Hydropower

Social, environmental & economical concerns

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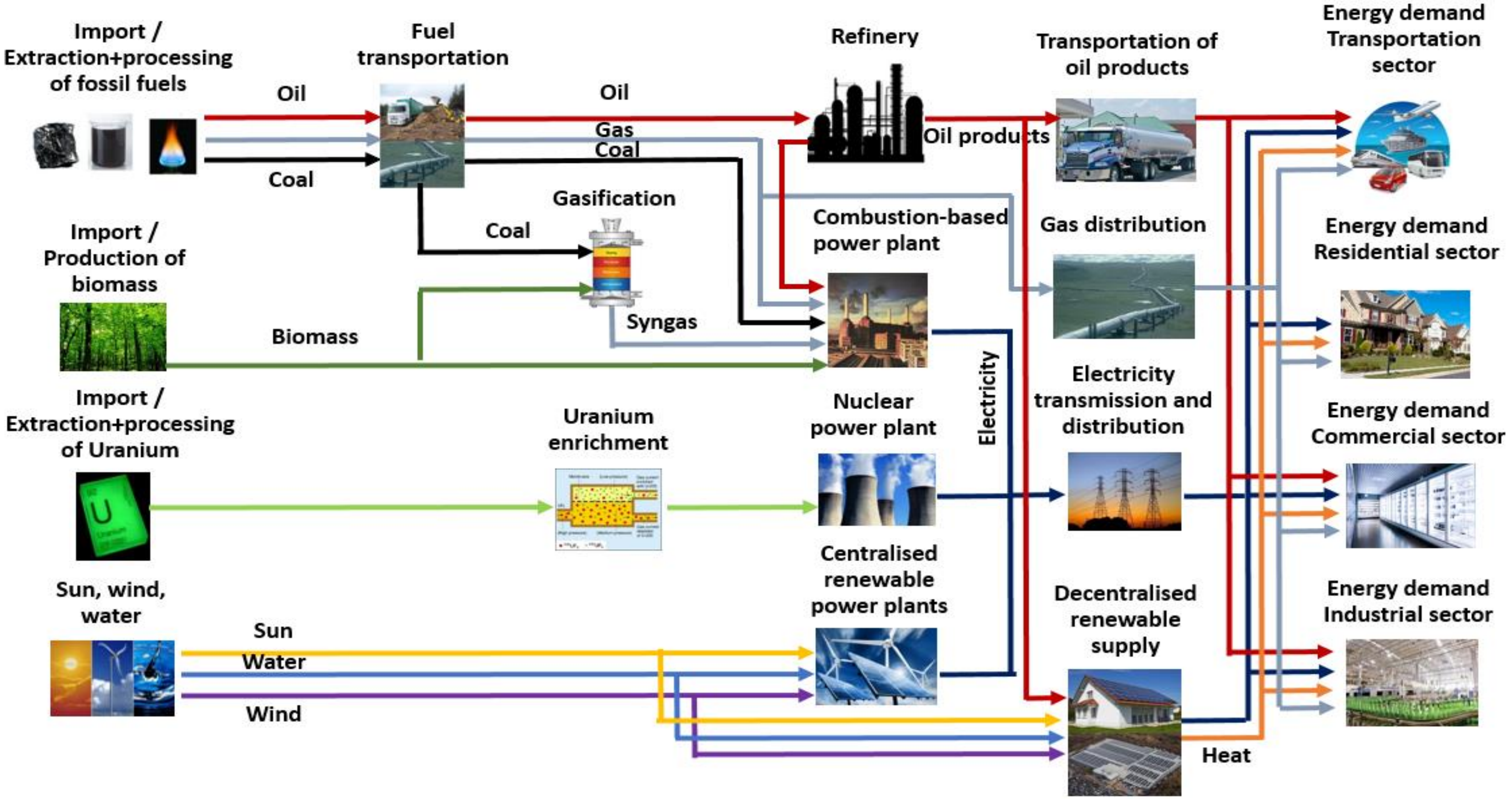
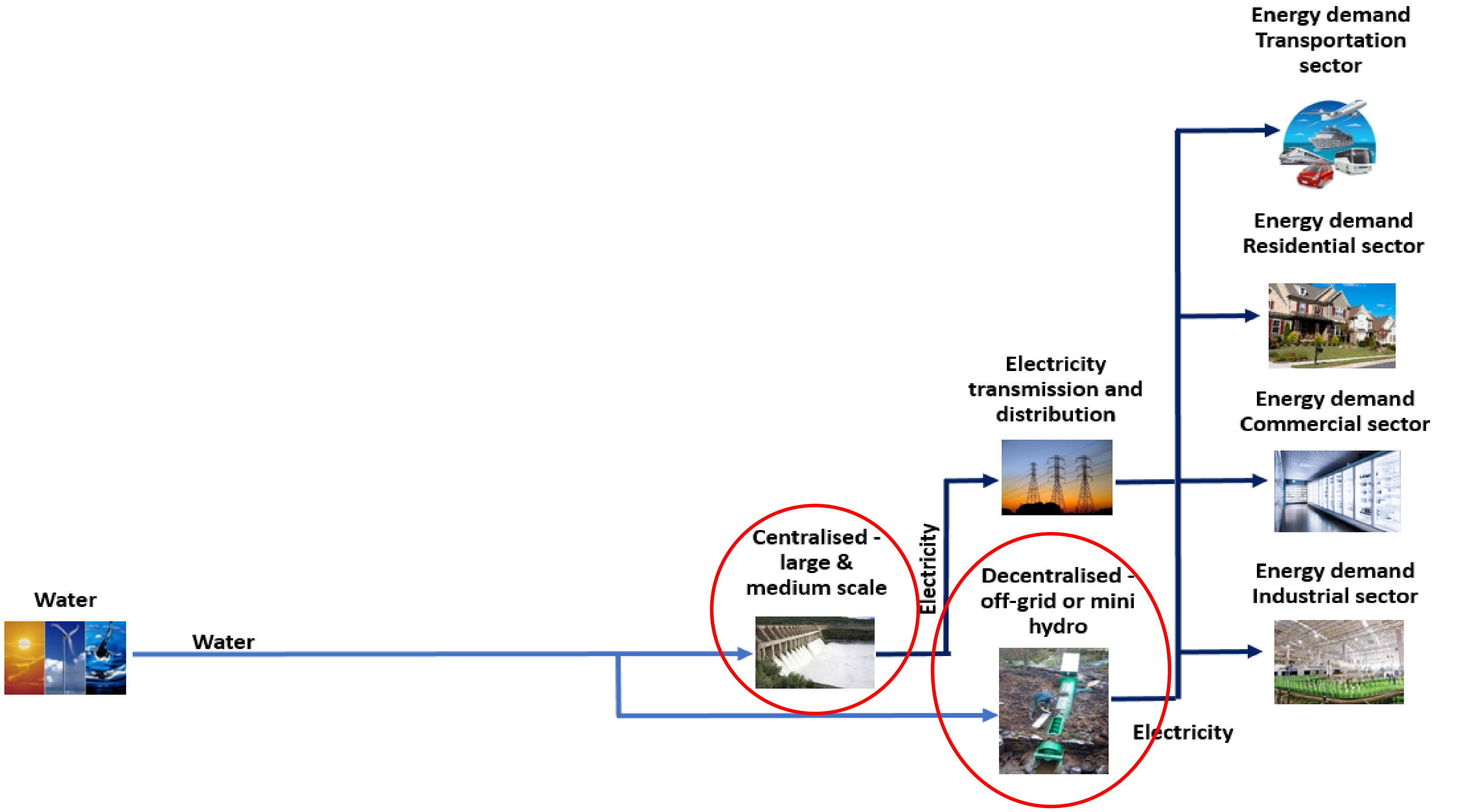
Introductory lecture – Energy commodities and technologies

Reference Energy System

Reference Energy System



Reference Energy System – Hydropower



Hydropower

Social, environmental and economic concerns

Global Trends

- Historical overview
- Demand
- Future generation
- Global capacity
- Global potential, generation & capacity

Historical overview

- Historically an increase in hydropower generation

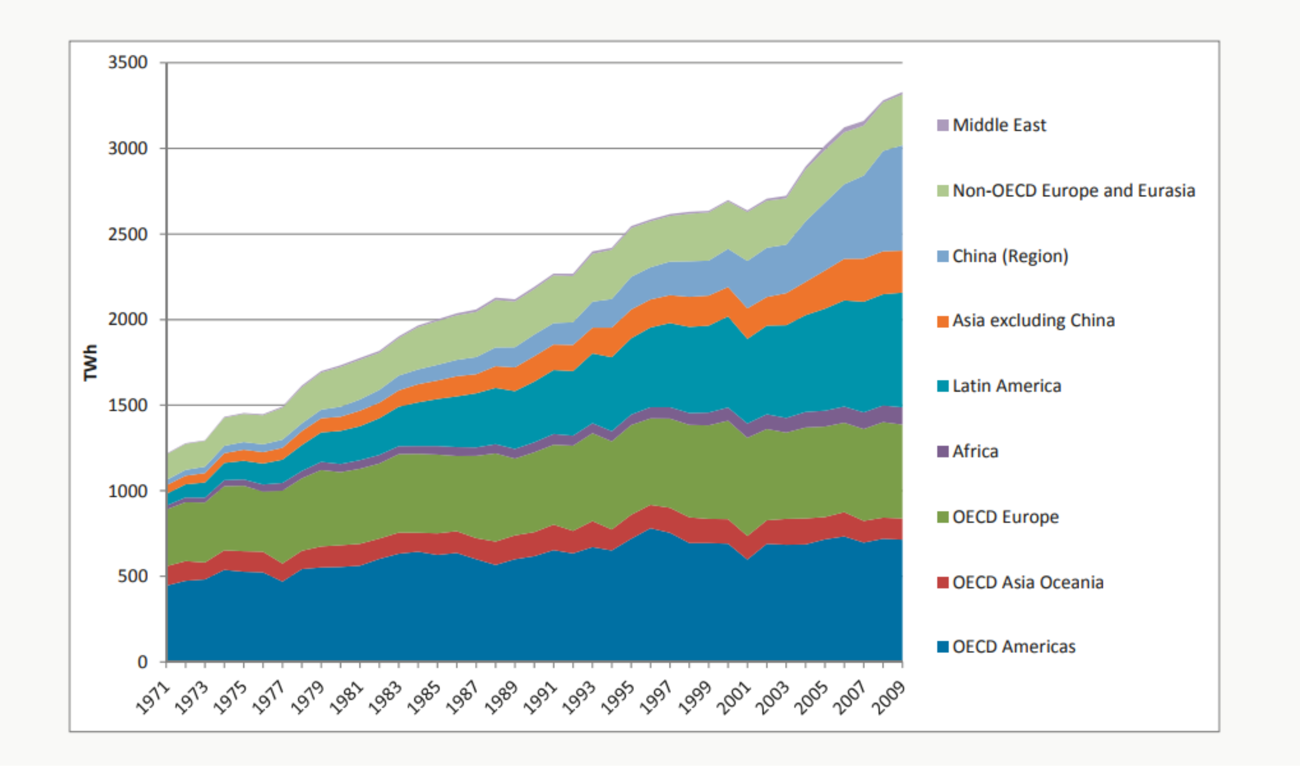
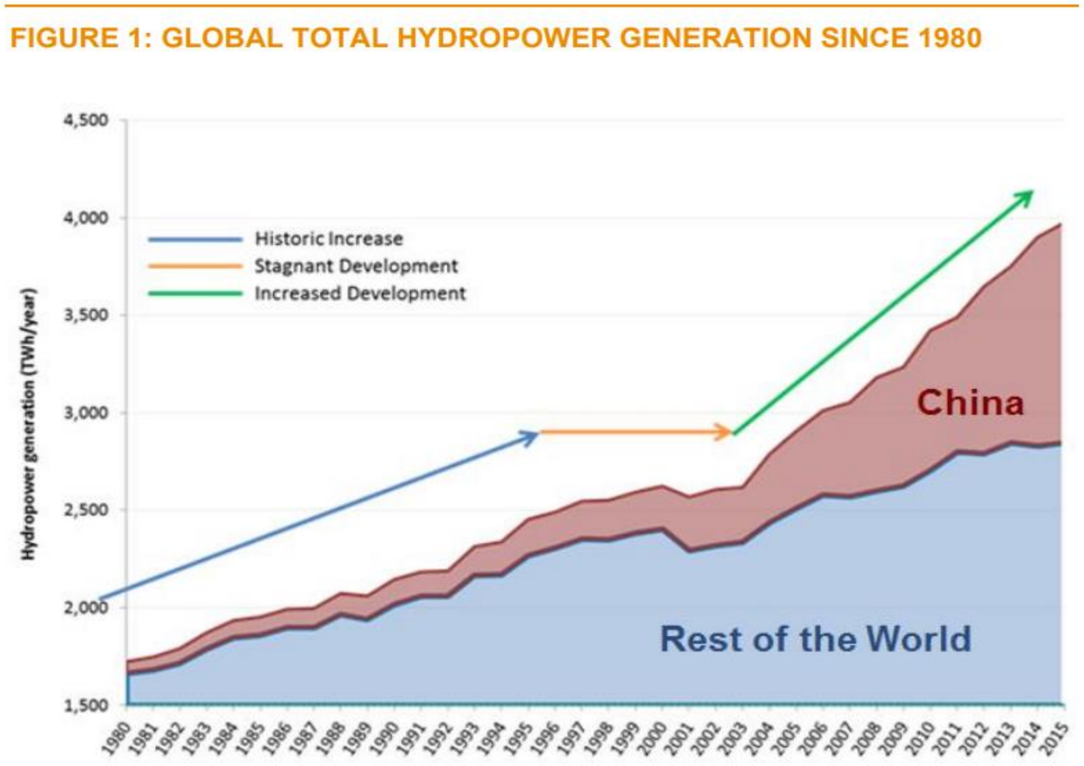


Figure 3.1: Hydropower generation by region, 1971 to 2009

Source: IRENA (2012)



Source: World Energy Council (2016)

Demand

- Despite large capacity and increase – not a major contributor to the energy demand

Table 2.2 ▷ **World primary energy demand by fuel and scenario** (Mtoe)

			New Policies		Current Policies		450 Scenario	
	2000	**2014**	**2025**	**2040**	**2025**	**2040**	**2025**	**2040**
Coal	2 316	3 926	3 955	4 140	4 361	5 327	3 175	2 000
Oil	3 669	4 266	4 577	4 775	4 751	5 402	4 169	3 326
Gas	2 071	2 893	3 390	4 313	3 508	4 718	3 292	3 301
Nuclear	676	662	888	1 181	865	1 032	960	1 590
Hydro	225	335	420	536	414	515	429	593
Bioenergy*	1 026	1 421	1 633	1 883	1 619	1 834	1 733	2 310
Other renewables	60	181	478	1 037	420	809	596	1 759
Total	**10 042**	**13 684**	**15 340**	**17 866**	**15 937**	**19 636**	**14 355**	**14 878**
Fossil-fuel share	*80%*	*81%*	*78%*	*74%*	*79%*	*79%*	*74%*	*58%*
CO_2 emissions (Gt)	**23.0**	**32.2**	**33.6**	**36.3**	**36.0**	**43.7**	**28.9**	**18.4**

* Includes the traditional use of solid biomass and modern use of bioenergy.

Source: IEA (2016)

Future generation

- Hydropower projected to increase its capacity – but remain fairly constant in terms of total share

- In terms of renewables, particularly wind and solar PV will increase

Table 6.2 ▷ **World electricity generation by source and scenario** (TWh)

			New Policies		Current Policies		450 Scenario	
	2000	2014	2025	2040	2025	2040	2025	2040
Total	**15 476**	**23 809**	**29 540**	**39 047**	**30 886**	**42 511**	**27 688**	**34 092**
Fossil fuels	10 017	15 890	17 175	20 243	19 183	26 246	14 113	8 108
Coal	6 005	9 707	9 934	10 787	11 479	15 305	7 062	2 518
Gas	2 753	5 148	6 514	8 910	6 957	10 361	6 466	5 389
Oil	1 259	1 035	727	547	746	580	585	200
Nuclear	2 591	2 535	3 405	4 532	3 319	3 960	3 685	6 101
Hydro	2 619	3 894	4 887	6 230	4 817	5 984	4 994	6 891
Other renewables	250	1 489	4 074	8 041	3 567	6 320	4 896	12 992
Fossil fuels	65%	67%	58%	52%	62%	62%	51%	24%
Coal	39%	41%	34%	28%	37%	36%	26%	7%
Gas	18%	22%	22%	23%	23%	24%	23%	16%
Oil	8%	4%	2%	1%	2%	1%	2%	1%
Nuclear	17%	11%	12%	12%	11%	9%	13%	18%
Hydro	17%	16%	17%	16%	16%	14%	18%	20%
Other renewables	2%	6%	14%	21%	12%	15%	18%	38%

Source: IEA (2016)

Global capacity

Capacity added in 2015

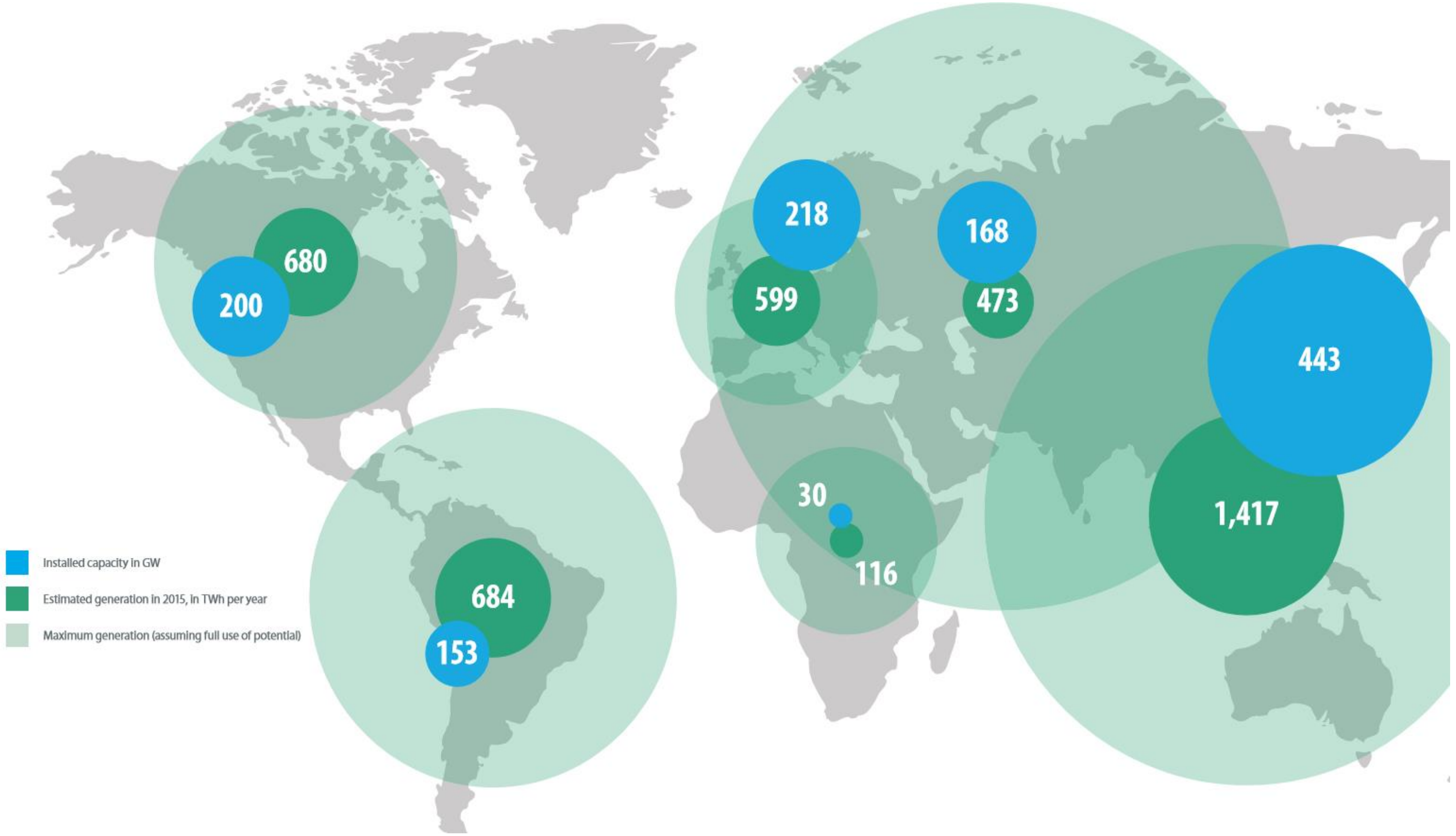
Source: IHA, 2016

Global potential, generation & capacity

- Technical potential, generation and installed capacity in 2015

- During 2015:
  - 33.7 GW new installed capacity
  - 2.5 GW pumped storage (2016: 5 GW)
  - 1,212 GW global capacity
  - 3,975 TWh generation

- China largest contributor

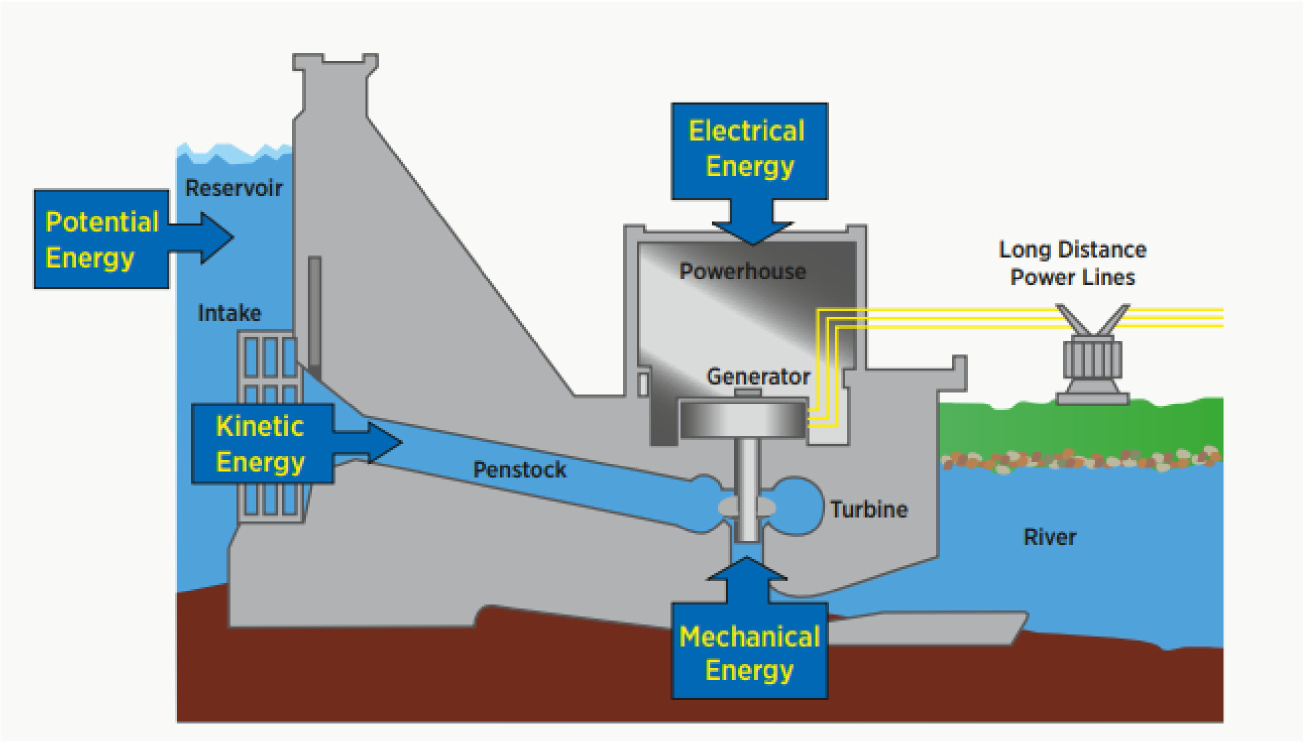


Source: IHA, 2016

Technologies in the hydropower chain

- Introduction
- Governing equations
- Technology overview
- Choice of turbines
- Reservoir operation
- Hydro specific technical parameters
- Economic concerns
- Environmental concerns
- Social concerns
- Climate Resilience

Introduction

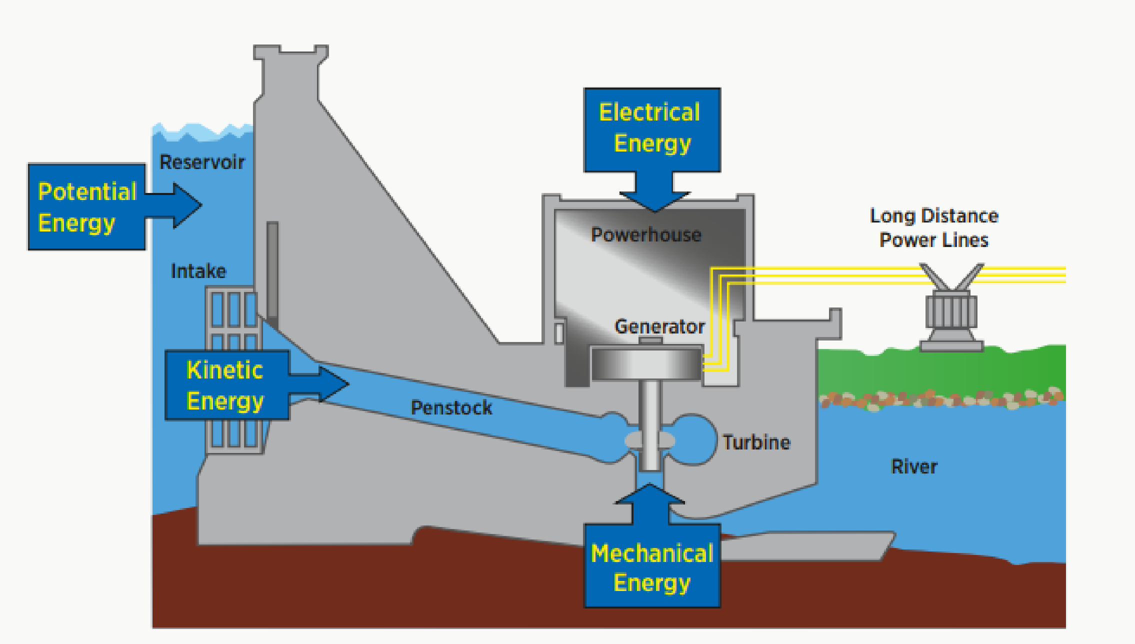


Source: Irena, 2012

- A big advantage of hydroelectric power is the ability to quickly and readily vary the amount of power generated, depending on the load presented at that moment.

Note! Many different ways and conventions to write these equations

Governing equations



Source: Irena, 2012

- H = Hydraulic head [m]
- ρ = Density of water [kg/m^3]
- V = Volume [m^3]
- n_t = Turbine efficiency [-]
- n_g = Generator efficiency [-]
- c= Environmental flow deduction factor [-]
- Q = Flow [m^3/s]
- S = Storage [m^3]
- E= Evaporation [m^3]
- P= Precipitation [m^3]
- PE= Percolation [m^3]
- t= time

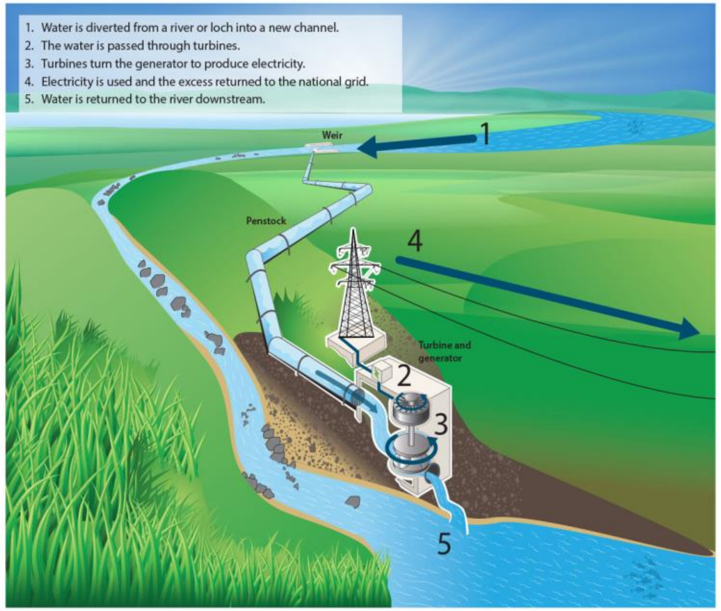
$$Water\ balance\ reservoir = S_t = S_{t-1} + \left(Q_{in,t} - Q_{out,t}\right) - (E_t - P_t) - (PE_t)\ [\mathrm{m}^3] \quad (1)$$

$$Potential\ energy\ reservoir = E = \rho * g * h * V\ [J] \quad (2)$$

$$Power\ output\ from\ hydropower = P = \rho \times g \times n_t \times n_g \times c \times \dot{Q} \times \mathrm{h}\ [\mathrm{W}] \quad (3)$$

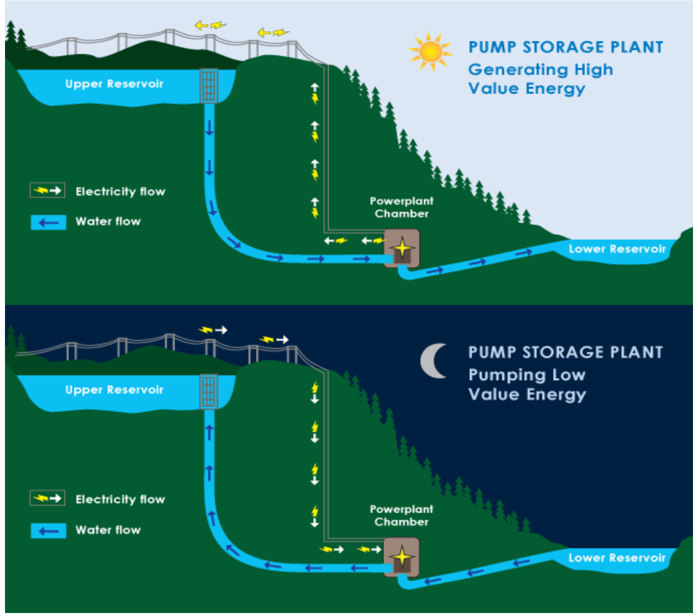
Technology overview

Classification of hydropower plants based on specification type



Run of the River plants

Storage hydropower

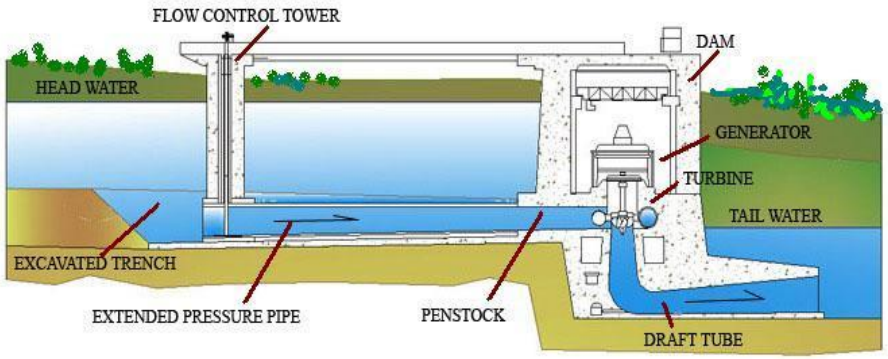


Pumped hydro storage

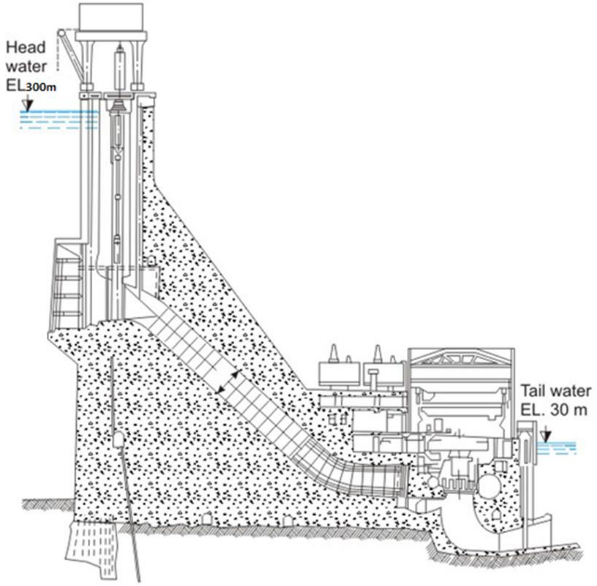
Hydropower: social, environmental and economic concerns

Technology overview

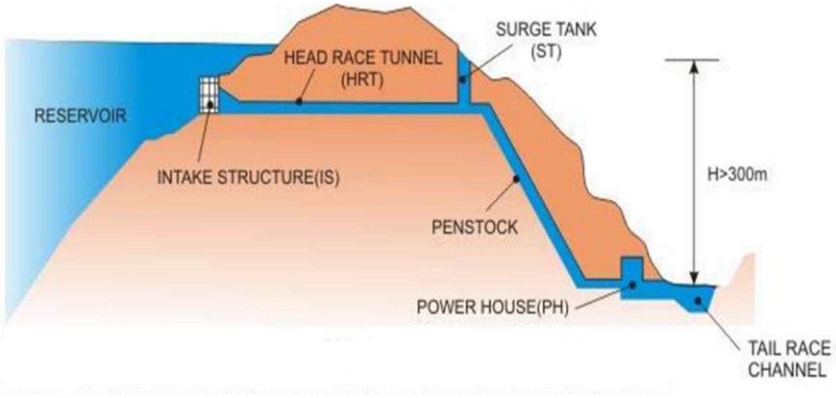
Classification of hydropower plants based on head



Low head



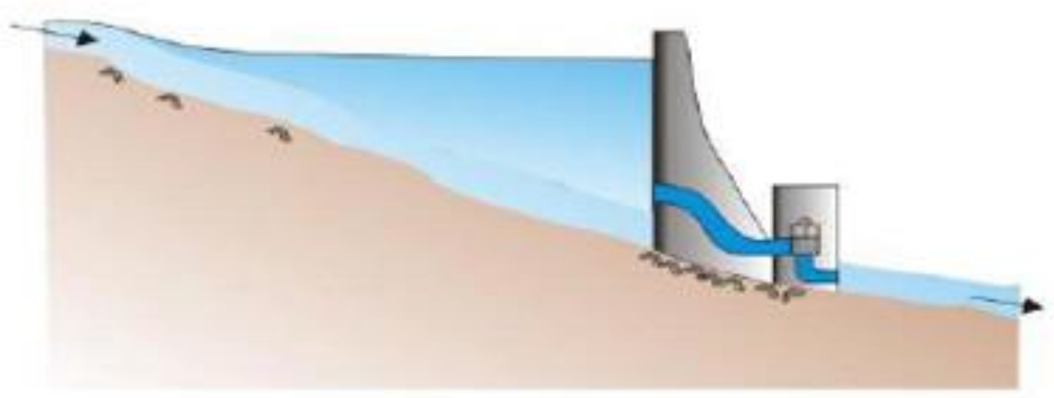
Medium Head



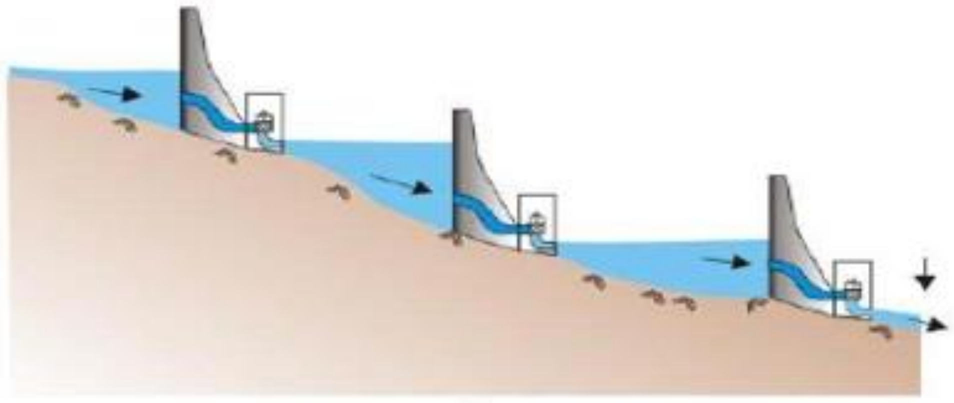
High Head

Technology overview

Classification of hydropower plants based on hydrological sequence



Single stage power plants



Cascade/Multistage hydropower plants

Technology overview

Classification of hydropower plants (Reservoirs) based on the purpose

- **Multi-purpose reservoirs**

  Water supply
  Flood control
  Soil erosion
  Environmental management
  Hydroelectric power generation
  Navigation
  Recreation
  Irrigation




Technology overview

Classification of hydropower plants based on Size

- LARGE: >100 MW
- MEDIUM: 25 – 100 MW
- SMALL: 1-25 MW
- MINI: 100 KW - 1MW
- MICRO: 5 – 100 KW
- PICO: < 5 KW

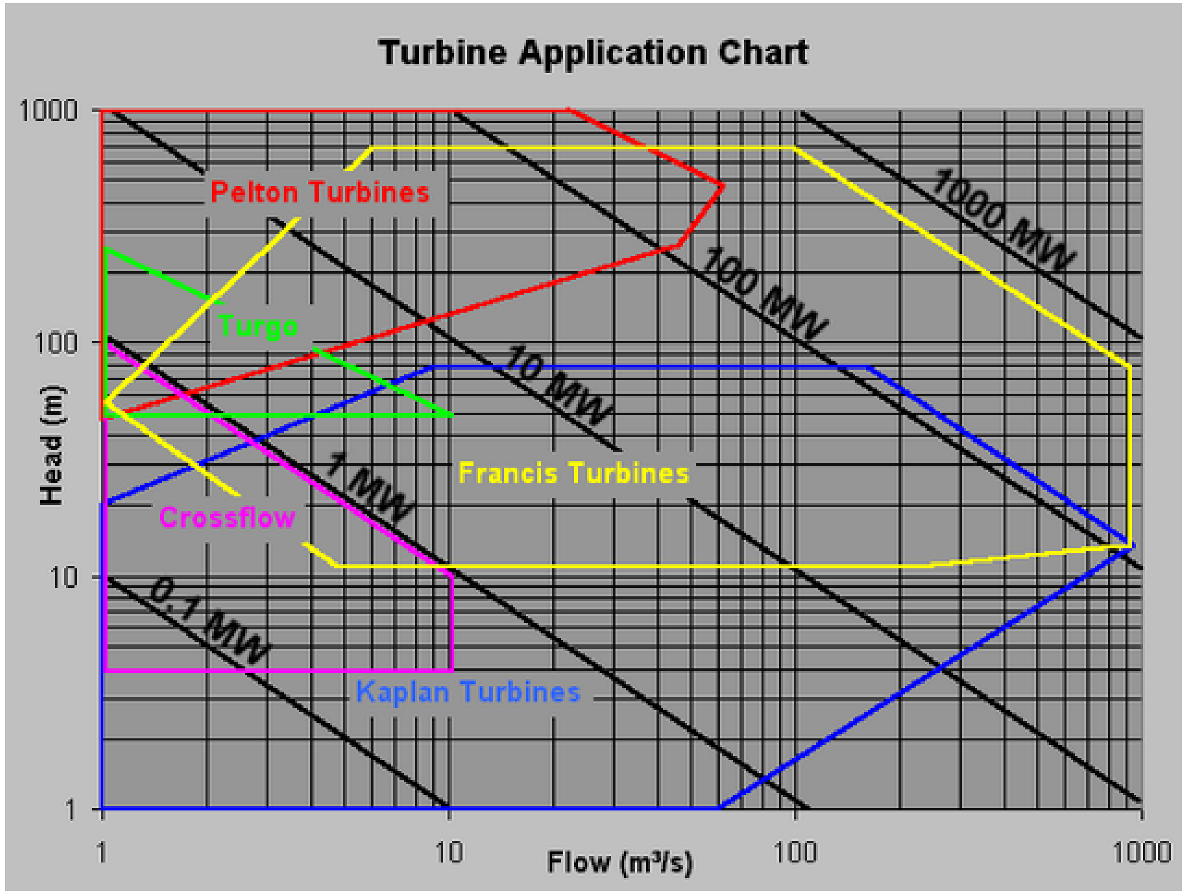
Choice of turbines

Reaction Turbines

- *Francis turbine*
- *Kaplan turbine*
- Tyson turbine
- Gorlov helical turbine

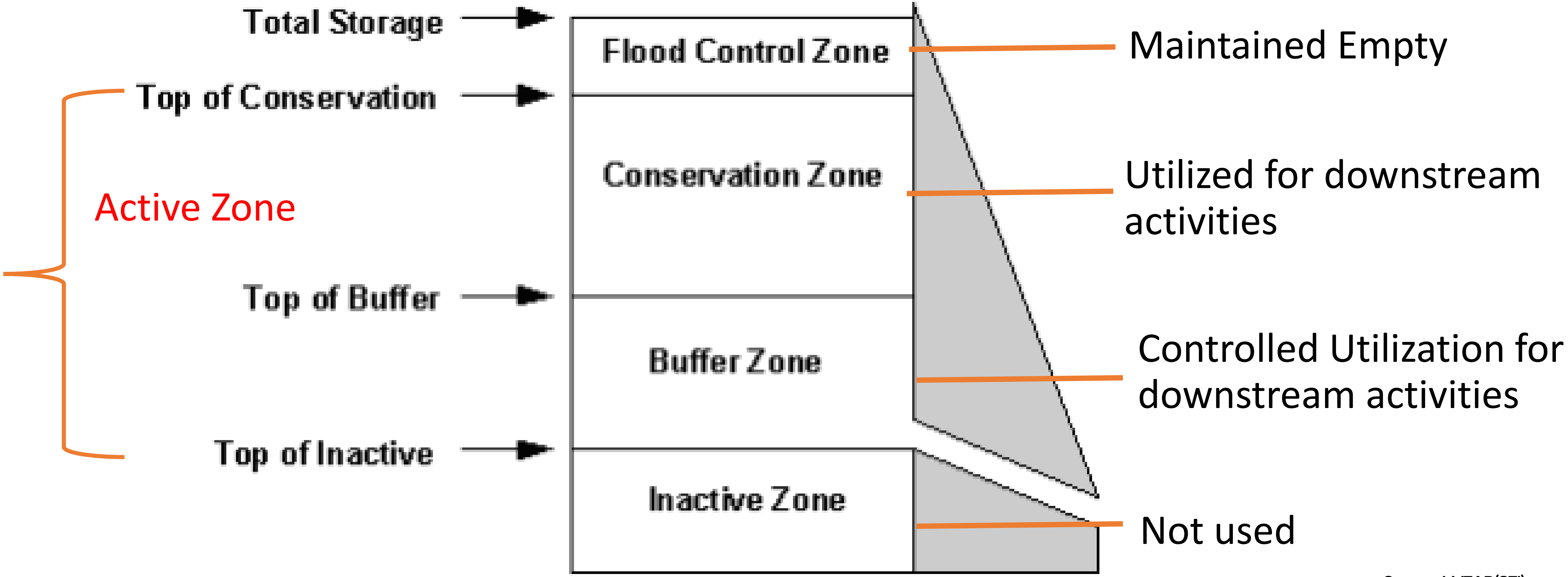
Impulse turbine

- *Pelton wheel*
- Turgo turbine
- Cross-flow turbine
- Jonval turbine
- Screw turbine



Source: Irena-ETSAP-technology briefs

Reservoir operation



Source: WEAP(SEI) user manual

Hydro specific technical parameters

- **Capacity factor**: The ratio of its actual output over a period of time, to its potential output if it were possible for it to operate at full nameplate capacity indefinitely.

Hydro Power plant capacity : 500 MW

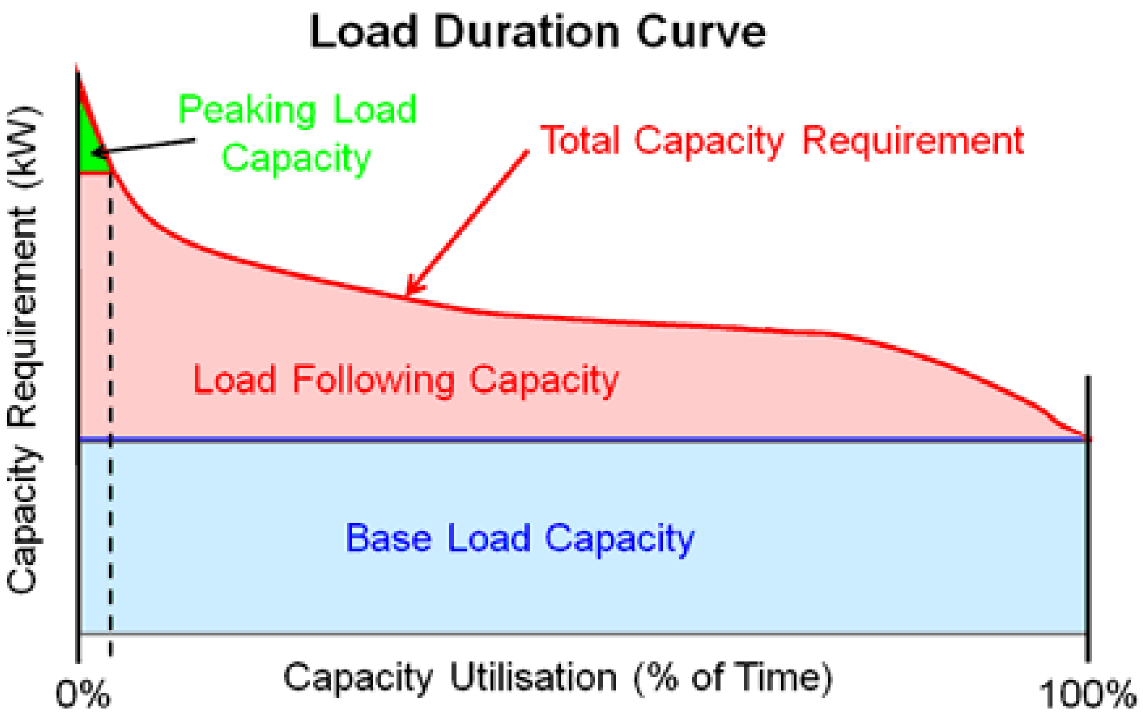
Annual electricity generation: 2000 GWh

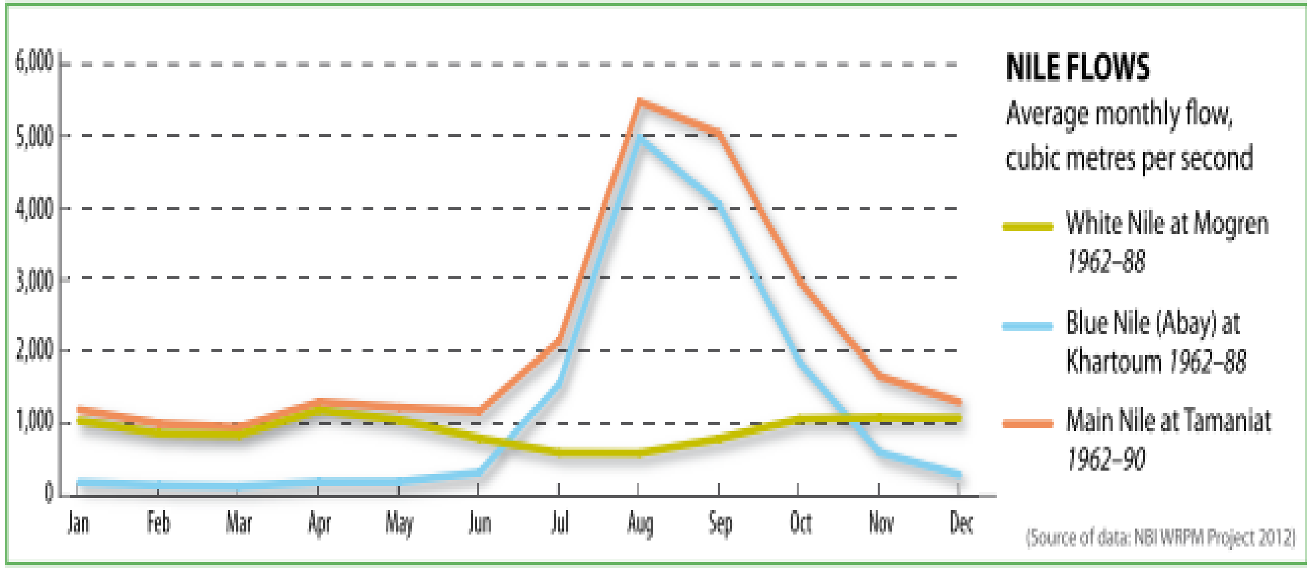
$$\text{Average annual capacity factor} = \frac{2000*1000\ (MWh)}{500(MW)*8760(hours\ in\ a\ year)} = 45.6\%$$

- **Availability Factor:** The availability factor of a power plant is the percentage of the time that it is available to provide energy to the grid. The availability of a plant is mostly a factor of its reliability and of the periodic maintenance it requires.

Hydro specific technical parameters

Load curves





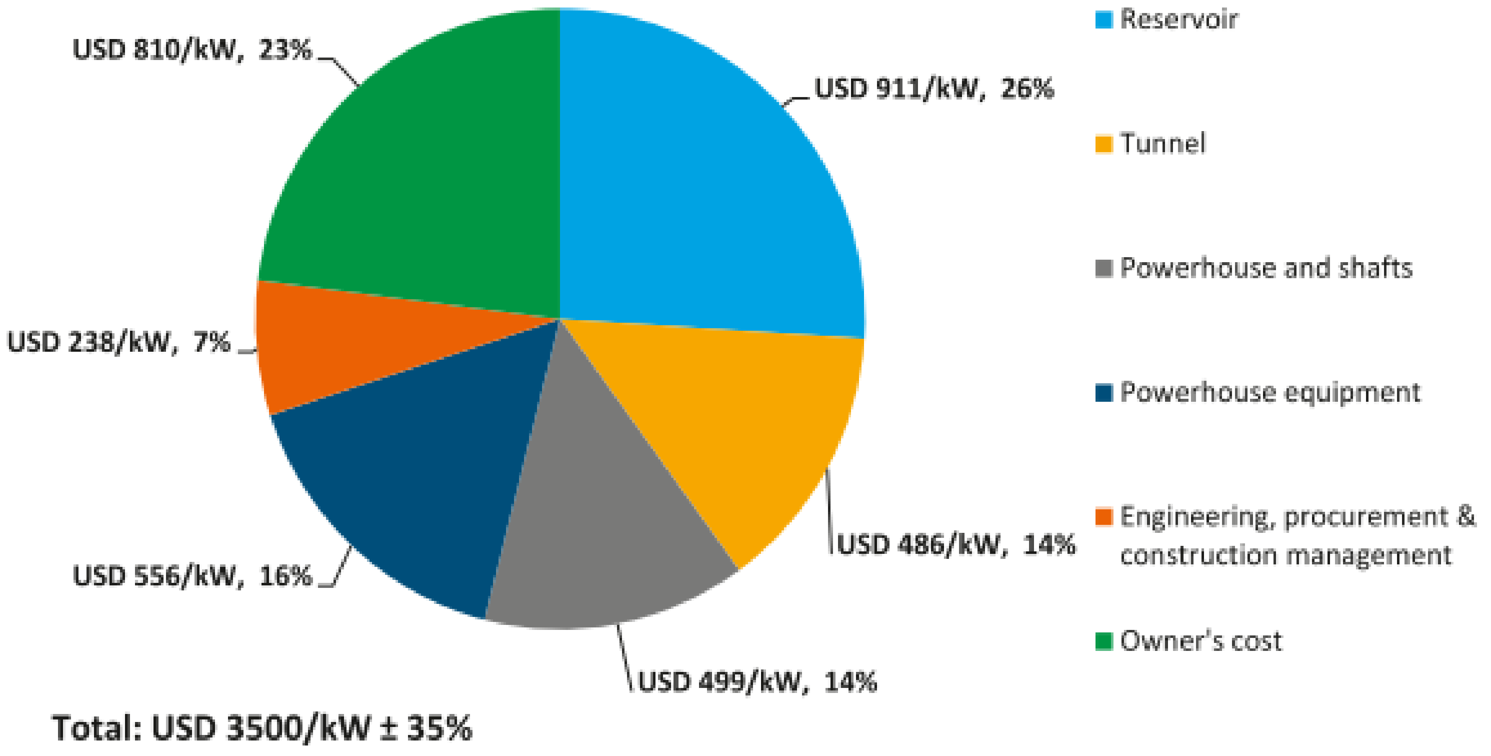
Economic concerns

Hydropower costs

- The civil works for the hydropower plant construction, including any infrastructure development required to access the site and the project development costs.
    - Dam and reservoir construction;
    - Tunneling and canal construction;
    - Powerhouse construction;
    - Site access infrastructure (roads etc);
    - Grid connection;
    - Engineering, procurement and construction (EPC);
    - Developer/owners costs (including planning, feasibility, permitting, etc.)
- The cost related to electro-mechanical equipment.
    - Turbines, generators, transformers, cabling and control systems

Economic concerns

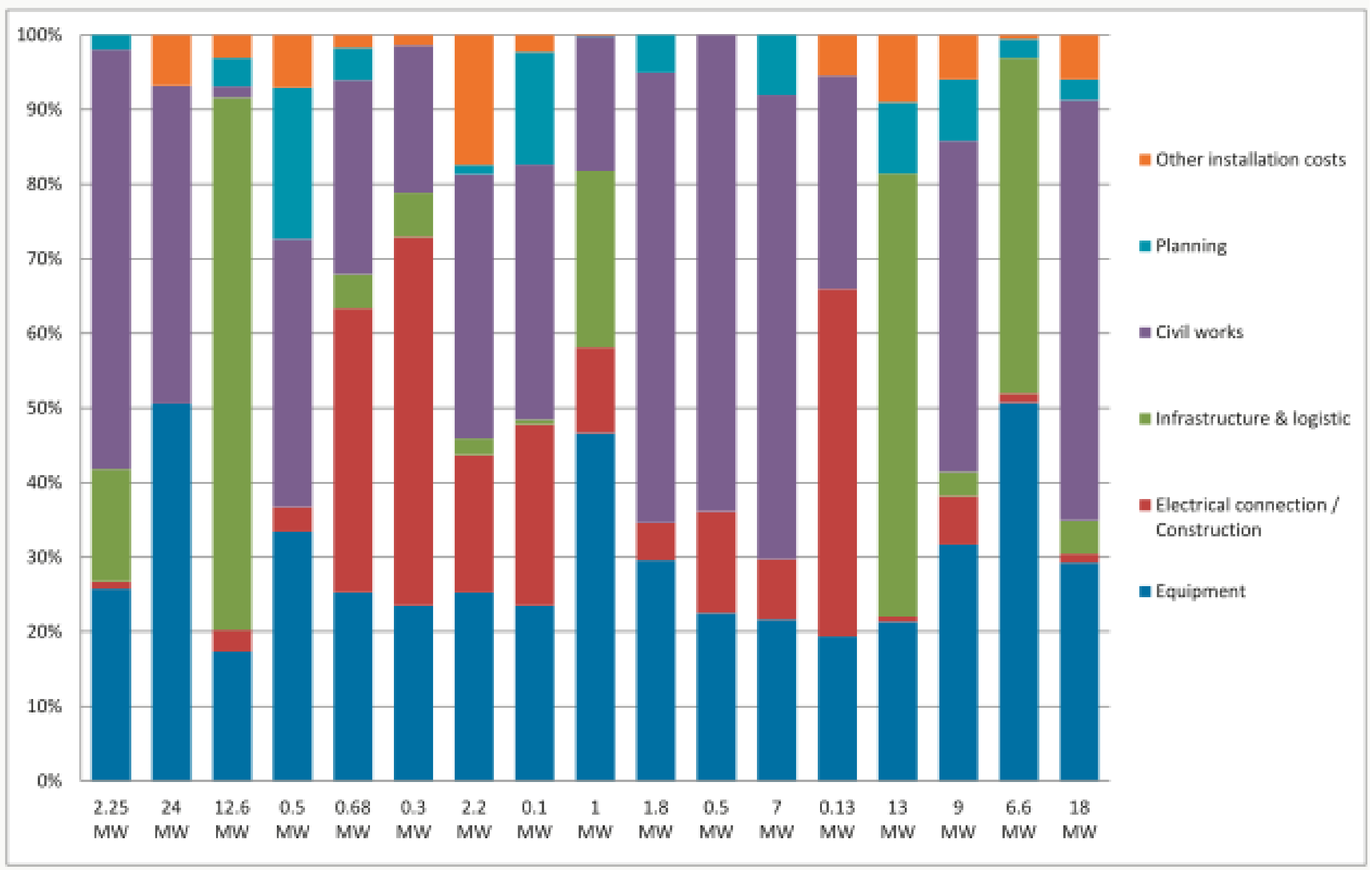
- Cost breakdown of an indicative 500 MW power plant in USA



source: Irena renewable energy technologies: cost analysis series

Economic concerns

- Cost breakdown for small hydro projects in developing countries



source: Irena renewable energy technologies: cost analysis series

Economic concerns

Representing costs in technoeconomic analysis

- Capital/Investment costs
- Operational & Maintenance costs

Size (MW)	Very Small (< 1)	Small (1-10)	Large (> 10)
Construction Time (Years)	6-10	10-18	18-96
Technical lifetime (Years)	100	100	100
Average Capacity Factor (%)	40-60	34-56	34-56
Maximum plant avaialbility (%)	98	98	98
Investment Cost	3400-10000 or more	1000-4000	1050-7650
OM cost (USD/KW/Yr)	45-250 or more	40-50	45 (average)
Economic lifetime (Years)	30	30	30

source: Irena–ETSAP technology briefs

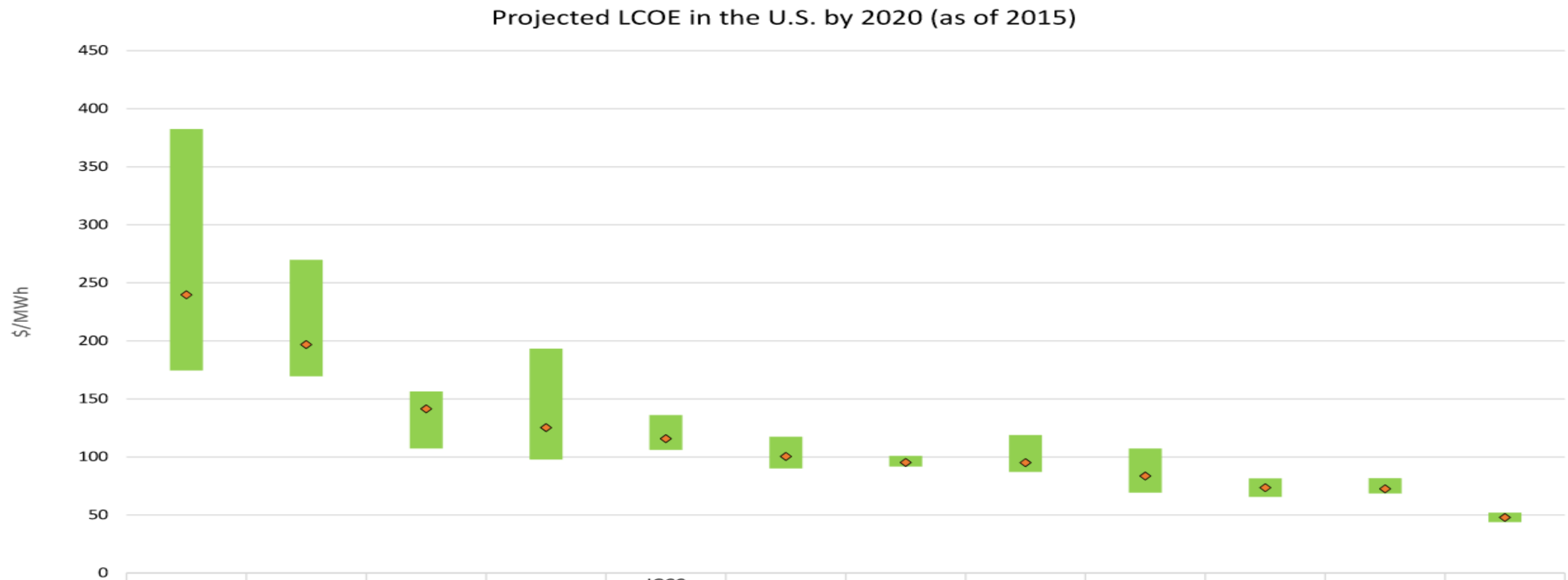
Economic concerns

$$LCOE = P_{MWh} = \frac{\sum(Capital_t + O\&M_t + Fuel_t + Carbon_t + D_t) * (1+r)^{-t}}{\sum MWh\ (1+r)^{-t}}$$

How much does it cost to produce electricity from hydropower plants

- LCOE- Levelized cost of electricity generation
- P_{MWh} = The constant lifetime remuneration to the supplier for electricity;
- MWh = The amount of electricity produced in MWh, assumed constant;
- $(1+r)^{-t}$ = The discount factor for year t (reflecting payments to capital);
- $Capital_t$ = Total capital construction costs in year t;
- $O\&M_t$ = Operation and maintenance costs in year t;
- $Fuel_t$ = Fuel costs in year t;
- $Carbon_t$ = Carbon costs in year t;
- D_t = Decommissioning and waste management costs in year t.

Economic concerns



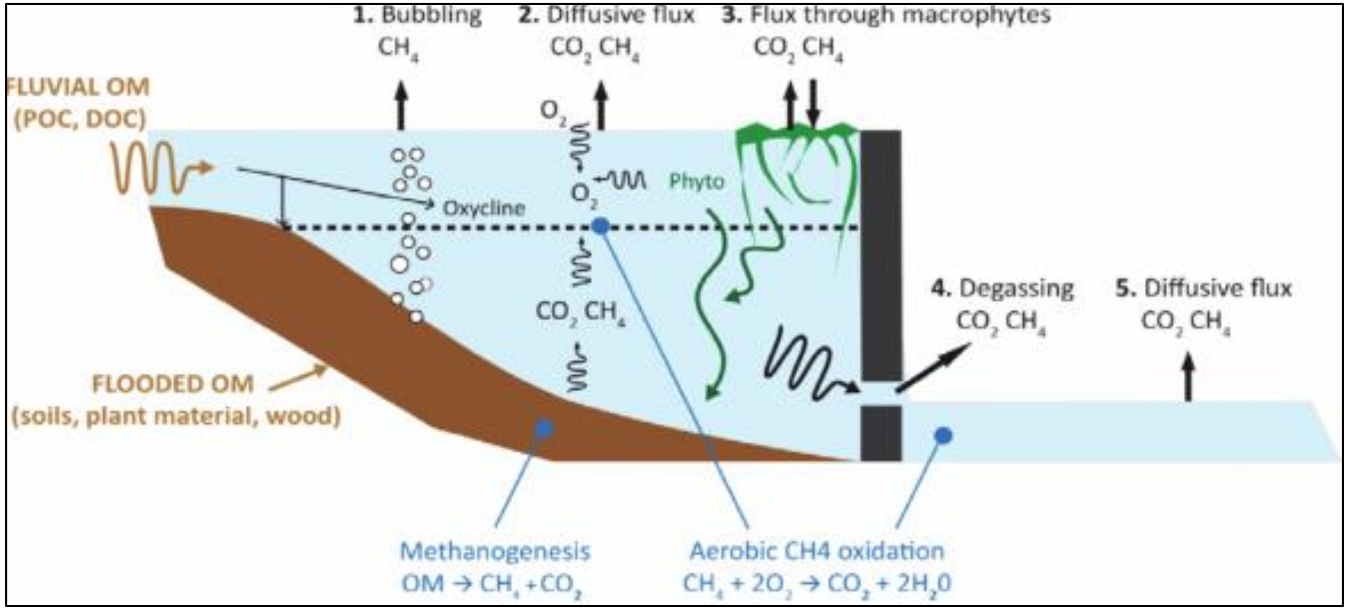
	Solar Thermal	Wind offshore	Natural Gas: Conventional Combustion Turbine	Solar PV	IGCC (Integrated Coal-Gasification Combined Cycle)	Biomass	Advanced Nuclear	Conventional Coal	Hydro	Wind onshore	Natural Gas: Advanced Combined Cycle	Geothermal
Minimum	174	170	107	98	106	90	92	87	69	66	69	44
◇ Average	240	197	142	125	116	101	95	95	84	74	73	48
Maximum	383	270	156	193	136	117	101	119	107	82	82	52

Environmental concerns

- ”It is a renewable energy source, so it is environmentally friendly”
- Hydropower is a component in a larger system – system thinking required

Environmental concerns

- Modification of primary watersheds
  - Change of landscape (inundation of large areas, deflection of rivers, creation of new infrastructure, loss of productive land/soils)
- Destruction of habitats & ecosystems - threat to flora and fauna
- Changes in river flow regime
- Possible emissions of methane (degradation of flora/organic matter in stagnant water)
- Deterioration of water quality – algae and oxygen depletion
- Sedimentation – storage capacity goes down, area of freshwater decreases & ecosystem impacts
- Reading recommendations: *The greater common good*



Source: Kumar & Sharma (2012)

Environmental concerns

Flash floods – rapid flooding due to, among others, heavy precipitation and dam failure

- Oroville Dam - California floods 2017

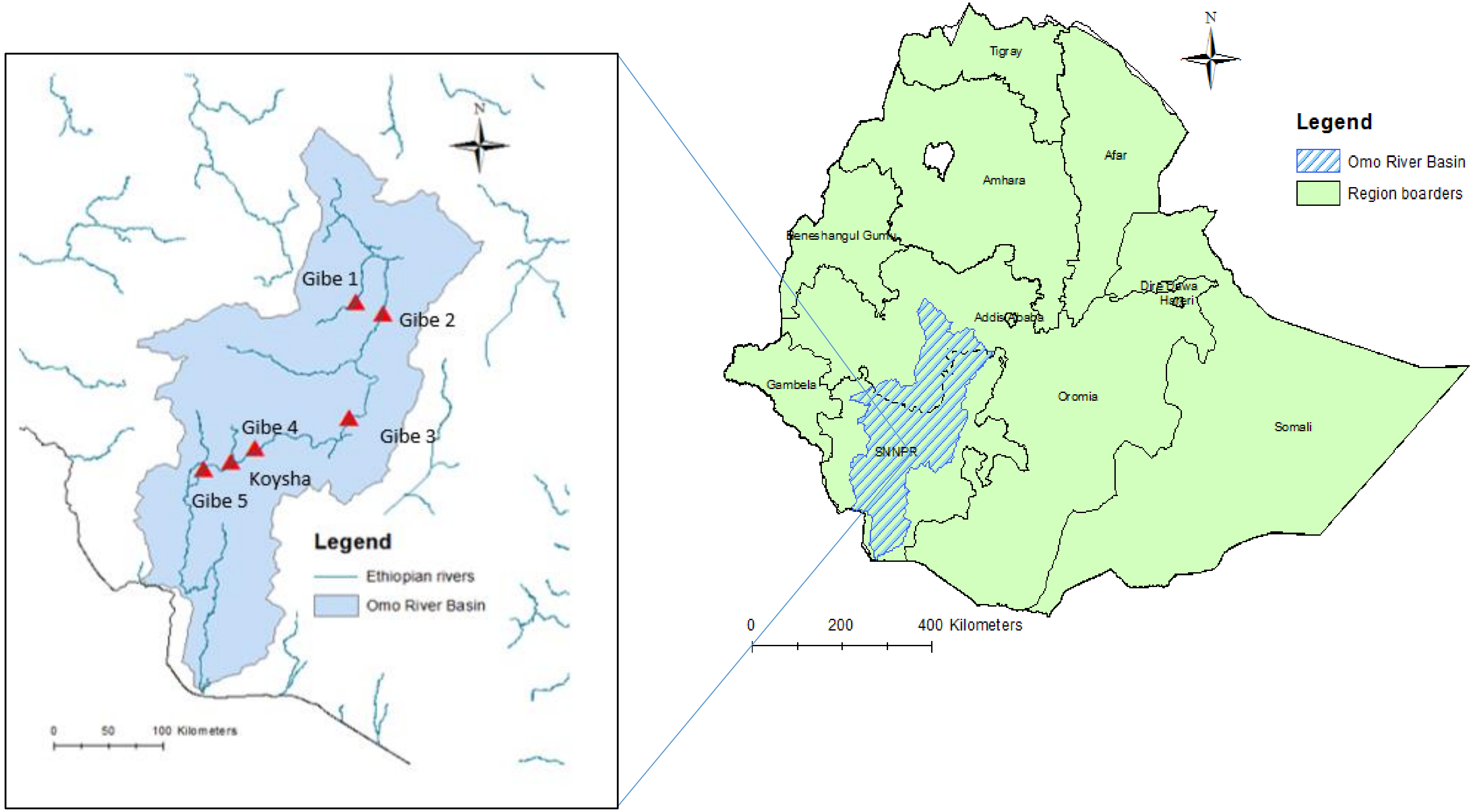
Source: Los Angeles Times (2017)

- Samarco dam holding waste from Iron ore mine - Brazil 2015

Source: Reuters (2017)

Environmental concerns

- Omo River Basin in Ethiopia
- Gibe cascading scheme – currently 3 power plants operation with more planned
- Major inflow to Lake Turkana, Kenya, in the south
- Gibe 3: 1,870 MW & 14,700 Mm3



Source: Sundin (2017) – adopted from Boulos (2017)

Environmental concerns

- Disruption in natural water balance
- Change in stream flow regime
- Change in Lake Turkana lake levels
- Change in river delta
- And other – some not yet observed

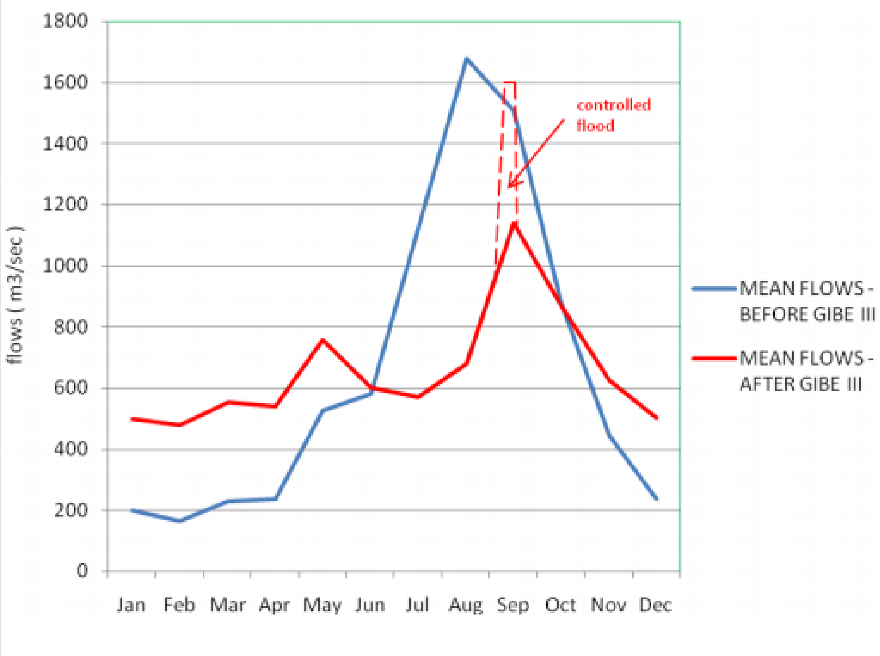
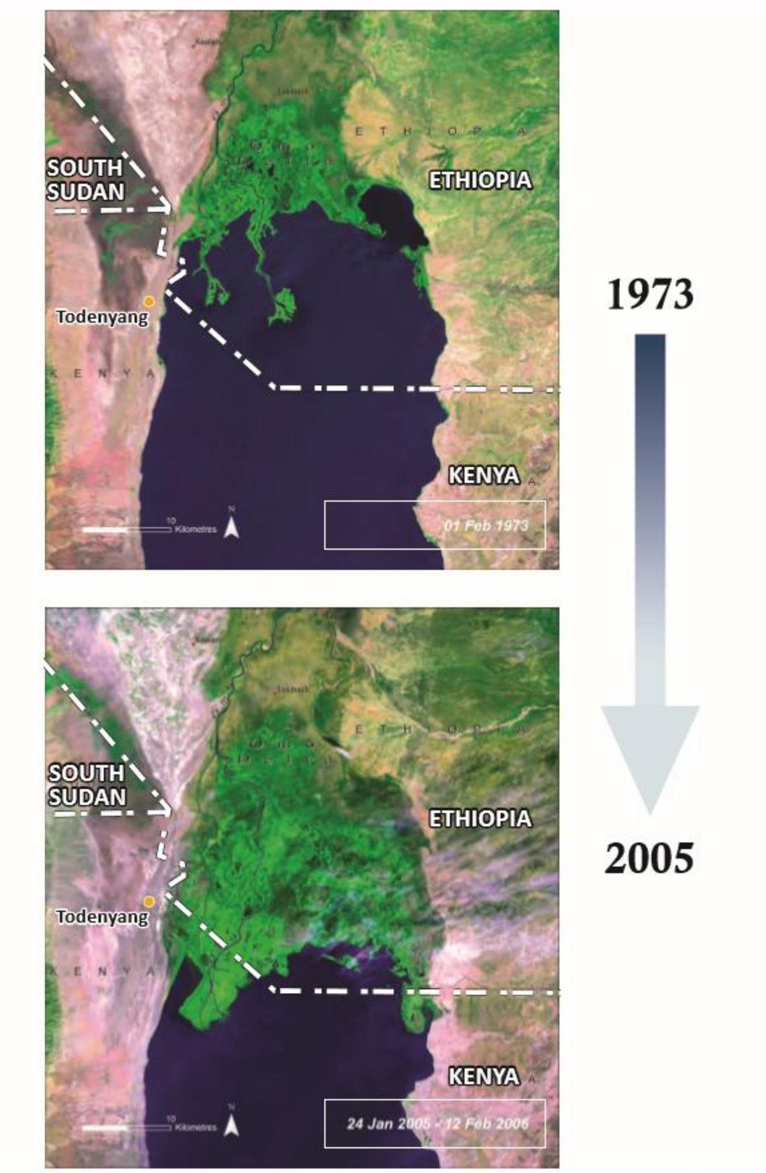


Figure 7.4: Monthly flows at Lake Turkana: average 1964-2001

Source: Avery (2012)

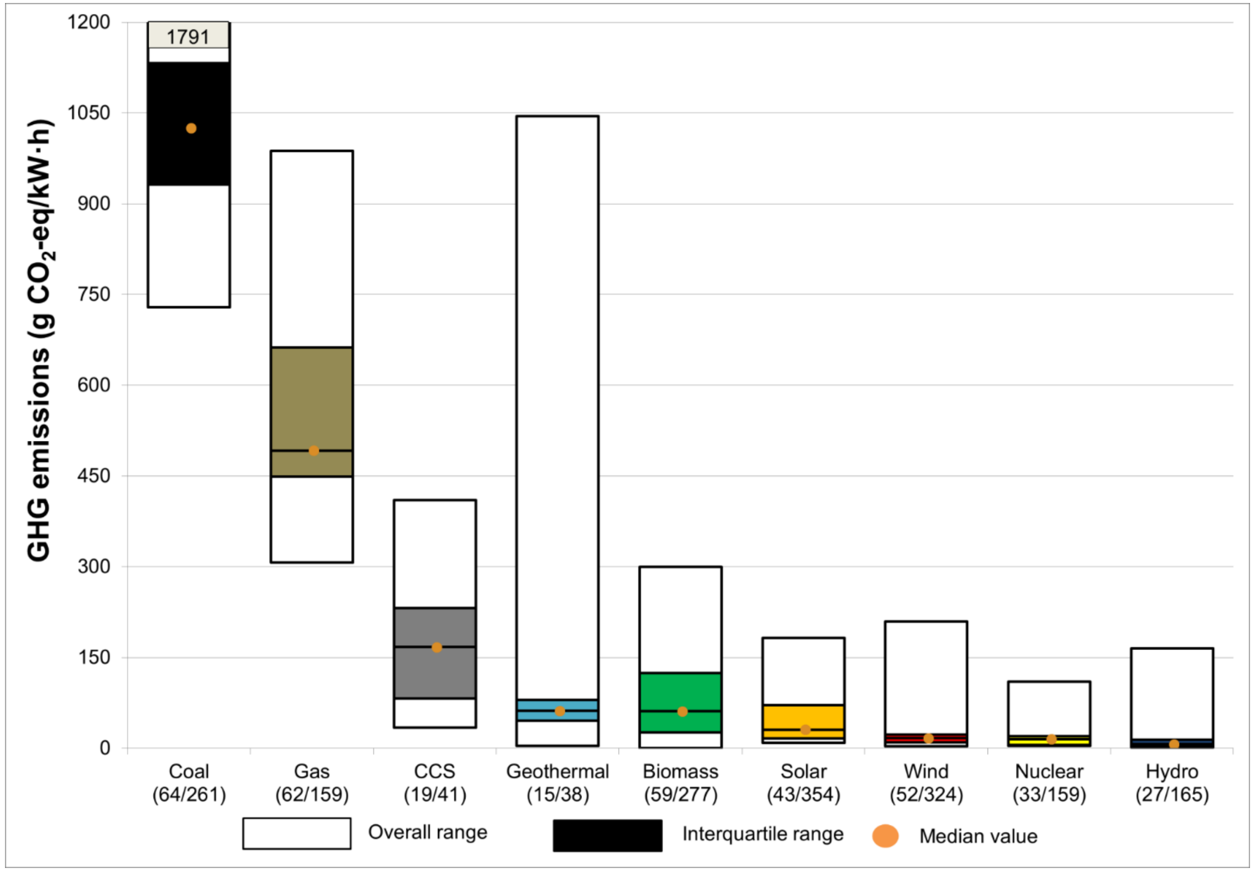
Fig. 2. Omo Delta Expansion; 1973 to 2005



Source: Carr (2012)

Environmental concerns

- Comparison of GHG-emissions between technologies
- Hydropower – not carbon neutral if considering its entire life cycle:
  - ➢ Construction and maintenance (material, transport etc.)
  - ➢ Reservoirs (methane gas – as discussed earlier)

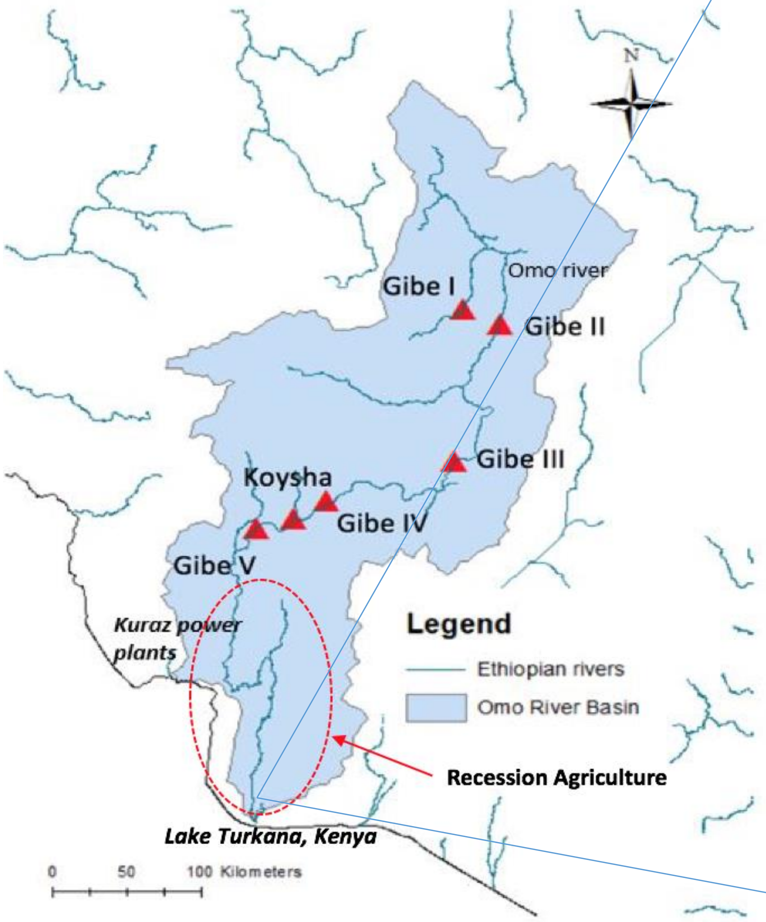


Social concerns

- Large contributor to electrifying people
- Generation possible to reflect the load
- Resettlement of local inhabitants
  - Political and cultural conflicts
  - Large dams in 20th century – 40-80 million people worldwide
- Sometime no direct benefits for local communities, electricity usually transferred over long distances – *accessibility*
- Transboundary rivers – 260 rivers in the world cross at least one boundary
- Multipurpose dams – However, competition of water – e.g. water for irrigation

Social concerns

- Omo River Basin
- Indigenous people depending on seasonal flooding
  - *Flood retreat cultivation*



Source: Sundin (2017) – adopted from Boulos (2017)

Source: Carr (2012)

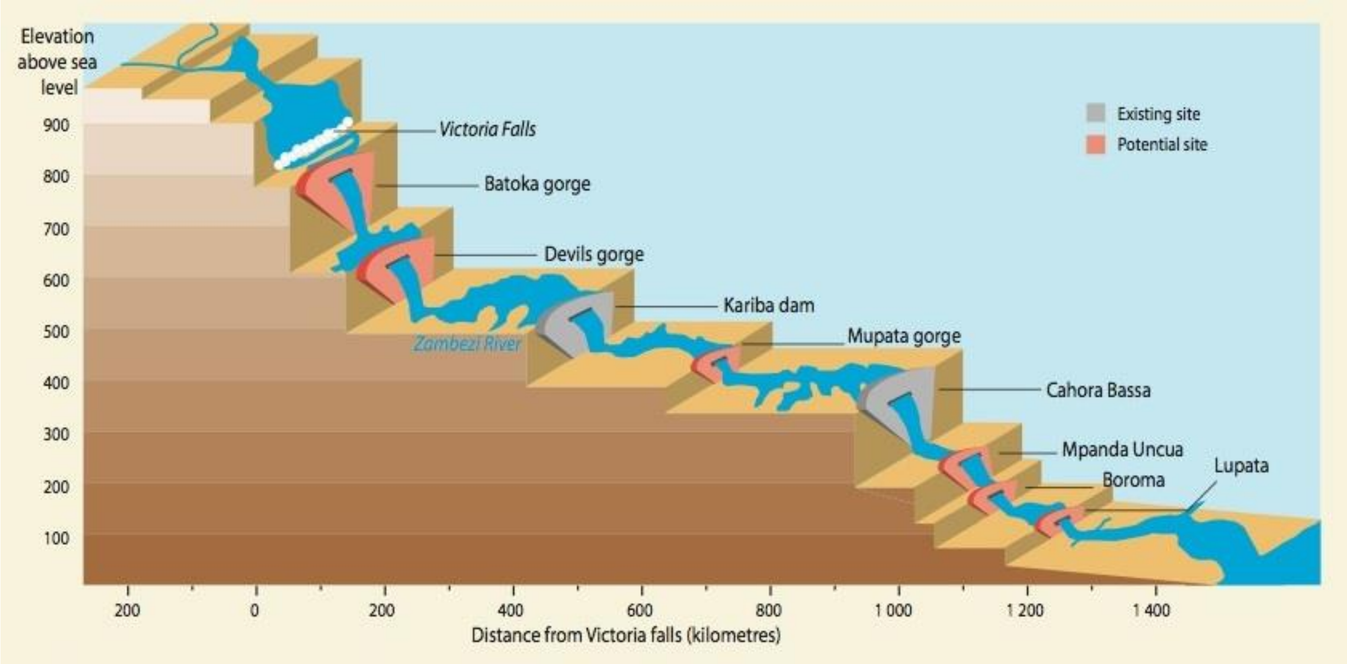
Social concerns

- Financial implications: rehabilitation of displacement, creating new job opportunities, loss of agricultural land, import of food etc.
- Grand Ethiopian Renaissance Dam Project – Nile River
- When finished – largest dam in Africa
- 6,000 MW – 15,000 GWh/year
- Geopolitics – Egypt example

Source: Salini Impregilo

Hydropower- Climate Resilience

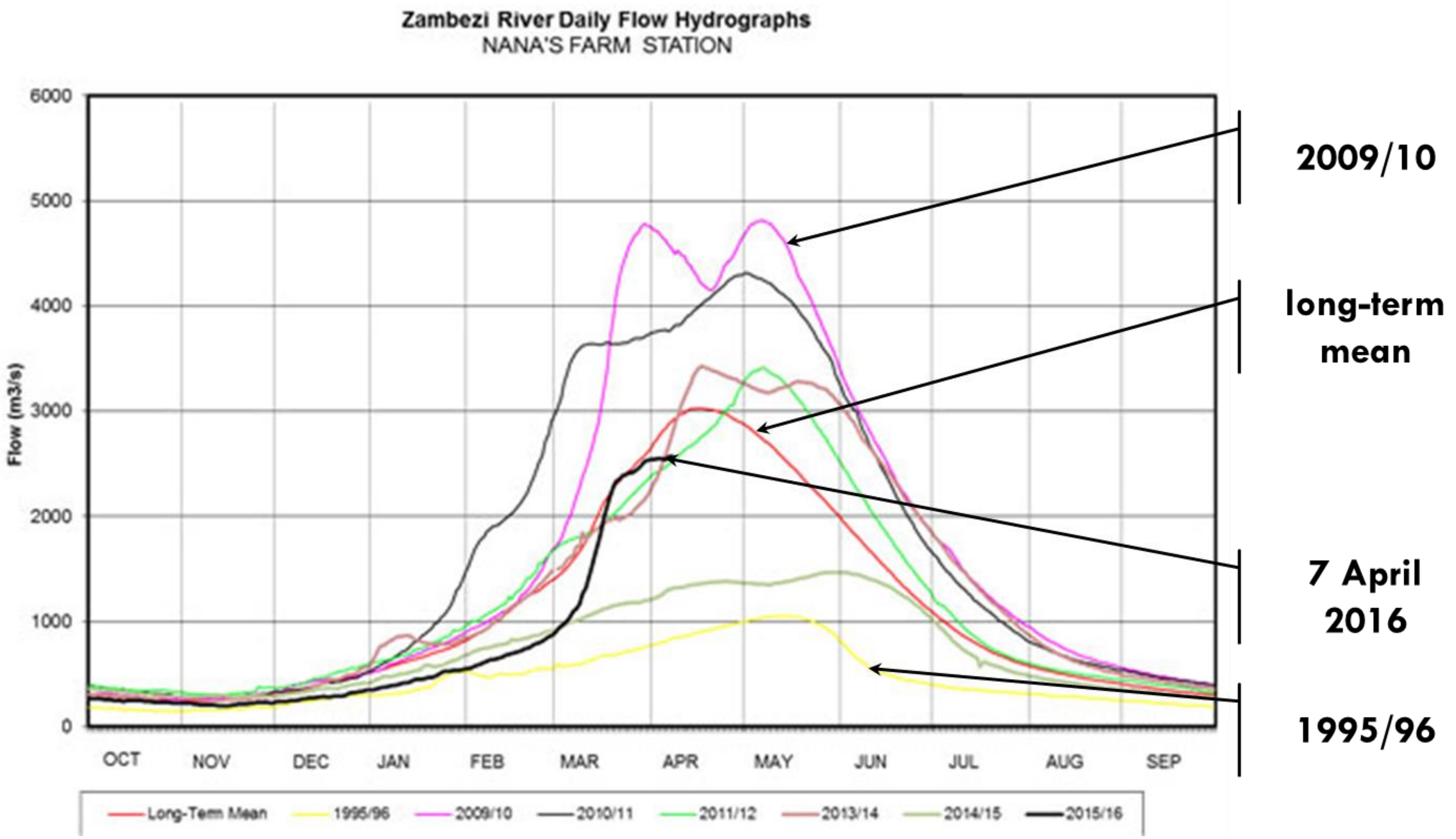
- Precipitation and Temperature affect water availability for hydro power
- If the future is
  - Dry: The energy system cannot depend only on Hydro
  - Wet: The energy system could take advantage of the increased water availability
- Our Electricity infrastructure needs climate proofing
- Example: Vulnerability of hydro-infrastructure development in the Zambezi River Basin
  - Extensive Hydropower expansion planned in the basin
  - The variation in the Zambezi river is highly variable
  - Potential for transboundary countries experiencing frequent blackouts or high electricity prices due to the loss of hydropower generation



Source: Zambezi River Basin Authority

Hydropower- Climate Resilience

- Our Electricity infrastructure needs climate proofing



Source: Zambezi River Basin Authority

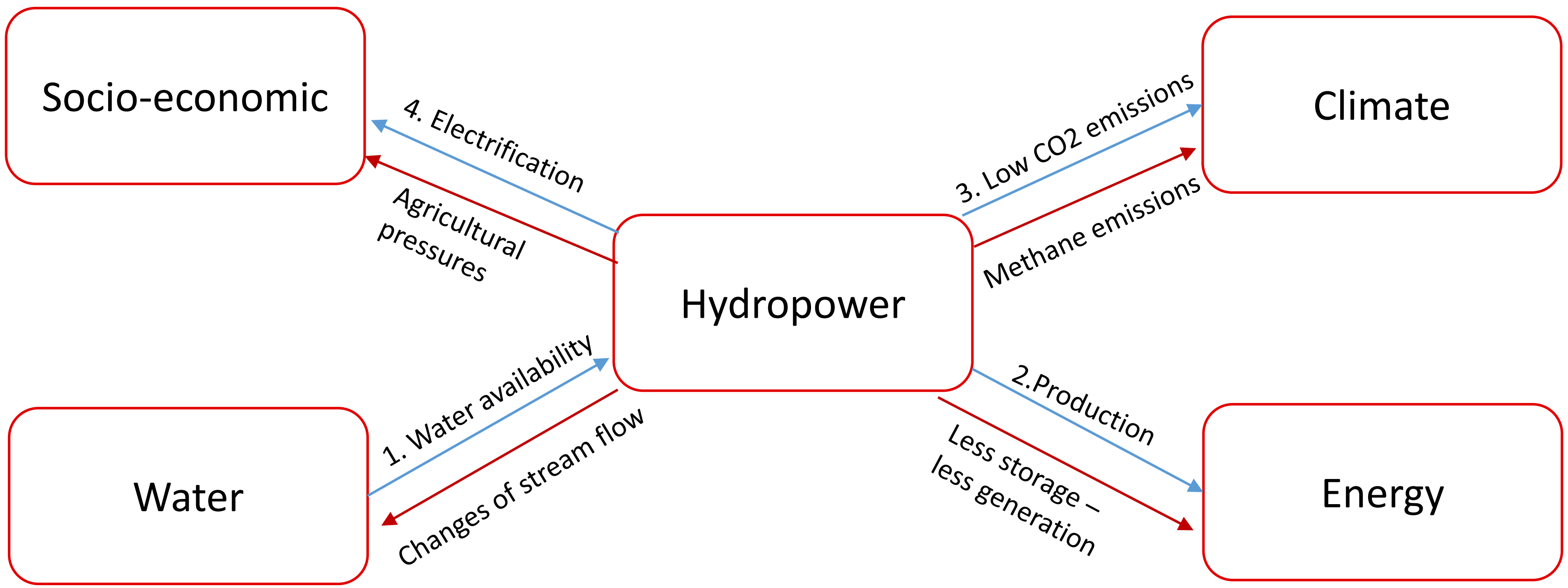
Conclusions

Conclusions

- Historic increase of hydropower capacity – today largest renewable
- Untapped potential – varying between continents
- Classification based on type, size, head, hydrological sequence and purpose of reservoir
- Different turbines – reaction & impulse
- Load curve – different rivers can meet demand at different times
- Cost of hydro is a function of the size and locations
- LCOE – hydropower one of the lowest
- Pressure on the environment – flooding, ecosystems
- GHG-emissions mainly from reservoirs and construction
- Pressure on the society – resettlement, agricultural practises
- Hydropower vulnerable to climate change – climate resilience

Key take away messages

Key messages



Effects or benefits or hydropower production

Diffuse or indirect implications

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Changelog and attribution

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