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Energy and Development: A Systems Engineering Approach for Planning Electricity Supply

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Energy and Development
A Systems Engineering Approach
For planning electricity supply

SELP 695: Integrative Project

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Introduction

- Bachelor of sciences in chemistry with minor in physics University Dijon (France)
- 1995-1997: High school profesor sciences (Paris)
- 1997-2003: Water Supply Suez-Dumez department of logistics (Paris)
- 2003-2005: Internet access development Cameroon
- 2007- Master of Sciences Systems Engineering (LMU)

Overview

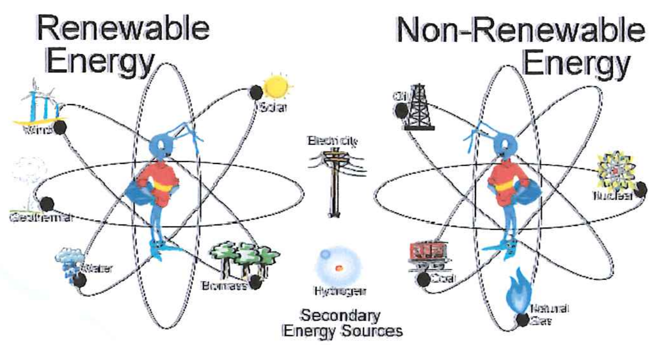
Project objectives

- Apply Systems Engineering approach to a real world problem with political, economical, social stakes
- Define requirements for a energy system
- Project planning and implementation
- Apply Risk management to a project
- Understand ethical issues within a project
- Life cycle

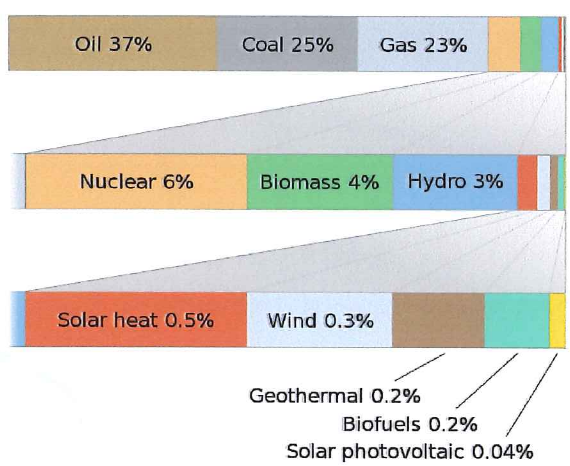
Introduction

- Today, energy is omnipresent in all aspects of modern life. Regardless of the region where we live in the world, we need energy for lighting, cooking, heating, transportation and so on.
- Two forms of energy in the nature
- Renewable energy, which is the energy generated from natural resource such as biomass, sunlight, wind, water, and geothermal.
- Non-renewable energy, which is the energy generated from fossil fuels such as oil, gas, and coal.

Energy



Energy consumption in the world in 2004

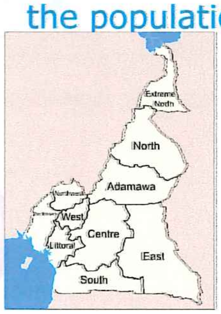


Energy use by countries

Country	Population	Average power per capita (watts)
USA	298,213,000	1,460
China	1,315,844,000	248
Germany	82,689,000	753
Japan	128,085,000	868
France	60,496,000	851
Brazil	186,405,000	226
Russia	143,202,000	785
South Africa	47,432,000	581
Cameroon	16,322,000	24

Needs, goals, objectives

- Only 25% of the population has access to electricity in Cameroon. In order to fight poverty and improve the standards of life of its population, the government of Cameroon has planned to provide access to electricity to 49% of the population by 2020.



Background Facts

- Population: 20 millions (2009 est.)
- Population growth rate: 2.19% (2009 est.)
- Industrial production growth rate: 4.7% (2008 est.)
- Electricity - production: 3.903 billion kWh (2006 est.)
- Electricity - consumption: 3.323 billion kWh (2006 est.)
- GDP (PPP) per capita: US $2,421 in 2005
- Public debt: 11.9% of GDP (2008 est.)
- Debt - external: $2.36 billion (31 December 2008 est.)
- The president Paul Biya has been in power since 1982

Mission

- Provide access to electricity to 49% of the population by 2020
- The government of Cameroon has identified the construction of the Lom Pangar Dam on the Sanaga River and two other dams namely, Natchigal Dam, and Meemvele Dam as a first solution for solving the gigantic problem of energy.
- 70 % of people living in ~~cities~~ rural and 30% living in urban areas.
- Access to electricity
  - People in rural areas 10 %
  - People in urban areas 60%
  - Total population 25%

Who are the stakeholders?

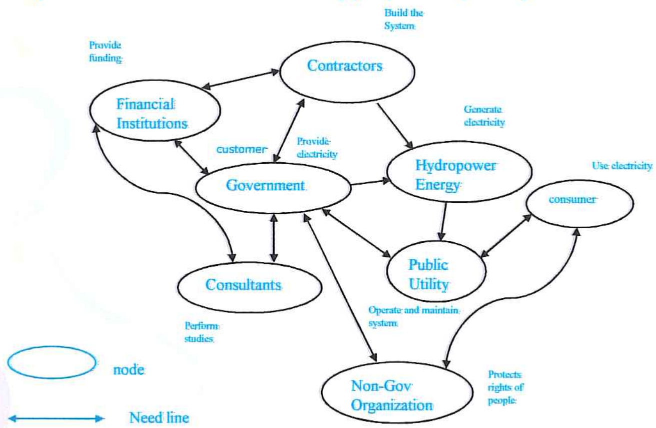
- Government of Cameroon
  - Increase the standards of living of its population
  - Fight against poverty
  - Provide access to electricity, water
- People of Cameroon
  - Receive electricity for lighting, cooking, television, and Internet and so on at affordable cost
  - Availability and Reliability of the service
  - Respect of people rights
- Financial institutions: World bank
  - Fight against poverty
  - Sustainable development
  - Provide assistance (technical, financial)

Who are the stakeholders?

- Non-governmental Organizations
  - Protect the rights of communities
  - Protect the environment and natural habitats
  - Investigate other energy options
- Public Utility
  - AES-SONEL supply electricity to the country of Cameroon
- Consultants
  - Perform studies

Stakeholders

- Operational View of the Energy System (OV-2)



Mission Feasibility

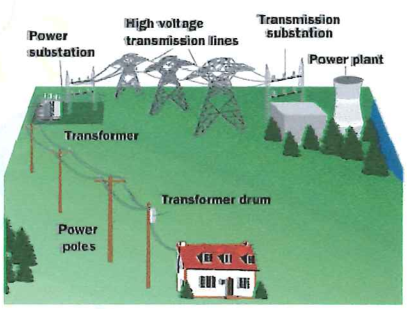
Electricity Forecasting

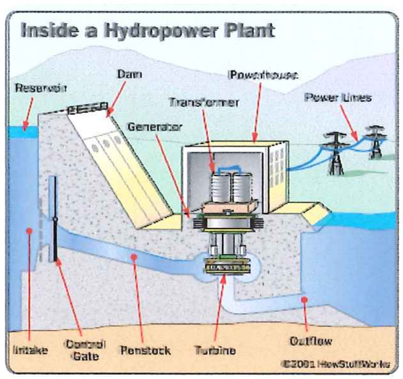
Electricity Consumption (billions kWh)	Actual (2009)	Prediction (2020)	Three Dams built (2020)
Individuals	1827	4577	4358
Industries, others	1496	2368	2254
Total	3323	6945	6613

Mission Feasibility

- 6945 billions kWh needed by 2020
- 6613 billions kWh produced with three dams
- We are 332 billions kWh (or 5%) below what is needed to satisfy the users' needs
- The mission is achievable assuming that other sources of energy may be used.

Hydropower system description





DAMS

- A Dam: a "barrier built across a water course for impounding water."
  - Embankment dams
  - Masonry dams
  - Gravity dam
- Several factors are considered with the selection of a type of dam
  - Topography
  - Dam foundation
  - Availability of construction materials
  - Flood hazard
  - Seismic hazard
  - Construction time
  - Climate
  - Governmental regulations
  - Available resources

Hydropower Plant

- **Intake** - Gates on the dam open and gravity pulls the water through the penstock, a pipeline that leads to the turbine. Water builds up pressure as it flows through this pipe.
- **Turbine** - The water strikes and turns the large blades of a turbine, which is attached to a generator above it by way of a shaft. The most common type of turbine for hydropower plants is the Francis Turbine, which looks like a big disc with curved blades. A turbine can weigh as much as 172 tons and turn at a rate of 90 revolutions per minute (rpm), according to the Foundation for Water & Energy Education (FWEE).
- **Generators** - As the turbine blades turn, so do a series of magnets inside the generator. Giant magnets rotate past copper coils, producing alternating current(AC) by moving electrons.
- **Transformer** - The transformer inside the powerhouse takes the AC and converts it to higher-voltage current.
- **Power lines** - Out of every power plant come four wires: the three phases of power being produced simultaneously plus a neutral or ground common to all three.
- **Outflow** - Used water is carried through pipelines, called tailraces, and re-enters the river downstream.

Trade studies

- Hydropower is a relatively clean, low-cost renewable source of energy that relies upon proven technology. Once built, hydropower, like all renewable sources has long operating costs and long life (over fifty years).
- Fossil fuels include oil, gas, and coal. Fossil fuels are non-renewable resources. Fossil fuels produces carbon dioxide which is one of the greenhouse gases that contributes to global warming.
- Solar power is by far the Earth's most available energy source, However, it is an intermittent energy source. High initial cost of installation.
- Wind power, along with solar power, is non-dispatchable, meaning that for economic operation all of the available output must be taken when it is available
- Geothermal power is cost effective, reliable, and environmentally friendly, but limited to areas near tectonic plate boundaries.

Environmental impact Assessment (EIA)

- Environmental impacts
  - The impact of reservoirs on terrestrial ecosystems and biodiversity: the construction of a storage dam and subsequent inundation of the reservoir area effectively kills terrestrial plants and forest and displace animals.
  - Greenhouse gas (GHG) emissions from reservoirs due to rotting vegetation are a recently identified problem.
  - Downstream Aquatic Ecosystems and biodiversity: Dams are intended to modify the natural flow of a river. Therefore they compromised the dynamic aspects of rivers that are fundamental to maintaining aquatic ecosystems.
  - Floodplain ecosystem: In Africa, the changed hydrological regime of rivers has adversely affected floodplain agriculture, fisheries, pasture and forest that constituted the organizing element of community livelihood and culture.
  - Fisheries: The blockage of sediment and nutrients, the modification of stream flow, and elimination of natural flood regime can all have significant negative effects on downstream fisheries.

Environmental impact Assessment (EIA)

- **Lom Pangar Dam environmental impacts**
- Fishing: villages both upstream and downstream of the dam site expressed concerns about its potential impact on their current fishing practices.
- Biodiversity: Forest issues and the Deng Deng Reserve:a region of great biodiversity,it contains one of the Africa's last hardwood forests and is a critical natural habitat for endangered gorillas and chimpanzees.
- Land impacts:People were concerned about the flooding of land used for farming and herding, and of forested zone.

Environmental impact Assessment (EIA)

- Lom Pangar Dam social impacts
- Displacement: The Lom Pangar Dam is expected to physically displace approximately 350 people. Concerns raised for people without land title. They may not receive adequate compensation or resettlements benefits.
- Livelihood impact:Gold exploitation: Gold is found in a zone that will be flooded near the town of Betare Oya. Many questions regarding gold mining have been raised by local residents.
- Risks associated with the Chad-Cameroon Pipeline project:The reservoir created by the Lom Pangar Dam would flood at least several kilometers of Chad-Cameroon oil pipe line which cross the East province on its way to the Cameroon's Atlantic coast.
- Cultural heritage impacts are still largely ignored in the planning process of large dams. Cultural heritage include: temples, shrines, sacred elements of the land area, and buildings.
- Numerous vector borne diseases are associated with dam reservoir in tropical areas.

Ethics

- Ethical issues are going to be examined within the Lom Pangar Dam project.
- Political, social and economic factors are always involved in the development of dams projects.
- Projects need many assumptions
  - Depending of political interests, decisions makers will pressure the engineers to limit studies to assumptions favorable to them.
  - Also extensive studies require more funding which is not always available.
- "Engineers shall hold paramount the safety, health, and welfare of the public and shall strive to comply with the principles of sustainable development in the performance of their professional duties."
  - fundamental canon of many engineering codes of ethics.

Ethics

- Ethical issue identified with the Lom Pangar Dam project.
- First ethical issue
  - Lack of public participation in the country energy need assessment.
  - The project appears to be prioritizing the needs of the Alucam aluminum smelter over the needs of the local population and the overall population of Cameroon.
- Utilitariasim:"Right action consists in producing the most good for the most people, giving equal consideration to everyone affected."

Ethics

- The second ethical issue identified in the Lom Pangar Dam is the public acceptance.
- The WCD identifies "gaining public acceptance" as the first of seven strategic priorities in dams projects. "acceptance emerges from recognizing rights, addressing risks and safeguarding the entitlements of all groups of affected people, particularly indigenous and tribal people, women, and other vulnerable groups."
- Inform consent: "First, people should be given not only the information they request, but all the information needed to make a reasonable decision. Second, they should not be subject to force, fraud or deception."

Ethics

- The third ethical issue identified is:
- The lack of transparency and disclosure of the Lom Pangar Dam project information.
- Information to be disclosed include:
  - A clear project calendar and timeline for all project related decisions
  - Supplemental environmental studies
  - Project feasibility studies.
  - Financing agreements for the construction of the Lom Pangar Dam and implementation of social and environmental mitigations measures

Systems Engineering

- A System: a set of interrelated components working together toward some common objective or purpose.
  - Systems are composed of components, attributes, and relationships.
  - No System is completely isolated from its environment.
- Systems Engineering: No commonly accepted definition in the literature.
  - "An interdisciplinary approach and means to enable the realization of successful systems" Incose
  - "An interdisciplinary, comprehensive approach to solving complex systems problems and satisfying stakeholders requirements."

SYSTEMS ENGINEERING

- Systems Engineering application areas
  - Aerospace systems
  - Transportation systems
  - Health care systems
  - Communications systems
  - Hydropower systems
  - Production/manufacturing systems
- Benefits of Systems Engineering include:
  - Less costs overruns
  - Less schedule delay
  - Better quality of products.

Requirements definition

- Provide electricity to 49% of the population by 2020.
- System level requirements
- Assumptions
  - All the hydropower plants represent one energy system
  - The energy system should be able to supply electricity to all the inhabitants of the country regardless of their location.

Requirements

- S1 (performance): The ES shall provide electricity to 12.5 million people around the country by 2020
- S2 (performance): The ES shall provide 4358 billion kWh by 2020
- S3 (performance): The ES shall be able to provide 30% of additional electricity capacity to compensate transportation losses
- S4 (performance): The ES shall provide electricity with continuity of service
- S5 (functional): The ES shall be able of generating electricity
- S6 (functional): The ES shall be able of transporting electricity
- S7 (functional): The ES shall allow the distribution of electricity
- S8 (functional): The ES shall be able to be operated and maintained
- S9 (constraint): The ES shall be built with the allowed budget
- S10 (constraints): The ES shall be built and operational before 2020
- S11 (constraint): The environmental and social impacts due to the ES shall be able to be mitigated
- S12 (constraint): The ES shall abide to all national and international energy regulations
- S13 (constraint): The price of electricity should be affordable for consumers

- We have defined six different stakeholders for the Energy System:
  - U1: Government of Cameroon
  - U2: People of Cameroon
  - U3: Non-governmental organizations and consultants
  - U4: Financial institutions (Banks, other loans)
  - U5: Public utility
  - U6: Contractors

Requirements Analysis

- Requirements traceability

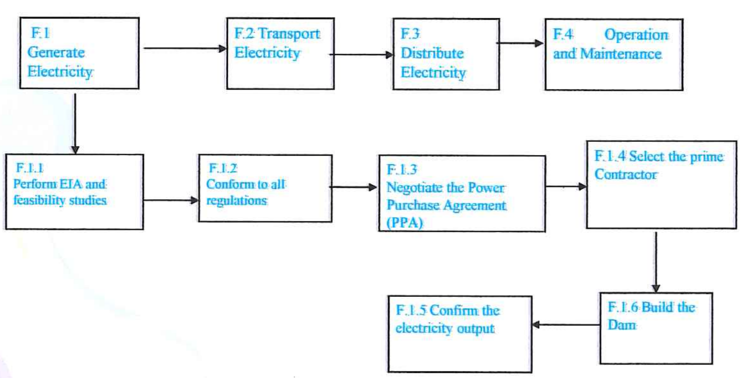
ID	System requirements	Backward Traceability
S1	The ES shall provide electricity to 12.5 million people around the country by 2020	U1,U2,U4, U5
S2	The ES shall provide 4358 billion kWh by 2020	U1,U2,U5
S3	The ES shall be able to provide 30% of additional electricity capacity to compensate transportation losses	U1,U2,U6
S4	The ES shall provide electricity with continuity of service	U1, U2,U5
S5	The ES shall be able of generating electricity	U1
S6	The ES shall be able of transporting electricity	U1

Requirements Analysis

- Requirements traceability

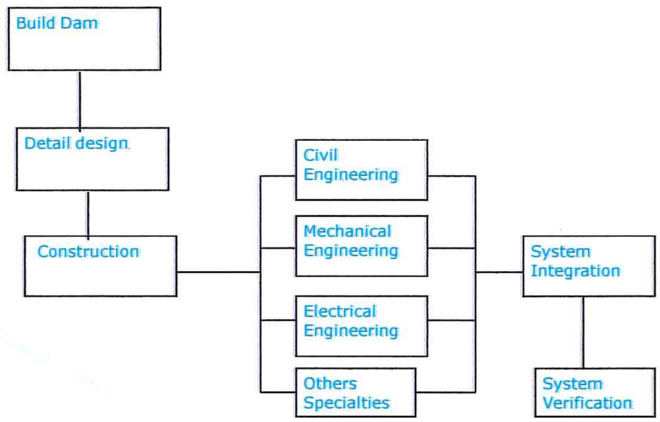
S7	The ES shall allow the distribution of electricity	U1
S8	The ES shall be able to be operated and maintained	U1,U5
S9	The ES shall be built with the allowed budget	U1,U4,U6
S10	The ES shall be built and be fully operational by 2020	U1,U2,U4
S11	The environmental and social impacts due to the ES shall be able to be mitigated	U2,U3,U4
S12	The ES shall conform to all national and international energy regulations	U1,U4
S13	The price of electricity should be affordable for consumers	U1,U5

Functional analysis



FFBD for electricity generation

Functional analysis



Risk management

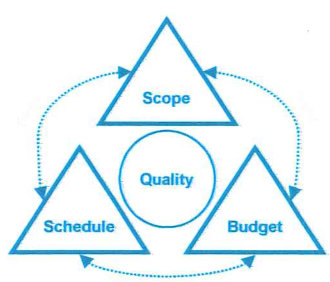
- Risk is inherent to all projects. This apply especially to large dams projects were many stakeholders with different goals are involved.
- Where are the risks?
- Social and environmental risks.
- Mitigation: Involve all the stakeholders in the decision making process.
- Economical risks
- Mitigation: Strategic Planning

Risk management

- During the construction phase costs overruns and schedules delays have been observed very often.
- The WCD states that: "Large dams have demonstrated a marked tendency towards schedule delays and costs overruns." The WCD found the average cost overrun of 81 large dam projects to be 56%.
- Reasons:
  - Poor technical cost estimates and supervision by sponsors.
  - Technical problems that arose during construction
  - Poor implementation by suppliers and contractors
  - Changes in external conditions (economic and regulatory)

Risk management

- The critical, day-to-day factors that drive project success are Scope, Schedule, Budget and Quality



Project planning and execution

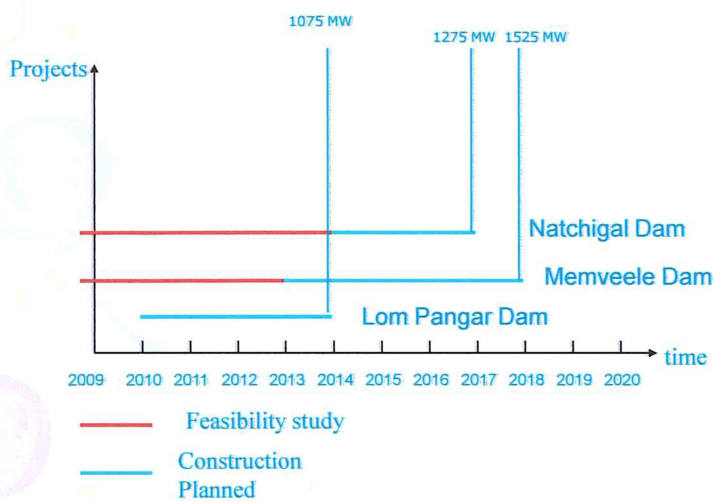
Typical Dam Project
- Feasibility study
- Detail Design
- Construction
- Operation and maintenance

- Feasibility study period:8 to 10 years
- Construction period:3 to 5 years
- Life cycle: over 50 years before major changes

Project planning and execution

Project	Electricity Output (MW)	Feasibility study	construction
Lom Pangar	175	Done	2010-2014
Meemvele	250	2005-2013	2013-2018
Natchigal	200	2006-2014	2014-2017

Project planning and execution



Life Cycle

- A key element of operating, efficiently for a long period is planning ahead and providing the people, the tools, and supplies for operating and maintaining the hydropower plant.
- The size of the organization for operating and maintaining a hydropower plant depends on these, among other factors:
  - The number of units
  - The size of units
  - The size of system operated by the utility
  - The complexity of the power plant
  - The utility resources available outside the plant for handling purchasing, maintenance, accounting, record keeping, real estate, and legal work.

Lessons Learned

- Engineering decisions are needed for forecasting water supply; for analyzing effects of operation on life of the equipment and efficiency of its operation.
- Preventive maintenance is the least costly and most effective means of prolonging the efficient, useful life of hydropower plant.
- Detailed schedules for inspection and routine maintenance of the equipment and systems at the plant.
- Develop checklists
- In Cameroon the volume of the reservoir has decreased because of a lack of maintenance. Recent droughts have also affected the performance of the system.

Conclusions/Recommendations

- Hydropower is a relatively clean, low-cost renewable source of energy that relies upon proven technology. Once built, hydropower, like all renewable sources, is considered to have long operating costs and long life.
- Energy should be included in a broader development objectives involving all the social actors.
- Investigate all the energy options especially in a country where 50% of the population live below the poverty threshold.
- The World Bank stated "Hydropower must be developed cautiously in the context of broader development goals, including responsible environmental management, poverty alleviation and social development, integrated water and energy management, and institutional development."