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Developing a Green Future

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The world hates change, yet it is the only thing that has brought progress.

- Charles Kettering, inventor and engineer

While humanity's rapid technological and economic progress has created greater societal wellbeing, it has compromised our environment's health.[1] There is technology which can prosper both our environment and society. No form of environmental damage devastates as much as anthropogenic climate change, which we will discuss.[2]

Fundamentals

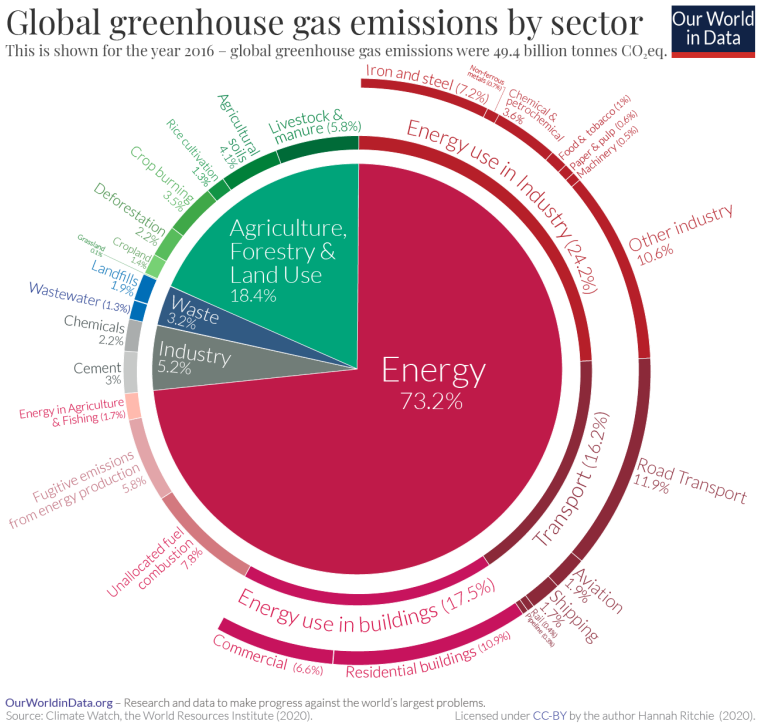
The Sun emits primarily visible electromagnetic radiation, and the Earth absorbs and re-emits primarily infrared radiation. Greenhouse gases (GHGs) absorb and re-emit some of this infrared radiation, heating the atmosphere.[3] A macroscopic change in global temperature is known as climate change.

But why is it described as being human-induced (anthropogenic)? Many of our practices cause GHG emissions. The most common GHGs that humans emit are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O).[4] GHG emissions are often measured in CO_2 equivalents, defined as

$$CO_2eq. = GWP \cdot m$$

, where *m* is the emission's mass and GWP (global warming potential) is the heat a gas can trap over 100 years divided by the heat CO_2 can trap over 100 years.[5] We can thereby determine the source of our emissions (see fig. 1).

While higher atmospheric GHG concentrations will only warm the atmosphere several degrees Celsius; heat waves, fires, droughts, and floods will become severer and commoner, and sea levels will rise due to melting ice.[6]



Veenhoven 2010;
[2] Sheppard, C. e… …s 2018, p. 12f.; Watson, J. *et al.* 2…
[3] American Chemic…
[4] NASA 2022; EPA…
[5] EPA 2021
[6] NASA 2022; NOA…

Energy

Fig. 1 (above): CO_2 eq. emissions by sector. Source: Richtie & Roser 2020 (c).

Fossil fuels, hydrocarbon-based fuels derived from decomposed plants and animals,[7] cause ≈95% of energy-related emissions.[8] The hydrocarbons' combustion produces heat, evaporating water. The steam is then compressed and spins a turbine. In the generator, a magnetic field is moved alongside coils of wires using the turbine's motion causing change in magnetic flux relative to the coils, which induct current (through an interaction described by Faraday's Law).[9]

There are, however, energy sources that do not substantially emit CO_2,[10] one of which is hydropower. In a storage hydro system, water is kept behind a dam and flows through when the valve is opened, spinning a turbine connected to a generator. Water is stored at a lower reservoir and pumped up to the top during a period of lower energy consumption. Conversely, a run-of-the-river hydro system uses the current of the river to spin a turbine.[11]

Secondly, nuclear power. Uranium-235, after having been split into two by fired neutrons, releases several other neutrons and creates a chain reaction. The reaction produces heat which evaporates water, and the compressed steam spins a turbine.[12]

Next, wind power. Wind spins the device's blades (thereby spinning a turbine), whose motion similarly generates electricity.[13]

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[7] Kopp 2021
[8] Richtie and Roser 2020 (a)
[9] Encyclopaedia Britannica 2020
[10] Ritchie and Roser 2020 (b)
[11] EERE n.d. (a); ARENA 2022 (a); EIA 2022.
[12] MIT Nuclear Reactor Laboratory 2021; WNA 2022; WNA n.d.; EIA 2021.
[13] Stierlwalt 2019; ARENA 2022 (b); EERE n.d. (b)

Finally, photovoltaics. In a solar cell, the p-type area contains silicon (tetravalent) doped with boron (trivalent), creating electron 'holes', regarded as positively charged particles. Contrarily, the n-type area has silicon doped with pentavalent phosphorus, freeing electrons unneeded in bonding. At the junction, electrons and holes diffuse, creating ions whose charge prevent further diffusion. This is called the depletion zone. When the zone is struck by a sufficiently energized photon, an electron is knocked from an ion, creating an electron and hole. Before diffusion, the depletion zone's charge pulls them into the p-type and n-type areas, where electrons and holes accumulate. A wire connecting the two areas thereby produces current.

Which energy source do the statistics favour?

	Deaths per trillion kWh[14]	**CO_2 eq. emitted per kWh (g)**[15]	**Levelized cost (AUD per mWh)**[16]
Hydro	1400	86 (660 MW), 6.1 (330 MW)	100.865
Nuclear	90	5.1	46.11 (long-term operation) 99.42 (standard)
Wind	150	7.8 (offshore) 12.5 (onshore)	72.05 (onshore) 126.80 (offshore)
Photovoltaics	440	23 (rooftop)	181.56 (rooftop)

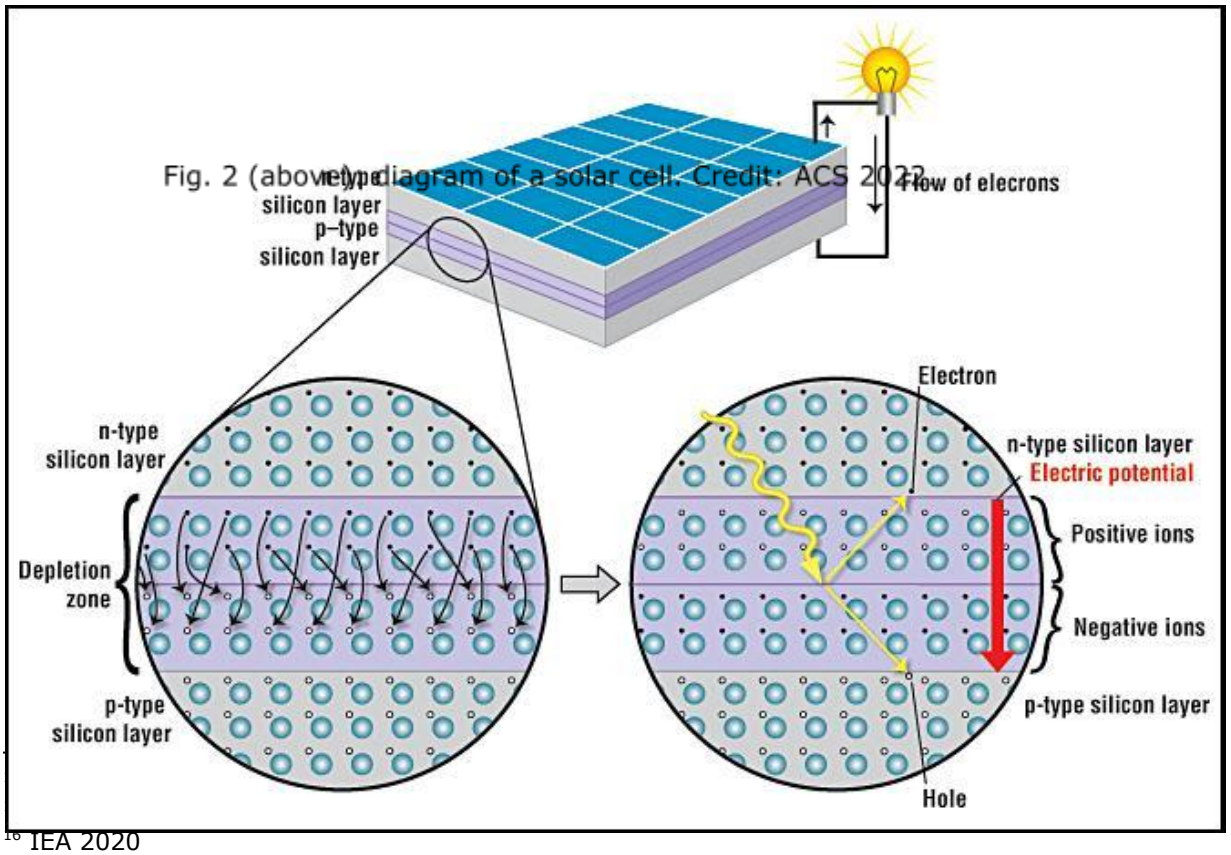

Fig. 2 (above) Cross-section diagram of a solar cell. Credit: ACS 2022

[16] IEA 2020

			80.69 (utility scale)
Coal	100000	912 (pulverized)	126.80

The data indicates the quality of all energy sources. Regional variation (significant) was not considered. Nuclear power is often protested by supporters of renewables, despite its quality (as the statistics indicate).[17] Critics often cite a high overnight cost, a statistic which fails to consider operation duration (as levelized cost does).[18] They also often cite its deadliness, which, although counterintuitive, is comparable to that of renewables.

Cars

While we can produce electricity by other means, cars facilitate internal combustion. Inducting a fuel-air mixture into the cylinder via the intake port, the piston moves downwards, sealed within a fixed cylinder. Then, moving upwards, the piston compresses the mixture with both ports closed. Subsequently, a spark ignites the compressed mixture, and the piston turns the crankshaft. Last, with the exhaust port opened, the piston pushes out the combustion products (some of which are CO_2).[19] One alternative to the internal combustion engine is the all-electric engine, which uses a chargeable lithium-ion battery.

Lithium easily loses electrons except for when it is in a metal oxide. Lithium atoms and metal oxide are stored in the cathode. The anode (opposite) contains graphite. An electrolyte separating these sides allows positive ions to pass through while repelling electrons. A wire connects the anode and cathode. During charging, voltage from a charger is applied and electrons are pulled from the lithium and travel through the wire to the anode, where they are stored with the graphite. Due to the negative charge, this pulls the positive ions in the cathode through the electrolyte into the anode. Conversely, discharging generates current. During discharging, load is attached to the wire and the ions move back to the metal oxide in the cathode (where they are stable) and the electrons travel through the wire and load, generating electricity. At the cathode, the electrons join with the ions.

[17] See, for example, Climate Council 2022.
[18] See, for example, Green 2020 (where only upfront cost and overnight cost are cited, not LCOE). For overnight cost vs LCOE, see WNA 2021.
[19] EERE 2013

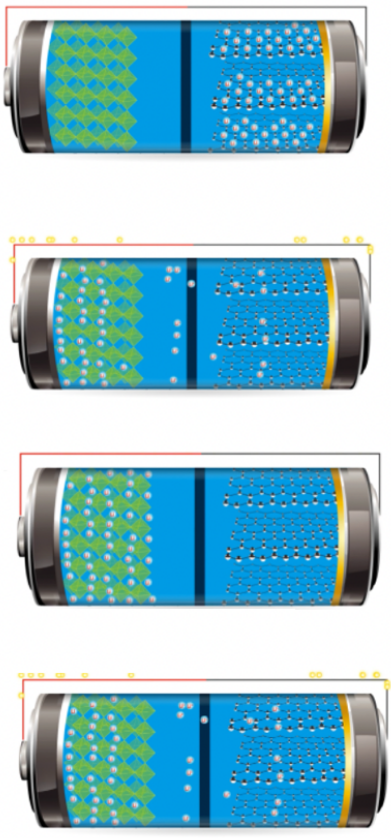

Fig. 3 (above): Diagram of a lithium-ion battery's four key stages: charged, discharging, discharged, and charging. Credit: EERE 2017.

The inverter converts the battery's DC to AC, which it sends to the motor. The motor works the same way as generators (specified above), but the previously existing voltage gets converted to rotatory motion and hence turns the wheels.[20] The EV market is fairly new, and is dominated by the automotive and energy company Tesla, Inc.

Assuming an automobile's annual range is 19,028 km, gasoline costs 1.638 AUD per L, and generates 10.33099 km of distance per L, and charging costs 0.19 AUD per kWh and generates 4.876 km of distance per kWh (assumptions provided by EERE), we derive the following statistics:

	Percentage of global sales (2021)[21]	**Annual CO2eq. emissions per vehicle (kg)[22]**	**AUD per km [23]**	**Mean upfront cost (USD)[24]**
Electric	9	1783	0.038	76,537
Combustion	91	5186 (gasoline)	0.15856	56,824 (full-size)

EVs clearly emit far less. However, when further EV development occurs, prices will continue dropping, making EVs financially beneficial.

[20] Nissan 2021; EERE n.d. (c); Tech Vision 2021.
[21] Pontes 2021
[22] EERE n.d. (f); EERE n.d. (e)
[23] EERE n.d. (d); EERE n.d. (e)
[24] Kelly Blue Book 2021

Land

Deforestation accounts for 2.2% of GHG emissions (CO_2 eq.). Photosynthesis is the process by which plant cells produce glucose from carbon dioxide and water, creating oxygen as a waste product –

$$6 \cdot CO_2 + 6 \cdot H_2O \rightarrow C_6H_{12}O_6 + 6 \cdot O_2$$

, and therefore, removing large amounts of trees has a net positive effect on atmospheric CO_2 concentrations, and is therefore regarded an emission. Deforestation occurs primarily due to agricultural and infrastructural expansion.[25]

One source of agricultural-related GHG emissions is fertilising, which primarily emits nitrous oxide due to denitrification (microbial reduction of nitrate and nitrite to N_2O and nitrogen, N_2).[26] This accounts for 4.1% of global emissions.[27] Fertilizer efficiency can be increased by

- Measuring crop demand and supplying fertilizer accordingly
- Avoiding fertilization after irrigation
- Checking 7-day weather forecast to avoid fertilizer volatility[28]

Crop burning causes 3.5% of GHG emissions. After harvesting, stubble remains. Farmers often burn stubble to clear land for sowing. Cutting stubble short enough to run one's foot through is sufficient, but laborious.[29] Stubble can be decomposed by spraying enzymes on it (which also fertilizes the soil), making it a more reasonable alternative.[30]

Livestock and manure cause 5.8% of GHG emissions. Enteric fermentation is the reduction of carbohydrates into simpler molecules by methanogens in the ruminant's digestive system. The by-product of methane is then expelled from the body.

We cannot eliminate livestock products due to their popularity. Adding methane inhibitors to livestock's diet for methanogens to produce ammonia (NH_3) rather than methane is, while more short-term, a viable solution. There is a proven reduction in methane emissions with varying efficacy and minimal risk.[31] Conversely, cultured meat, whereby an animals' stem cells are removed and grown in a petri dish (in vitro), reduces GHG emissions by 78-96%. Other benefits include a lower risk of disease, 82-96% lower water use, and 99% less land use.[32]

Implementation

We have delt with problems accounting for 84.65% of global GHG emissions but have not yet discussed their implementation.

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[25] Live Science n.d.; Richtie and Roser 2020 (c)
[26] DPIRD 2021; Agriculture Victoria 2021
[27] Richtie and Roser 2020 (c)
[28] Agriculture Victoria 2021
[29] Agriculture Victoria 2022
[30] Deghan 2021; Tuomisto & Mattos 2011.
[31] Hristov *et al.* 2015; Milman 2021; Beil 2015.
[32] University of Colorado Boulder 2021; Tuomisto & Mattos 2011.

A subsidy is a government investment in a company or industry to lower price, thereby expanding demand and consumption. Considering this, Government investment in nuclear power, uranium mining, electric vehicles, renewables and efficient agricultural methods would be beneficial in terms of climate change mitigation and potentially national economic development.[33] A tax's effect is the opposite of a subsidy - it increases price to knock out some consumers. A carbon tax is designed to deter people from producing CO_2 emissions. Due to the low demand elasticity of energy, this will cause serious inflation. A carbon tax is not appropriate for some countries but may be for others – this should be assessed on a case-by-case basis.[34]

[33] IRENA 2016; Winston 2010; NEA 2020; Encyclopaedia Britannica 2021.
[34] McLure 2022; The World Bank 2022.

Reference List

Agriculture Victoria 2021, *Greenhouse Gas Cycles in Agriculture*, Government of Victoria, viewed 29 April 2022, <https://agriculture.vic.gov.au/climate-and-weather/understanding-carbon-and-emissions/greenhouse-gas-cycles-in-agriculture#h2-0>.

Agriculture Victoria 2022, *Nitrogen Fertilisers – Improving Efficiency and Saving Money*, Government of Victoria, viewed 29 April 2022, <https://agriculture.vic.gov.au/climate-and-weather/understanding-carbon-and-emissions/nitrogen-fertilisers-improving-efficiency-and-saving-money>.

American Chemical Society (ACS) 2022 (a), *Greenhouse Gases*, Washington, viewed 22 April 2022, <https://www.acs.org/content/acs/en/climatescience/greenhousegases.html>.

American Chemical Society (ACS) 2022 (b), *How a Solar Cell Works*, Washington, viewed 26 April 2022, <https://www.acs.org/content/acs/en/education/resources/highschool/chemmatters/past-issues/archive-2013-2014/how-a-solar-cell-works.html>.

Australian Renewable Energy Agency (ARENA) 2022 (a), *Hydropower/Pumped Hydro Energy Storage*, Australian Government, Canberra, viewed 25 April 2022, <https://arena.gov.au/renewable-energy/pumped-hydro-energy-storage/>.

Australian Renewable Energy Agency (ARENA) 2022 (b), *Wind Energy*, Australian Government, Canberra, viewed 26 April 2022, <https://arena.gov.au/renewable-energy/wind/>.

Beil, L 2015, 'Getting Creative to Cut Methane from Cows', *ScienceNews*, viewed 30 April 2022, <https://www.sciencenews.org/article/getting-creative-cut-methane-cows>.

Climate Council 2022, *Nuclear Power Stations Are Not Appropriate for Australia - and Probably Never Will Be*, viewed 11 June 2022, <https://www.climatecouncil.org.au/nuclear-power-stations-are-not-appropriate-for-australia-and-probably-never-will-be/>.

Conca, J 2012, 'How Deadly Is Your Kilowatt? We Rank The Killer Energy Sources', *Forbes*, 10 June, viewed 25 April 2022, <https://www.forbes.com/sites/jamesconca/2012/06/10/energys-deathprint-a-price-always-paid/?sh=6f8249da709b>.

Conn, R 2019, 'Nuclear Fusion', in *Encyclopaedia Britannica*, accessed 21 April 2022, <https://www.britannica.com/science/nuclear-fusion>.

Deghan, S 2021, 'Burning Issue: How Enzymes Could End India's Problem with Stubble', *The Guardian*, viewed 29 April 2022, <https://www.theguardian.com/global-development/2021/dec/10/burning-issue-how-enzymes-could-end-indias-problem-with-stubble>.

Department of Primary Industries and Regional Development 2021, *Reducing Nitrous Oxide Emissions from Agricultural Soils of Western Australia,* Government of Western Australia, viewed 29 April 2022, <https://www.agric.wa.gov.au/climate-change/reducing-nitrous-oxide-emissions-agricultural-soils-western-australia>.

Editors of Encyclopaedia Britannica 2020, 'Planck's Radiation Law', in *Encyclopaedia Britannica,* viewed 16 May 2022, <https://www.britannica.com/science/Plancks-radiation-law>.

Editors of Encyclopaedia Britannica 2021, 'Subsidy', in *Encyclopaedia Britannica,* viewed 16 May 2022, <https://www.britannica.com/topic/subsidy>.

Energy Information Administration (EIA) 2021, *Generating Electricity*, Federal Government of the United States, Washington, D.C., viewed 11 June 2022, <https://www.eia.gov/energyexplained/electricity/how-electricity-is-generated.php>.

Energy Information Administration (EIA) 2021 (b), *Nuclear Explained*, Federal Government of the United States, Washington, D.C., viewed 25 April 2022, <https://www.eia.gov/energyexplained/nuclear/>.

Energy Information Administration (EIA) 2022, *Hydropower Explained*, Federal Government of the United States, Washington, D.C., viewed 25 April 2022, <https://www.eia.gov/energyexplained/hydropower/>.

Environmental Protection Agency (EPA) 2016, *Atmospheric Concentrations of Greenhouse Gases*, Federal Government of the United States, Washington, D.C., viewed 23 April 2022, <https://www.epa.gov/climate-indicators/climate-change-indicators-atmospheric-concentrations-greenhouse-gases>.

Environmental Protection Agency (EPA) 2021, *Understanding Global Warming Potentials*, Federal Government of the United States, Washington, D.C., viewed 23 April 2022, <https://www.epa.gov/ghgemissions/understanding-global-warming-potentials>.

Environmental Protection Agency (EPA) 2022, *Basics of Climate Change*, Federal Government of the United States, Washington, D.C., viewed 23 April 2022, <https://www.epa.gov/climatechange-science/basics-climate-change>.

Green, J 2020, 'Supporters of Nuclear Power Need a Reality Check: It's Staggeringly Expensive', *The Sydney Morning Herald*, viewed 17 May 2022, <https://environment/climate-change/supporters-of-nuclear-power-need-a-reality-check-it-s-staggeringly-expensive-20200308-p547wv.html>

Harrison, R (ed.) 2014, *Pollution: Causes, Effects and Control*, 5th edn., Royal Society of Chemistry, Cambridge.

Hristov, A, Oh, J, Giallongo, F, Frederick, T, Harper, M, Weeks, H, Branco, A, Moate, P, Deighton, M, Williams, S, Kindermann, M & Duval, S 2015, 'An Inhibitor Persistently Decreased Enteric Methane Emission from Dairy Cows with No Negative Effect on Milk Production', *Proceedings of the National Academy of Sciences of the United States of America*, vol. 112, no. 34, pp. 10663-10668.

International Energy Agency (IEA) 2020, *Projected Costs of Generating Electricity 2020*, Paris, viewed 26 April 2022, <https://www.iea.org/reports/projected-costs-of-generating-electricity-2020>.

International Renewable Energy Agency (IRENA) 2016, *Renewable Energy Benefits: Measuring the Economics*, viewed 1 May 2022, <https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2016/IRENA_Measuring-the-Economics_2016.pdf>.

Kelly Blue Book 2021, 'Eight Straight: New-Vehicle Prices Mark Another Record High in November 2021, According to Kelley Blue Book', *Cision: PR Newswire*, 10 December, viewed 28 April 2022, <https://www.prnewswire.com/news-releases/eight-straight-new-vehicle-prices-mark-another-record-high-in-november-2021-according-to-kelley-blue-book-301442015.html>.

Kopp, O 2021, 'Fossil Fuels', in *Encyclopaedia Britannica*, accessed 11 June 2022, <https://www.britannica.com/science/fossil-fuel>.

Live Science n.d., *Deforestation: Facts, Causes & Effects*, viewed 11 June 2022, <https://www.livescience.com/27692-deforestation.html>.

Mann, M 2021, 'Greenhouse Gases', in *Encyclopaedia Britannica*, accessed 21 April 2022, <https://www.britannica.com/science/greenhouse-gas>.

Massachusetts Institute of Technology Nuclear Research Laboratory 2021, *The Fission Process*, Cambridge, Massachusetts, viewed 25 April 2022, <https://nrl.mit.edu/reactor/fission-process>.

McLure, C 2022, 'Taxation', in *Encyclopaedia Britannica,* viewed 1 May 2022, <https://www.britannica.com/topic/taxation>.

Milman, O. 2021, 'Feeding Cows Seaweed Could Cut Their Methane Emissions by 82%, Scientists Say', *The Guardian*, viewed 30 April 2022, <https://www.theguardian.com/environment/2021/mar/18/cows-seaweed-methane-emissions-scientists>.

National Aeronautics and Space Administration (NASA) 2022 (b), *How Do Photovoltaics Work*?, Federal Government of the United States, Pasadena, viewed 26 April 2022, <https://science.nasa.gov/science-news/science-at-nasa/2002/solarcells>.

National Aeronautics and Space Administration (NASA) 2022, *Global Climate Change: Vital Signs of the Planet*, Federal Government of the United States, Pasadena, viewed 20 April 2022, <https://climate.nasa.gov/>.

National Oceanic and Atmospheric Administration (NOAA)) 2021, *Climate change impacts*, viewed 11 June 2022, <https://www.noaa.gov/education/resource-collections/climate/climate-change-impacts>.

Nissan 2021, *How Do Electric Cars Work?*, Yokohama, Japan, viewed 27 April 2022, <https://www.nissanusa.com/experience-nissan/news-and-events/how-do-electric-cars-work.html>.

Nuclear Energy Agency (NEA) 2020, *Uranium Supply*, viewed 1 May 2022, <https://www.oecd-nea.org/jcms/pl_22152/uranium-supply>.

Office of Energy Efficiency and Renewable Energy (EERE) 2013, *Internal Combustion Engine Basics*, Federal Government of the United States, Washington, D.C., viewed 26 April 2022, <https://www.energy.gov/eere/vehicles/articles/internal-combustion-engine-basics#:~:text=In%20a%20spark%20ignition%20engine,piston%20during%20the%20power%20stroke.>.

Office of Energy Efficiency and Renewable Energy (EERE) n.d. (a), *How Hydropower Works*, Federal Government of the United States, Washington, D.C., viewed 25 April 2022, <https://www.energy.gov/eere/water/how-hydropower-works>.

Office of Energy Efficiency and Renewable Energy (EERE) n.d. (b), *How Do Wind Turbines Work?*, Federal Government of the United States, Washington, D.C., viewed 26 April 2022, <https://www.energy.gov/eere/wind/how-do-wind-turbines-work>.

Office of Energy Efficiency and Renewable Energy (EERE) n.d. (c), *How Do All-Electric Cars Work?*, Federal Government of the United States, Washington, D.C., viewed 27 April 2022, <https://afdc.energy.gov/vehicles/how-do-all-electric-cars-work>.

Office of Energy Efficiency and Renewable Energy (EERE) n.d. (d), *Charging Plug-In Electric Vehicles at Home*, Federal Government of the United States, Washington, D.C., viewed 27 April 2022, <https://afdc.energy.gov/fuels/electricity_charging_home.html>.

Office of Energy Efficiency and Renewable Energy (EERE) n.d. (e), *Data Sources and Assumptions for the Electricity Sources and Emissions Tool*, Federal Government of the United States, Washington, D.C., viewed 27 April 2022, <https://afdc.energy.gov/vehicles/electric_emissions_sources.html>.

Office of Energy Efficiency and Renewable Energy (EERE) n.d. (f), *Emissions from Electric Vehicles*, Federal Government of the United States, Washington, D.C., viewed 8 May 2022, < https://afdc.energy.gov/vehicles/electric_emissions.html>.

Pontes, J 2021, *World EV Sales — Tesla Model 3 Wins 4th Consecutive Best Seller Title In Record Year*, viewed 8 May 2022, <https://cleantechnica.com/2022/01/30/world-ev-sales-tesla-model-3-wins-4th-consecutive-best-seller-title-in-record-year/>.

Richtie, H. & Roser, M. 2020 (a), *Fossil Fuels*, Our World in Data, viewed 26 April 2022, <https://ourworldindata.org/fossil-fuels>.

Ritchie, H. & Roser, M. 2020 (b), *Energy Mix*, Our World in Data, viewed 25 April 2022, <https://ourworldindata.org/energy-mix>.

Ritchie, H. & Roser, M. 2020 (c), *CO_2 Emissions by Fuel*, Our World in Data, viewed 25 April 2022, <https://ourworldindata.org/emissions-by-fuel >.

Ritchie, H. & Roser, M. 2020 (d), *GHG Emissions*, Our World in Data, viewed 25 April 2022, <https://ourworldindata.org/greenhouse-gas-emissions>.

Roser, M. 2013, *Economic Growth*, Our World in Data, viewed 16 May 2022, <https://ourworldindata.org/economic-growth>.

Schmidt-Rohr, K., 2015, 'Why Combustions Are Always Exothermic, Yielding About 418 kJ per Mole of O_2', *Journal of Chemical Education*, vol. 92, no. 12, 1 September, pp. 2094 – 2099.

Sheppard, C. (ed.) 2019, World Seas: *An Environmental Evaluation Volume III: Ecological Issues and Environmental Impacts*, 2nd edn., Elsevier.

Skiba, U. 2008, 'Denitrification', in *Encyclopaedia of Ecology*, viewed 29 April 2022, <https://www.sciencedirect.com/science/article/pii/B9780080454054002640>.

Stierwalt, S. 2019, 'How Does Wind Energy Work?', *Scientific American*, 8 August, viewed 26 April 2022, <https://www.scientificamerican.com/article/how-does-wind-energy-work/>.

Tech Vision 2021, *How Do Electric Vehicles Work?*, online video, 31 October, viewed 27 April 2022, <https://www.youtube.com/watch?v=GHGXy_sjbqQ>.

Tuomisto, H & Mattos, M 2011, 'Environmental Impacts of Cultured Meat Production', *Environmental Science and Technology*, vol. 45, no. 14, June, pp. 6117-6123.

United Nations 2018, In Brief: The State of World Fisheries and Aquaculture, viewed 20 April 2022, <https://www.fao.org/3/ca0191en/ca0191en.pdf>.

United Nations Economic Commission for Europe (UNECE) 2021, *Carbon Neutrality in the UNECE Region: Integrated Life-cycle Assessment of Electricity Sources*, Geneva, viewed 26 April 2022, <https://unece.org/sites/default/files/2022-04/LCA_3_FINAL%20March%202022.pdf>.

University of Colorado Boulder 2021, *Lab Grown Meat - An Emerging Industry*, Boulder, viewed 30 April 2022, <https://www.colorado.edu/ecenter/2021/10/20/lab-grown-meat-emerging-industry>.

Veenhoven, R 2010, 'Life is Getting Better: Societal Evolution and Fit with Human Nature', *Social Indicators Research*, vol. 97, no. 1, December, pp. 105-122.

Watson, J., Shanahan, D., Marco, M., Allan, J., Laurence, W., Sanderson, E., Mackey, B., & Venter, O., 2016, 'Catastrophic Declines in Wilderness Areas Undermine Global Environment Targets', *Current Biology*, vol. 26, no. 21, 7 November, pp. 2929-2934, viewed 21 April 2022, <https://www.cell.com/current-biology/pdfExtended/S0960-9822(16)30993-9>.

Winston, A. 2010, 'Going Green for the Economy', *Harvard Business Review*, viewed 1 May 2022, <https://hbr.org/2010/08/going-green-for-the-economy>.

World Bank 2022, *Pricing Carbon*, Washington, D.C., viewed 1 May 2022, <https://www.worldbank.org/en/programs/pricing-carbon>.

World Nuclear Association 2021, *Economics of Nuclear Power,* London, viewed 17 May 2022, <https://world-nuclear.org/information-library/economic-aspects/economics-of-nuclear-power.aspx>.

World Nuclear Association 2022, *Physics of Uranium and Nuclear Energy,* London, viewed 25 April 2022, <https://world-nuclear.org/information-library/nuclear-fuel-cycle/introduction/physics-of-nuclear-energy.aspx>.

World Nuclear Association n.d., *How Does a Nuclear Reactor Work?*, London, viewed 25 April 2022, <https://world-nuclear.org/nuclear-essentials/how-does-a-nuclear-reactor-work.aspx>.

Figures

Fig. 1: from Ritchie, H & Roser, M 2020 (c), *Emissions by Sector*, Our World in Data, viewed 24 April 2022, <https://ourworldindata.org/emissions-by-sector>.

Fig. 2: American Chemical Society (ACS) 2022 (b), *How a Solar Cell Works*, Washington, viewed 26 April 2022, <https://www.acs.org/content/acs/en/education/resources/highschool/chemmatters/past-issues/archive-2013-2014/how-a-solar-cell-works.html>.

But what personal action can one take? Assuming sufficient capital is available, photovoltaics can be installed on one's roof, and an EV can be purchased. However, does donating to innovation/research facilities have a greater proportional effect? Or, conversely, does donating to non-prestigious education, especially in third-world countries, have a greater proportional effect? Performing such a calculation would be laborious, if not impossible. It is up to the reader to decide for themselves. Another option is the purchase of shares in companies or futures in commodities that correspond to the lowering of CO_2

Fig. 3: Office of Energy Efficiency and Renewable Energy (EERE) 2017, *How Does a Lithium-ion Battery Work?*, Federal Government of the United States, Washington, D.C., viewed 8 May 2022, <https://www.energy.gov/eere/articles/how-does-lithium-ion-battery-work>.

emissions (e.g., Tesla, Inc.; or uranium futures). This can also provide the investor a profit – a victory both financially and ethically.

In conclusion, one should be meticulous about where his or her money goes. While a lot of this is subjective and open-ended, it does not prevent one from performing rational and scrupulous analysis.