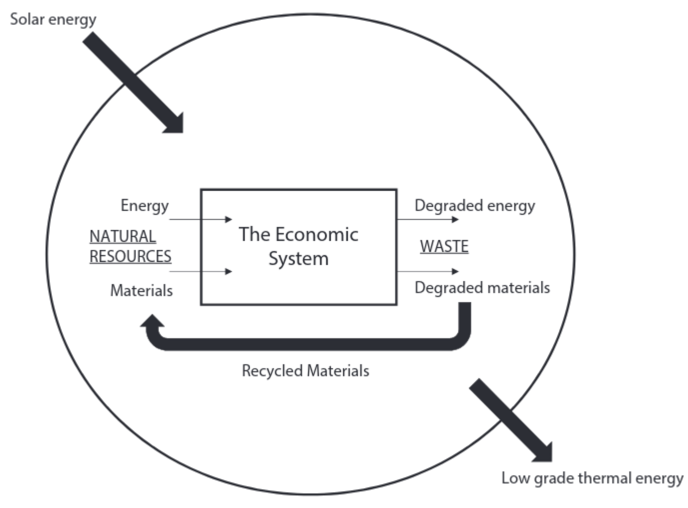

Fig. 1.2 Entropy and ecological economics

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.

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

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 residential 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

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 → 2NO
- **Nitrogen dioxide**: 2 NO + O_2 → 2 NO_2
- **NO_x + oxygen radical**: NO_2 + higher energy sunlight → NO + O
- **Ground-level ozone**: O + O_2 → 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 → 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
- $\rho = 1.2kg \cdot m^{-3}$ (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.

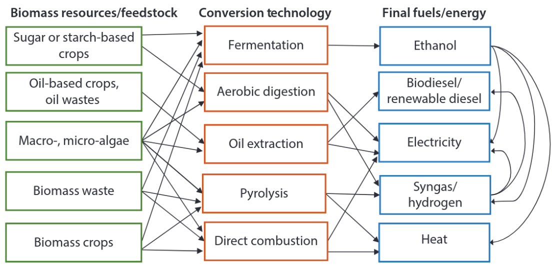

Fig. 5.15 Different platforms for biofuels to energy

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): 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)