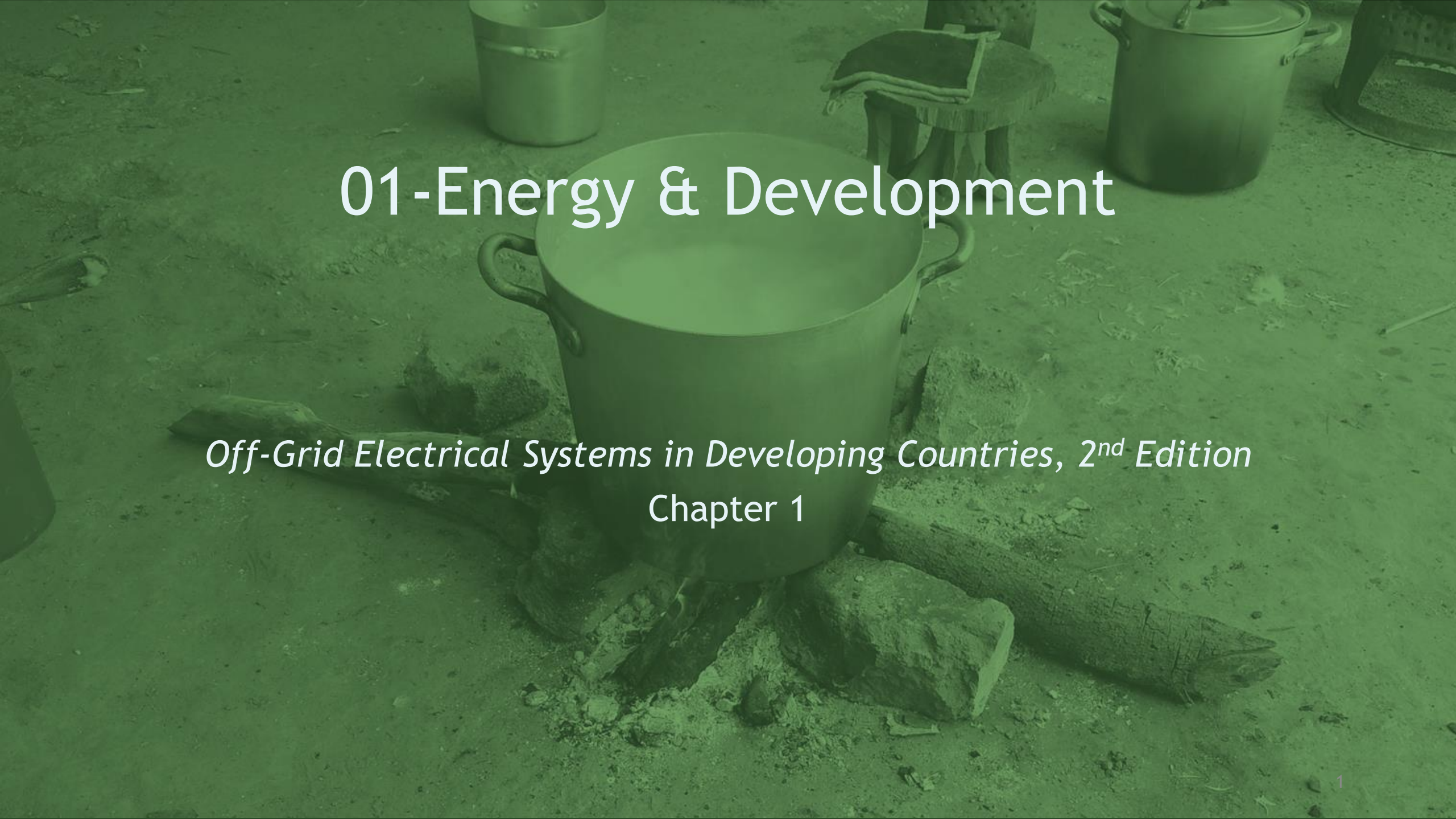

# 01-Energy & Development

*Off-Grid Electrical Systems in Developing Countries, 2nd Edition*

Chapter 1

# Preface

- These lectures slides are intended to accompany the textbook *Off-Grid Electrical Systems in Developing Countries, 2nd Edition, 2025* written by Dr. Henry Louie and published by SpringerNature
- Additional content, explanations, derivations, examples, problems, errata, and other materials are found in the book and on www.drhenrylouie.com
- To request solutions, explanations, permissions to use author-supplied images, or if you notice an error, please email the author at hlouie@ieee.org
- Inquiries about guest lectures, seminars, or trainings can be made to hlouie@ieee.org
- If you want to support work in electricity access, consider donating to KiloWatts for Humanity or IEEE Smart Village

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# Learning Outcomes

At the end of this lecture, you will be able to:

- ✓Explain the state and trends of global energy and electricity supply and consumption with a particular focus on Sub-Saharan Africa and developing countries
- ✓Describe and contrast different technical approaches to electricity access
- ✓Define energy justice and energy equity
- ✓Solve energy supply, conversion, and consumption problems using engineering and mathematical principles

# Off-Grid Electrification

Off-Grid Electrification: *providing electricity to an unserved population by a means other than a connection to the existing centralized grid*

# Why Study Off-Grid Electrification?

## Humanitarian/social justice

- rural poor most likely to be energy impoverished
- access to electricity improves lives and livelihoods

## Business opportunity

- >200,000 mini-grids needed
- >30 million solar lanterns and solar home systems sold each year

## Intellectual merit

- intersection of technology & society
- dynamic and growing space—there is a need for innovation and problem solvers
- technical principles are widely applicable

# Terminology: “Third World” Countries

- Antiquated way of classifying countries based on political ideology
  - First World: United States, Western Europe,  etc. (capitalist countries)
  - Second World: USSR, (communist countries)
  - Third World: the other countries
- “Third world” should be avoided

# “Developing” Countries

- No universal definition of a “developing” country
  - United Nations does not have a definition of developing country
- “Development” is often based on per person Gross Domestic Product
- Alternate terms:
  - Global South
  - Emerging Markets/Frontier Markets
  - Least Developed Countries
  - Less Economically Developed Countries
- Associated Press recommends using “Developing Country”

See https://unstats.un.org/unsd/methodology/m49/

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Afghanistan | British Indian Ocean Territory | Democratic People's Republic of Korea | Guam | Madagascar | Nigeria | Samoa | Tokelau |
| Algeria | British Virgin Islands | Democratic Republic of the Congo | Guatemala | Malawi | Niue | Sao Tome and Principe | Tonga |
| American Samoa | Brunei Darussalam | Djibouti | Guinea | Malaysia | Northern Mariana Islands | Saudi Arabia | Trinidad and Tobago |
| Angola | Burkina Faso | Dominica | Guinea-Bissau | Maldives | Oman | Senegal | Tunisia |
| Anguilla | Burundi | Dominican Republic | Guyana | Mali | Pakistan | Seychelles | Turkey |
| Antarctica | Cabo Verde | Ecuador | Haiti | Marshall Islands | Palau | Sierra Leone | Turkmenistan |
| Antigua and Barbuda | Cambodia | Egypt | Honduras | Martinique | Panama | Singapore | Turks and Caicos Islands |
| Argentina | Cameroon | El Salvador | India | Mauritania | Papua New Guinea | Sint Maarten (Dutch part) | Tuvalu |
| Armenia | Cayman Islands | Equatorial Guinea | Indonesia | Mauritius | Paraguay | Solomon Islands | Uganda |
| Aruba | Central African Republic | Eritrea | Iran (Islamic Republic of) | Mayotte | Peru | Somalia | United Arab Emirates |
| Azerbaijan | Chad | Eswatini | Iraq | Mexico | Philippines | South Africa | United Republic of Tanzania |
| Bahamas | Chile | Ethiopia | Jamaica | Micronesia (Federated States of) | Pitcairn | South Georgia and the South Sandwich Islands | United States Minor Outlying Islands |
| Bahrain | China | Falkland Islands (Malvinas) | Jordan | Mongolia | Puerto Rico | South Sudan | United States Virgin Islands |
| Bangladesh | China, Hong Kong Special Administrative Region | Fiji | Kazakhstan | Montserrat | Qatar | Sri Lanka | Uruguay |
| Barbados | China, Macao Special Administrative Region | French Guiana | Kenya | Morocco | Republic of Korea | State of Palestine | Uzbekistan |
| Belize | Colombia | French Polynesia | Kiribati | Mozambique | Réunion | Sudan | Vanuatu |
| Benin | Comoros | French Southern Territories | Kuwait | Myanmar | Rwanda | Suriname | Venezuela (Bolivarian Republic of) |
| Bhutan | Congo | Gabon | Kyrgyzstan | Namibia | Saint Barthélemy | | Viet Nam |
| Bolivia (Plurinational State of) | Cook Islands | Gambia | Lao People's Democratic Republic | Nauru | Saint Helena | Syrian Arab Republic | Wallis and Futuna Islands |
| Bonaire, Sint Eustatius and Saba | Costa Rica | Georgia | Lebanon | Nepal | Saint Kitts and Nevis | Tajikistan | Western Sahara |
| Botswana | Côte d'Ivoire | Ghana | Lesotho | New Caledonia | Saint Lucia | Thailand | Yemen |
| Bouvet Island | Cuba | Grenada | Liberia | Nicaragua | Saint Martin (French Part) | Timor-Leste | Zambia |
| Brazil | Curaçao | Guadeloupe | Libya | Niger | Saint Vincent and the Grenadines | Togo | Zimbabwe |

UN-designated developing countries/regions

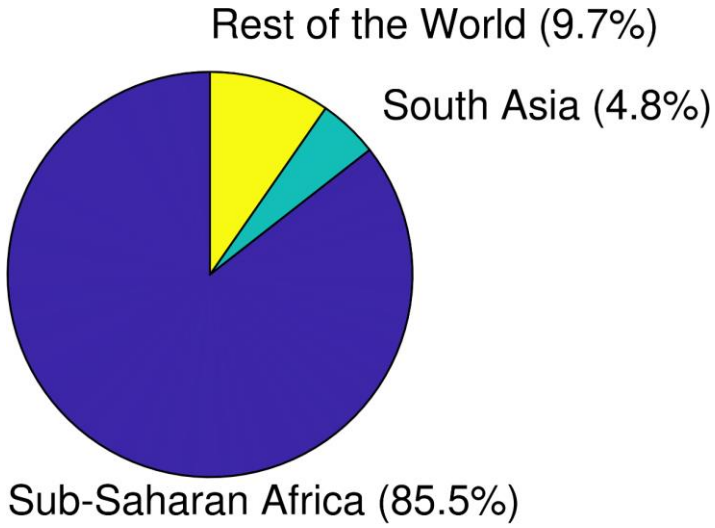
See also "Least Developed Country"

# General Developing Country Characteristics

- High levels of poverty
- Poor nutrition, healthcare, education
- Vulnerable to external threats

# Electricity Access

- As of 2022 +685 million people are without access to electricity in their home
- Majority live in Sub-Saharan Africa (SSA)



# The Grid is Not Everywhere

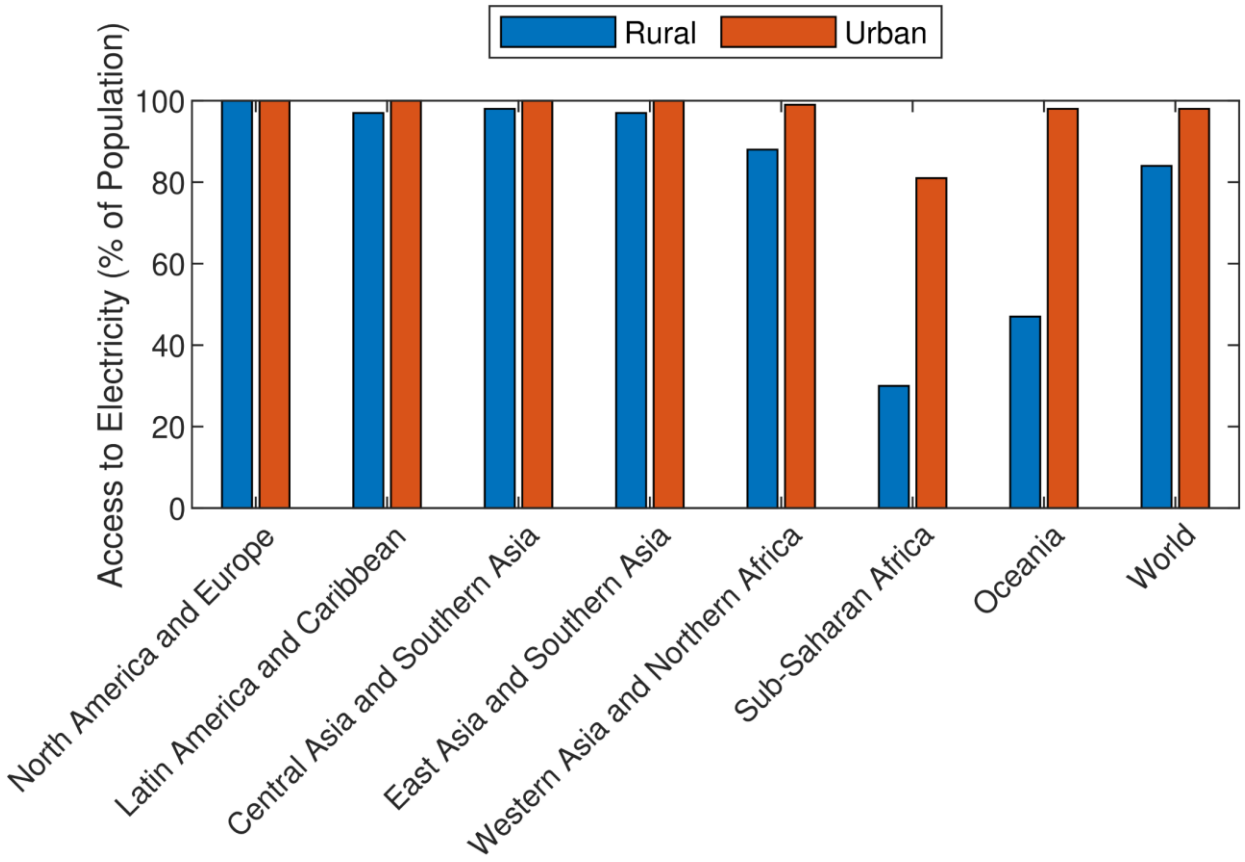
Zambia

(*courtesy: H. Louie*)

Navajo Nation (Southwest U.S.)

(*courtesy: H. Louie*)

# Rural Penalty




majority of those without electricity live in rural areas

(*courtesy: H. Louie*)

# Rural Communities

# Energy & Human Development

Access to energy underpins all human activities


food


transportation


healthcare


education

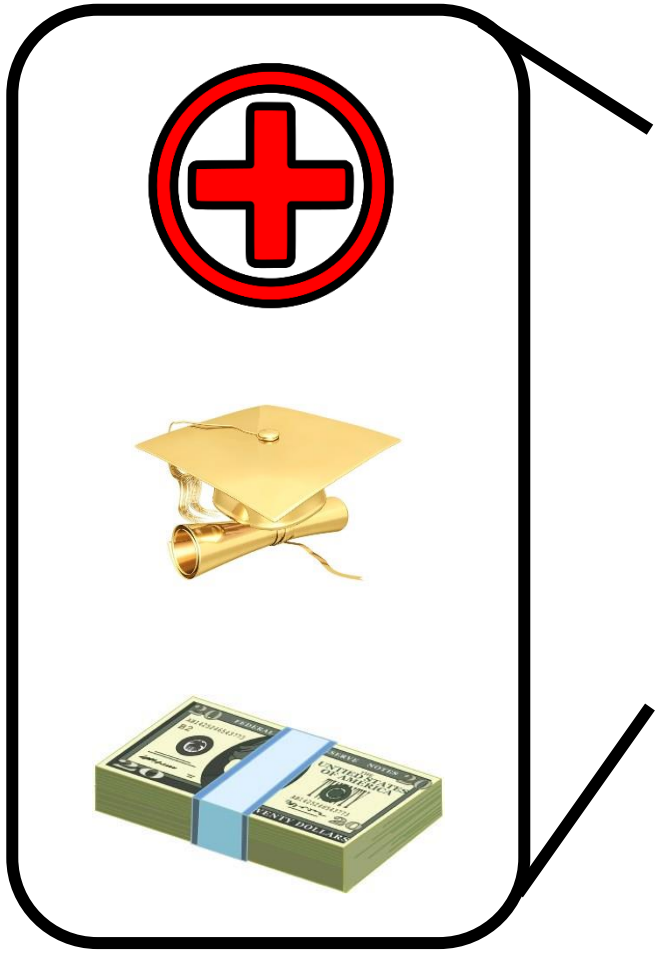

business

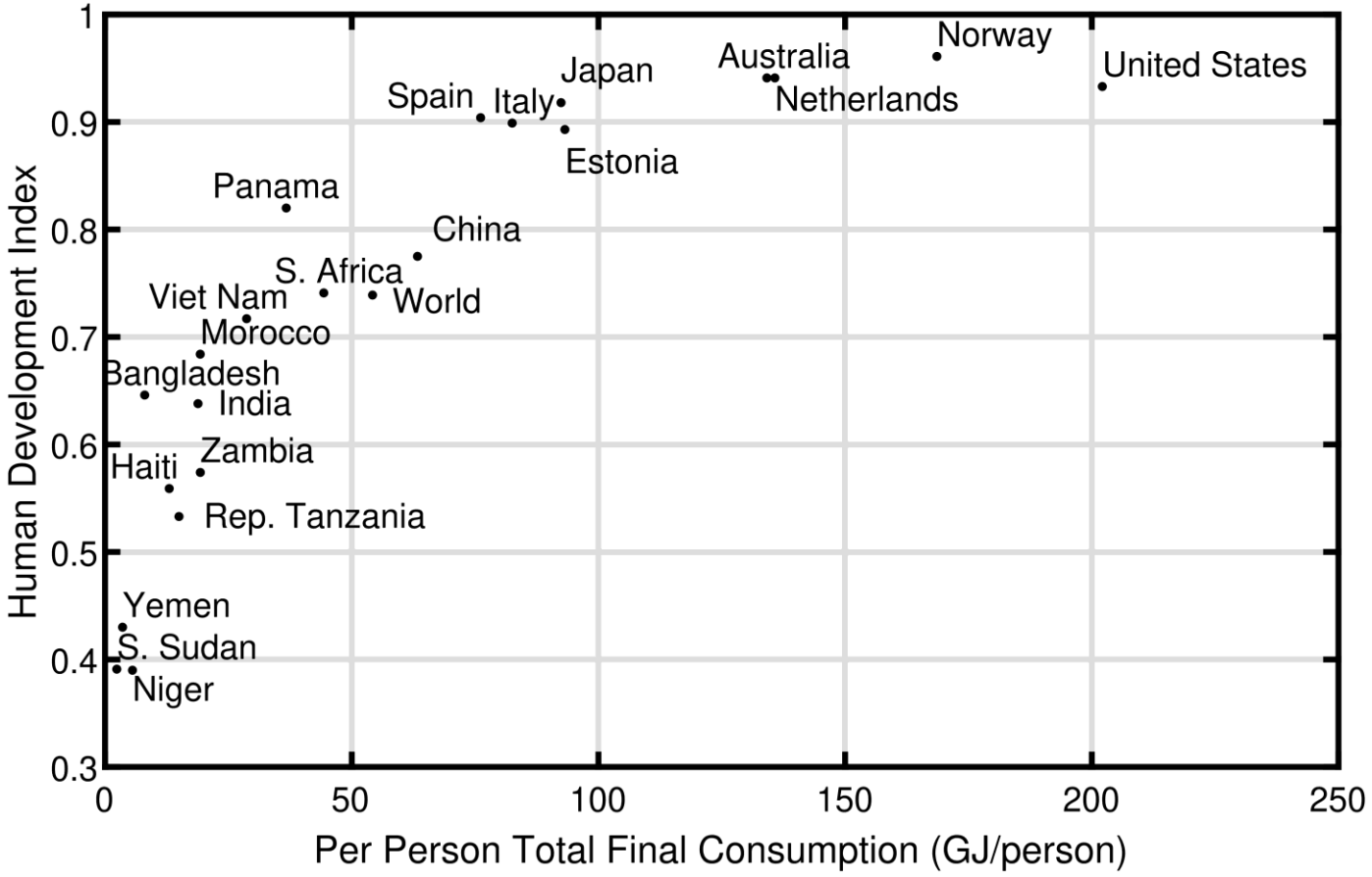

entertainment


information/
communication


Which other SDG are enabled by access to electricity?

# Human Development Index





# Units of Energy

| Unit | joules |
|---|---|
| Joule (J) | 1 |
| Calorie (cal) | 4.1868 |
| British Thermal Unit (BTU) | 1055.87 |
| Watthour (Wh) | 3600 |
| Kilocalorie (C, kcal) | 4186.8 |
| Kilowatthour (kWh) | $3.6 \times 10^6$ |
| Kilogram of oil equivalent (koe) | $41.868 \times 10^6$ |
| Megawatthour (MWh) | $3.6 \times 10^9$ |
| Tonne of oil equivalent (toe) | $41.868 \times 10^9$ |
| Quad (quad) | $1055.87 \times 10^{15}$ |
| Gigajoule (GJ) | $1 \times 10^9$ |
| Terawatthour (TWh) | $3.6 \times 10^{15}$ |

Electrical energy is commonly expressed in watthours (Wh) (or kWh, MWh, TWh) rather than joules

The average house in the U.S. consumes 30 kWh of electricity each day

# Example 1.2

The 2013 average annual per person energy total final consumption in Zambia was 25.6 GJ. Compute the average daily consumption in kilowatthours per day.

# Example 1.2

The 2013 average annual per person energy total final consumption in Zambia was 25.6 GJ. Compute the average daily consumption in kilowatthours per day.

$$25.6\ \text{GJ/yr} = \frac{25.6\ \text{GJ/yr}}{365\ \text{day/yr}} = 70.1\ \text{MJ/day}$$

$$70.1\ \text{MJ/day} = \frac{70.1\ \text{MJ/day}}{3.6\ \text{MJ/kWh}} = 19.5\ \text{kWh/day}$$

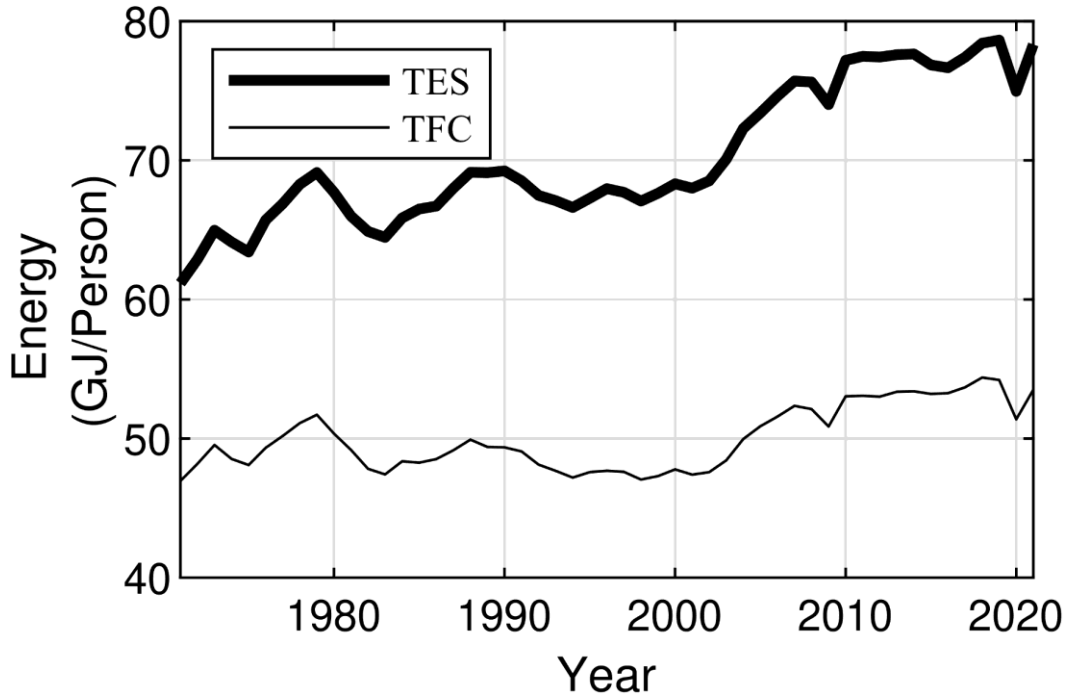
# Total Energy Supply and Total Final Consumption

- Total Final Consumption (TFC): energy users consume to meet their needs
- Total Energy Supply (TES): the energy supplied to realize TFC

TFC > TES due to losses in the energy system

# Total Energy Supply and Total Final Consumption

Global per person TFC (and TES) have shown an increasing trend



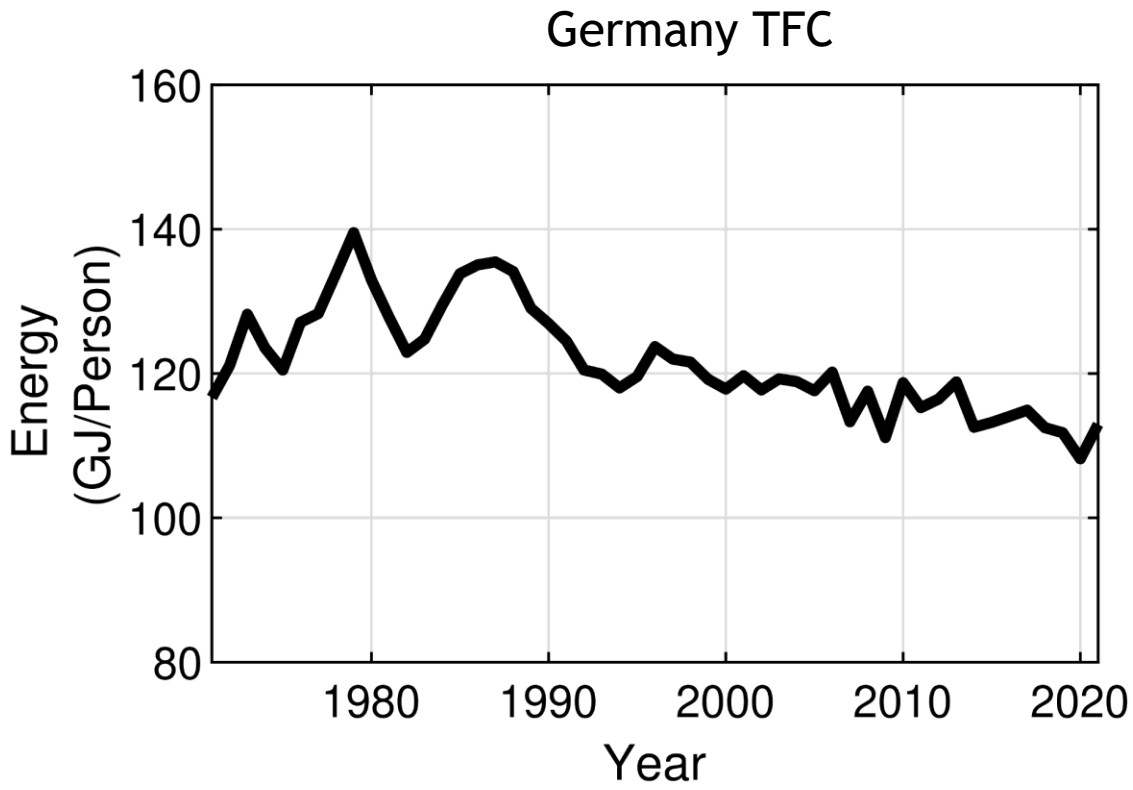

What caused the temporary dip in consumption in 2008-2009?

What caused the temporary dip in consumption in 2020?

# Energy Consumption Trends

- Increasing trend in consumption is not universal
- Several developed countries have stagnant or declining per person consumption

What do you think caused the decline in Germany's TFC?



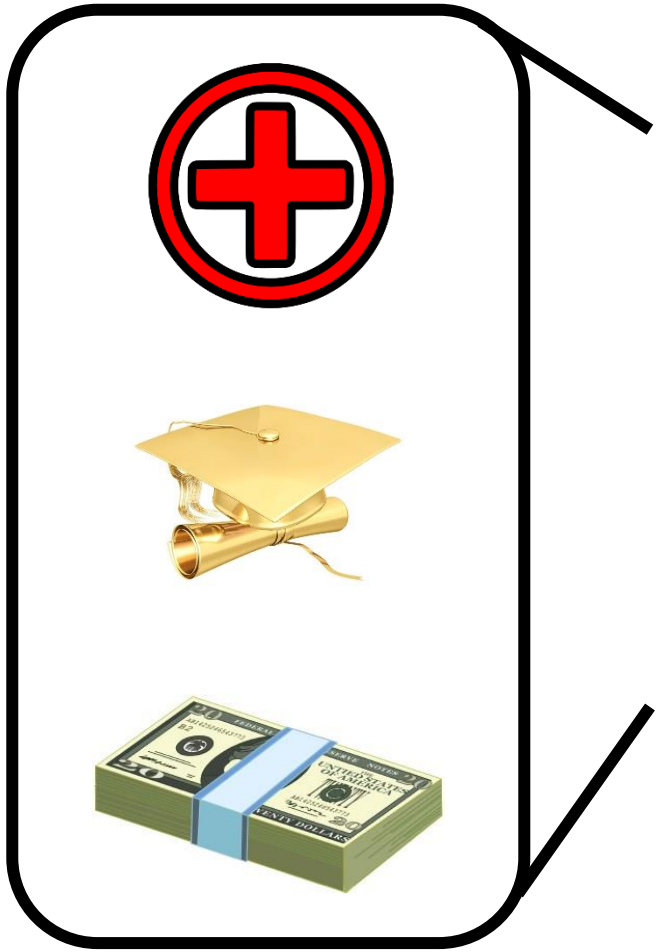
# Energy Inequality

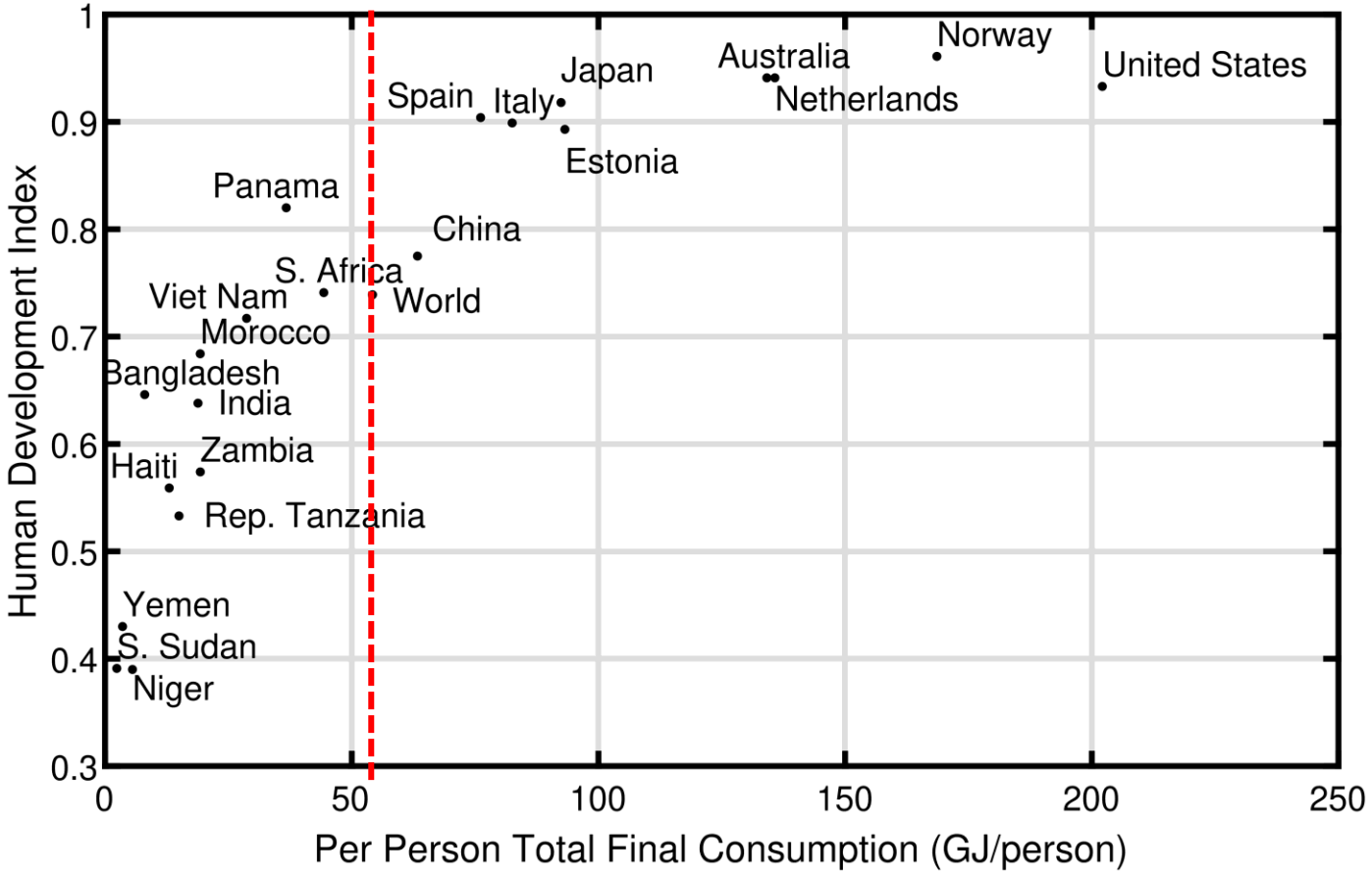
- World average per person TFC is 56 GJ/person/year
- Vast inequality in consumption
  - Canada: 209 GJ/person/year
  - Sub-Saharan Africa (average): 21 GJ/person/year

The over 1.25 billion people in Africa consume less than 6% of the world's energy

# Energy Inequality

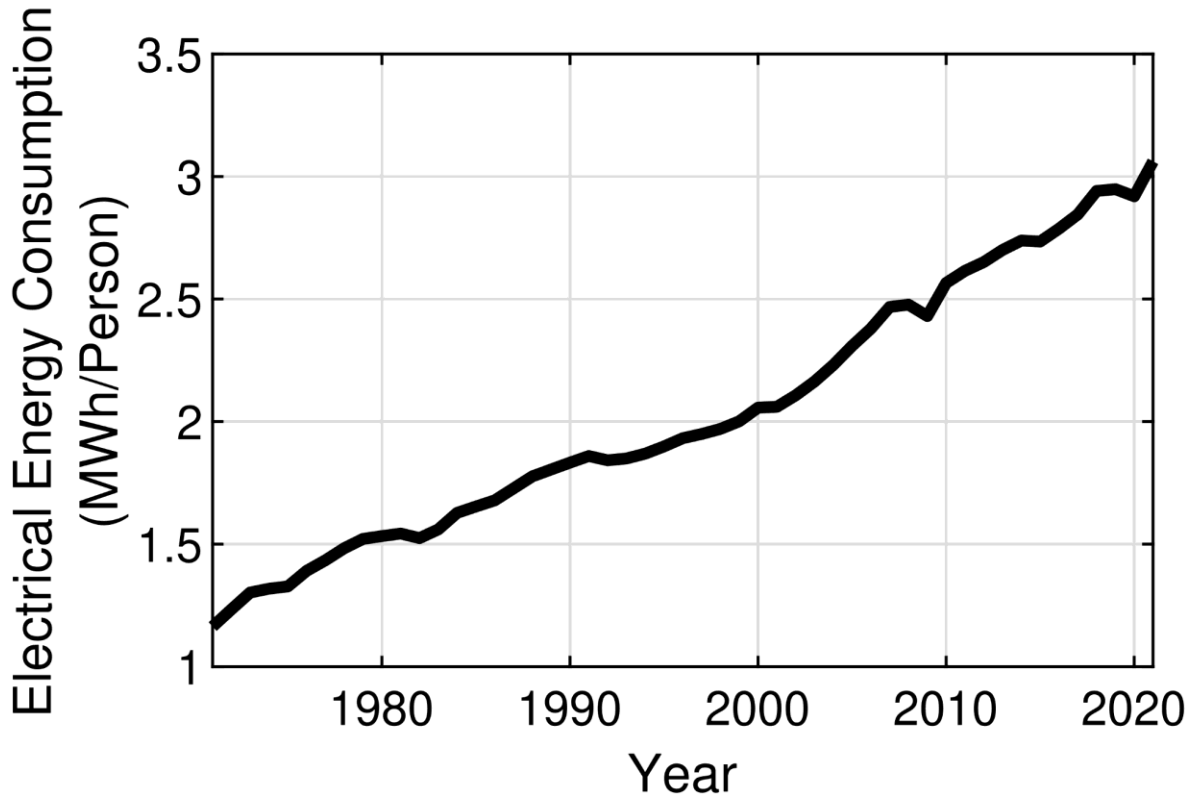
If energy consumption was equal, HDI would be approximately 0.75–a reasonable standard of living





# Global Electricity Consumption

- Global electricity production: 28,519 TWh (2021)
- Global per person electricity consumption has steadily increased



# Match the country/region to its electricity consumption

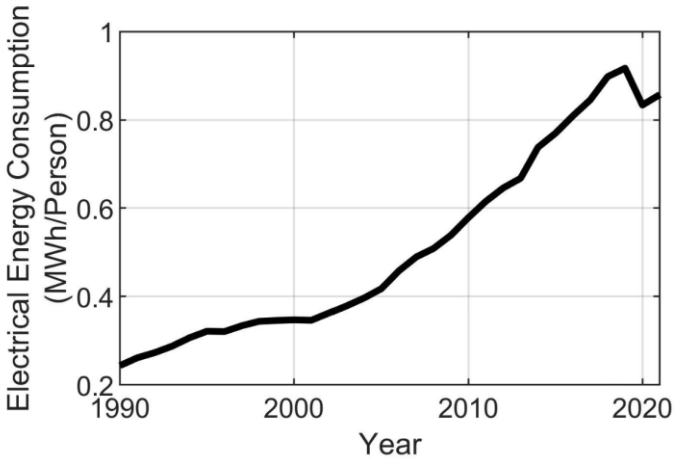
China

India

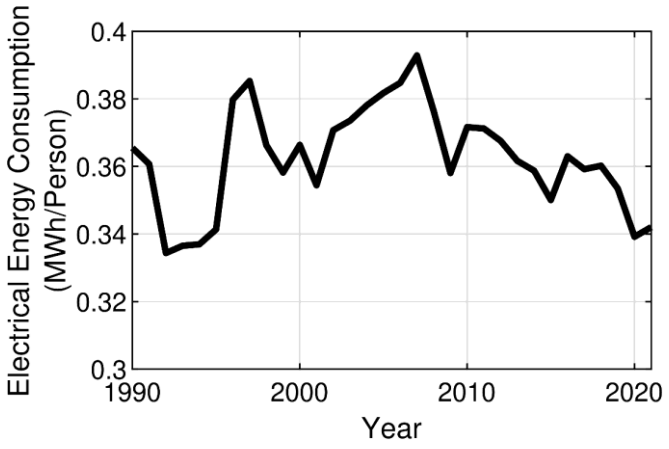
Sub-Saharan Africa

United States

Country/Region: _____




Country/Region: _____

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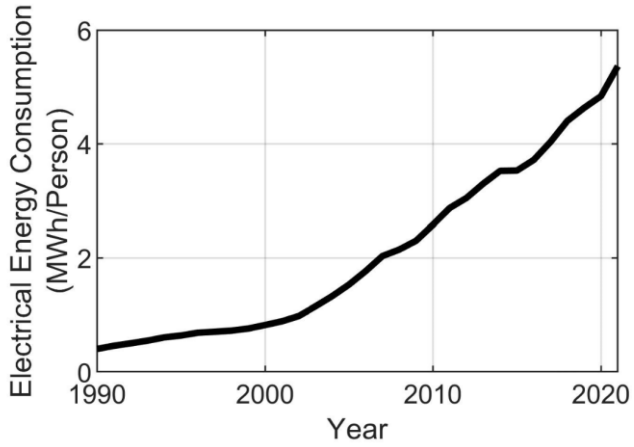
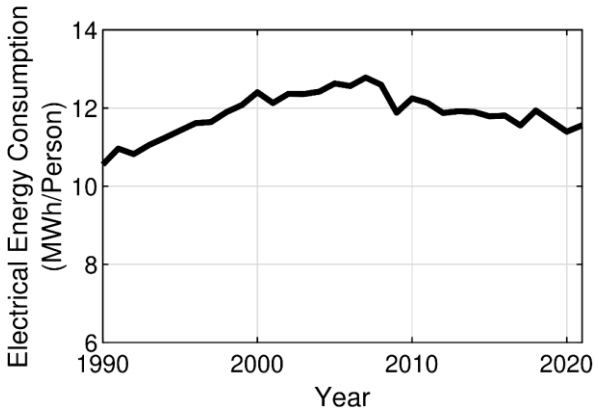


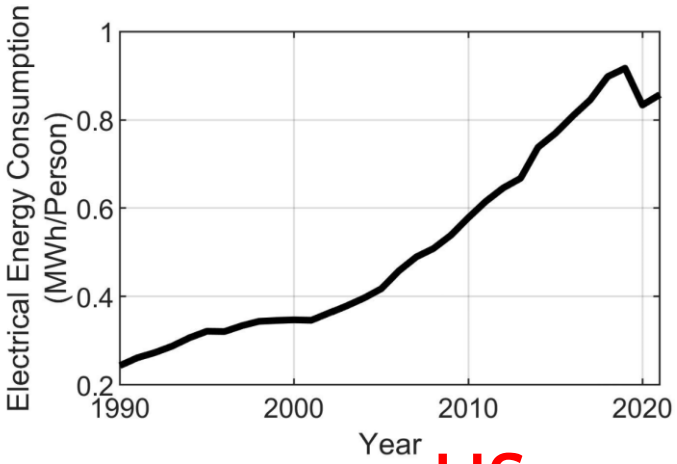

Country/Region: _____



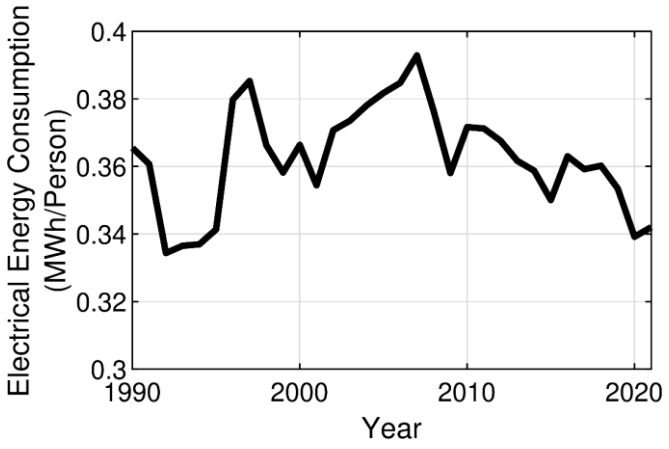
# Match the country/region to its electricity consumption

- China
- India
- Sub-Saharan Africa
- United States

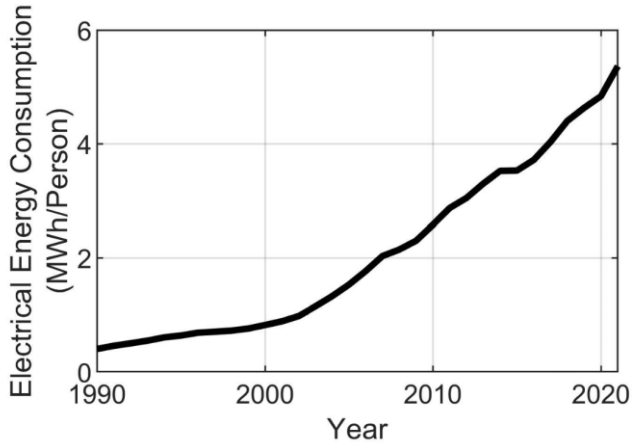
Country/Region: India



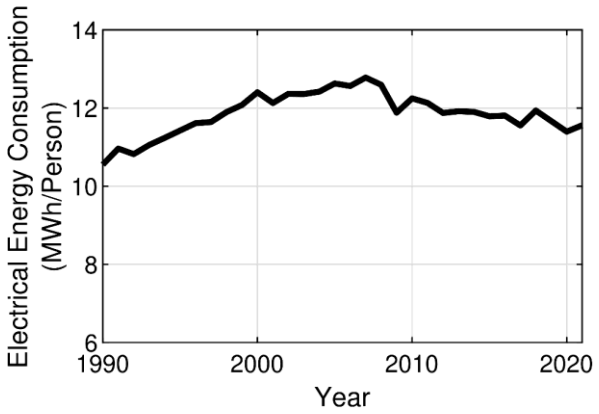

Country/Region: SSA




Country/Region: China

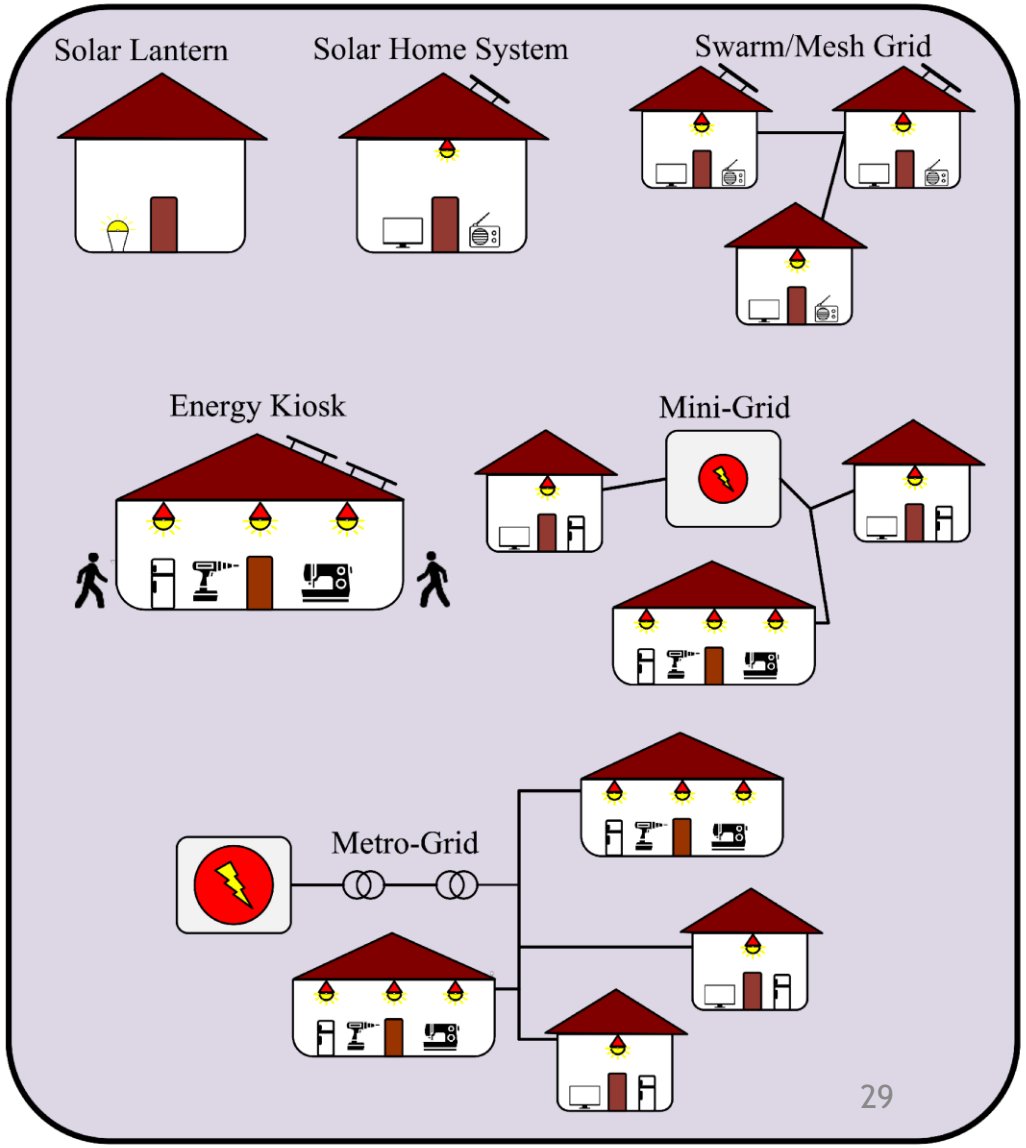



Country/Region: US

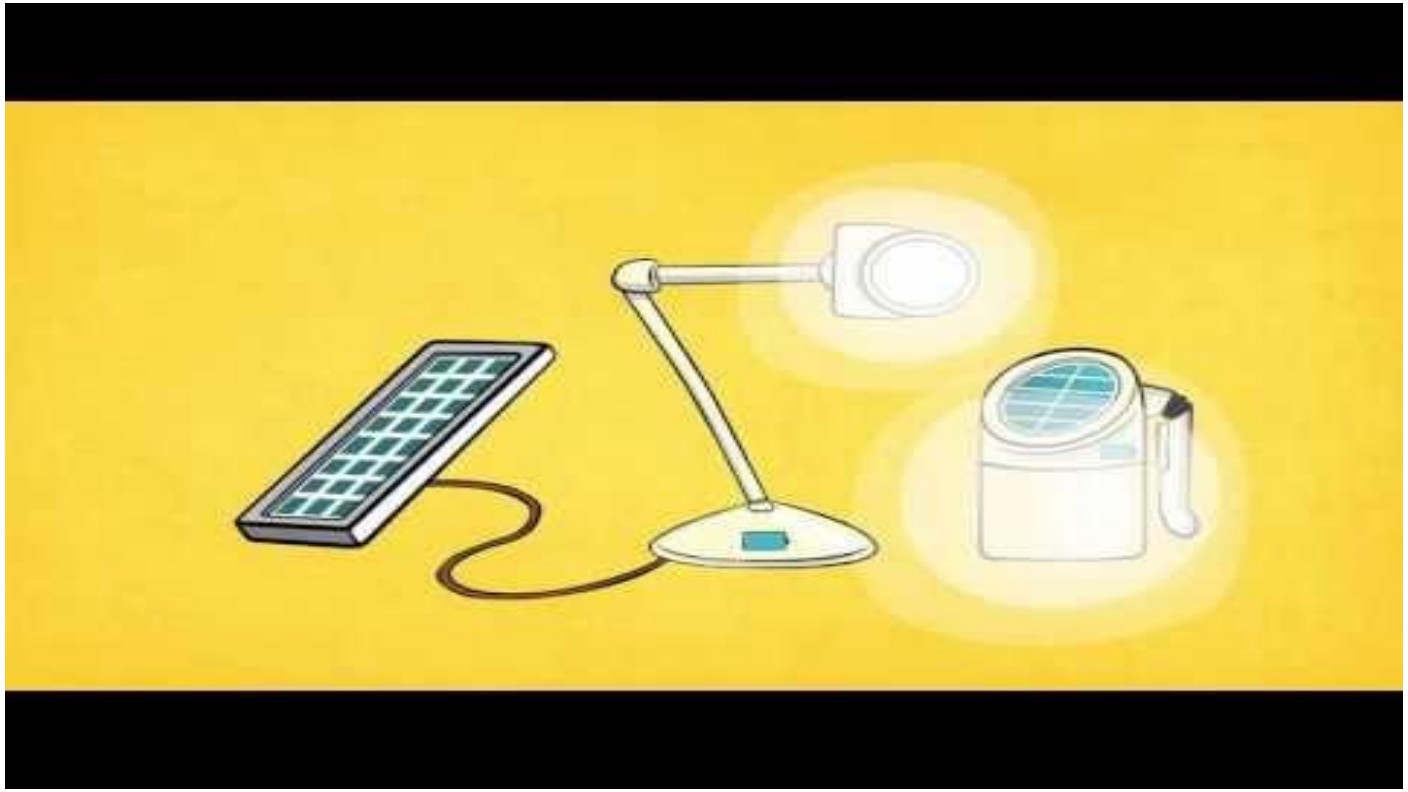


# Electrification Approaches

There is no “one size fits all” solution to electrification



# Solar Lanterns & Solar Home Systems



https://www.youtube.com/watch?v=isuhjBlB9jY&t=1s

Source: Lighting Africa

# Solar Lanterns (“pico solar”)

- “Entry level” electricity access
- Components
  - small (<10W) photovoltaic (PV) panel
  - Battery (usually <20Wh)
  - LED light(s)
  - USB port for charging (on larger systems)
- Designed for portability
- Low-cost $5-$20

d.Light S30

Sun King Pro 2000

M-KOPA 4

forsera Group
PSHS 3000

# Solar Home Systems (SHS)

- Higher-tier electricity access
- Components
  - Larger PV panel (usually 20W to 60W)
  - Battery (100Wh-300Wh)
  - LED lights
  - USB ports
  - Inverter (larger systems)
  - Appliances (DC TVs, fans)

BBOXX

d.light X850

# Mesh- and Swarm-Grids

- Emerging electrification approach
- Owners of SHS connect to each other using low voltage DC to share battery capacity and solar production
- Distribution system can grow in an *ad hoc* manner
- Lower cost than a mini-grid

# Energy Kiosks (Charging Stations)

- High tier electricity access, focusing on businesses and productive uses of electricity
- Can supply high-power loads
  - refrigerators
  - pumps
  - mills
- Walk-up retail service model
  - phone/battery recharging
- No or limited distribution system


(*courtesy KiloWatts for Humanity*)

# Mini-Grids (also “micro-grid”)

- High tier electricity access
- Tens to hundreds of user connections
- Low voltage distribution system

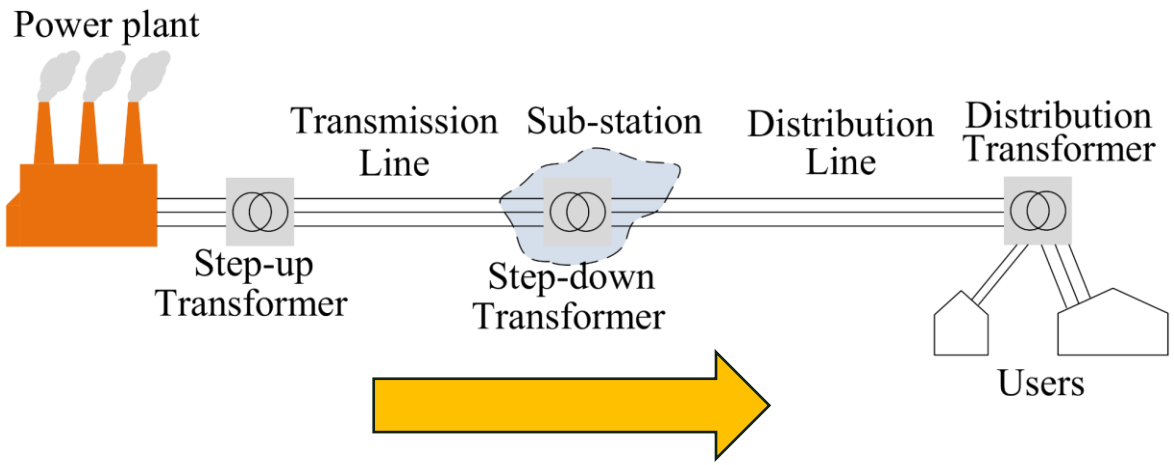
(*courtesy PowerGen Renewable Energy*)

# Metro-Grids

- High tier electricity access
- Large mini-grid that serves an urban area
- High capacity (usually +1 MW)
- +1000 end-user connections
- Medium (+11 kV) distribution

# Grid Electrification

- High tier electricity access
- Extend existing grid to connect users
- Millions of user connections
- Low cost
- Can have low reliability



# What is Energy Equity?

An energy system:

- where all members of society are able to access and afford a basic and necessary amount of energy
- where all members of society are able to authentically participate in the energy system's decision-making process
- that recognizes the diversities and needs of all groups, especially those disadvantaged or marginalized

**Energy Equity is when people fairly share the benefits and burdens of the energy system**

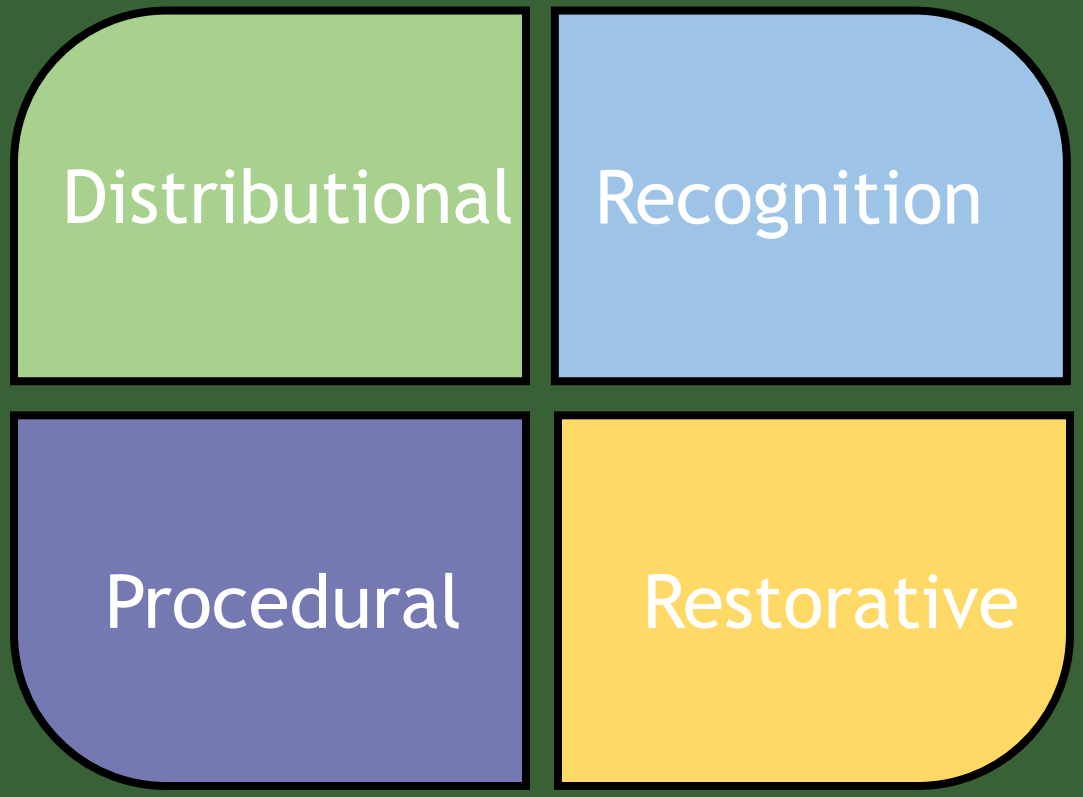
# Energy Justice: removing barriers to energy equity

# Energy equity is achieved through energy justice

# Tenets of Energy Justice

What is the distribution of benefits and negative impacts? Where do inequities occur?

How are decisions made?




Who benefits, who is burdened, who governs?

How can past inequities be restored and be prevented in the future?

# Summary

- Access to energy is enables high quality of life, including benefits to education, income, and health
- Global average total energy supply is 80 GJ/person, with 56 GJ/person being consumed
  - there is wide variation in consumption
- Electrification approaches include: solar lanterns, solar home systems, mesh- and swarm-grids, energy kiosks, mini-grids, and metro-grids
- Energy equity and energy justice are important frameworks to assess electrification programs