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Appropriate solutions for upgrading energy-related research laboratories within the EU ENERGISE project: the case of Technical University of Kenya and Technical University of Mombasa

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Acronyms

ACP-EU: African, Caribbean and Pacific Group – European Union

AGE: Annual Gas Expenditure

AICD: Africa Infrastructure Country Diagnostic

AP: Average Price

BBV: Biogas Bag Volume

CHP: Combined heat and power

CPI: Corruption Perceptions Index

TDASW: Total Daily Amount of Solid

DBC: Daily Biogas Consumption

DBP: Daily Biogas Production

DEP: Daily Energy Potential

DGR: Daily Gas Requirement

DTSC: Daily Total Solids Content

DTVSC: Daily Total Volatile Solids Content

EBT: Energy Balance Table

ECDE: Early Childhood Development and Education

EDI: Energy Development Index

EI: Education Index

EISD: Energy Indicators for Sustainable Development

ENERGISE: Enlarged Network in Education and Research for a Growing Impact of Sustainable Energy

EP: Electricity Penetration

ERB: Electricity Regulatory Board

ERC: Energy Regulatory Commission

FED: Foreign Energy Dependence

GDP: Gross Domestic Product

GNI: Gross National Income

HBCB: Hourly Biogas Consumption by Burners

HDI: Human Development Index

HEI: Higher Education Institution

HELB: Higher Education Loans Board

HRFS: Heat Required to warm the Feed Stream

HRT: Hydraulic Retention Time

HVDC: High Voltage Direct Current
IAEA: International Atomic Energy Agency
ICT: Information and Communication Technology
IEA: International Energy Agency
II: Income Index
IPP: Independent Power Producer
KATTI: Kenya Association of Technical Training Institutions
KCPE: Kenya Certificate of Primary Examination
KCSE: Kenya Certificate of Secondary Examination
KENET: Kenya Education Network
KETRACO: Kenya Electricity Transmission Company Limited
KIE: Kenya Institute of Education
KNEC: Kenya National Examination Council
KPLC: Kenya Power and Lighting Company
LCOE: Levelized Cost of Energy
LEI: Life Expectancy Index
LHV: Lower Heating Value
LIE: Low Income Countries
LPG: Liquefied Petroleum Gas
MCRT: Mean Cell Residence Time
MDGs: Millennium Development Goals
MNSP: Maximum Number of Served People
MoA: Ministry of Agriculture
MoE: Ministry of Energy
MoEST: Ministry of Education, Science and Technology
NEP: Net Energy Production
NFE: Non Formal Education
NGO: Non-Governmental Organization
OECD: Organization for Economic Cooperation and Development
OFDS: Organic Fraction Daily Selected
ORL: Organic Loading Rate
PGI: Poverty Gap Index
POP: Points of Presence
PPA: Power Purchase Agreement
PPP: Purchasing Power Parity

REA:	Rural Electrification Authority
REP:	Rural Electrification Programme
RES:	Renewable Energy Sources
SGP:	Specific Gas Production
SHC:	Specific Heat Capacity
STI:	Science Technology Innovation
TE:	Technical Education
TFC:	Total Final Consumption
TPES:	Total Primary Energy Supply
TS:	Total Solids
TTI:	Technical Training Institution
TUK:	Technical University of Kenya
TUM:	Technical University of Mombasa
TVET:	Technical and Vocational Education Training
TVS:	Total Volatile Solids
UNDP:	United Nation Development Programme
UNIDO:	United Nations Industrial Development Organization
VOFDS:	Volume of the Organic Fraction Daily Selected
WARMA:	Water Resources Management Authority
YP:	Young Polytechnics

Abstract

This work aims at assessing the current status of didactical laboratories in Kenyan Higher Education Institutions (HEI), with a focus on the Technical University of Kenya (TUK) and the Technical University of Mombasa (TUM). Its final goal consists of recommending appropriate energy related solutions for the labs' upgrading.

The study is carried out as part of the assessment phase of EU Edulink ENERGISE Project, funded by the European Commission with support of ACP-EU Cooperation Programme in Higher Education. This project has the purpose of boosting the contribution of HEIs' network in Ethiopia, Kenya and Tanzania working on Energy Engineering curricula to promote access to energy, efficiency and related socio-economic development. The ultimate goal of the project consortium, with Politecnico di Milano as co-ordinator, will be to develop and deliver innovative curricula in Sustainable Energy Engineering.

In order to understand more deeply the context, a preliminary analysis of the Kenyan socio-economic and energy situation is carried out, including also a comparison with the other East Africa countries and Italy.

In addition, an overview on the status of education in energy engineering in the country is presented, thanks to two different investigation's methodologies. The first refers to the data analysis obtained from questionnaires, completed by students and staff members of different Kenyan universities, whereas the second consists in the literature review, which defines the main weaknesses of the education system.

Specifically, this thesis focuses on modernization's proposal for the laboratories of the country's two technical universities, i.e. TUK and TUM. For this reason, the assessment was completed by direct observation and on-site interviews in order to verify the present equipment and the availability of spaces and services necessary for the establishment or improvement of educational workshops. Such meetings both with the HEIs' staff and with representatives of the most important International Organizations present in the country proved to be an useful means to understand the internal dynamics with a first-hand experience and to complete the questionnaires' missing responses through the primary sources.

On the basis of the information collected and the needs emerged from the meetings, an evaluation of the appropriate technologies is conducted and different scenarios are examined and compared. In this perspective, all the options considered are addressed to solve the two main problems identified in the campuses, that are the inefficient waste management system in TUK and the frequent electricity interruptions figured out in TUM.

The final choice is made not only on the basis of a merely economic criterion, but also looking at the action's sustainability, that means to figure out if the maintenance is easily feasible, if the spare parts are smoothly available and if the technology's use is durable over time.

Key words: didactical laboratories, TUK, TUM, upgrading, EU Edulink ENERGISE Project, access to energy, appropriate technologies, inefficient waste management system, electricity interruptions, sustainability.

Sommario

Questo lavoro mira a valutare lo status attuale dei laboratori didattici nelle università del Kenya, focalizzandosi in particolare su due istituti, Technical University of Kenya (TUK) e Technical University of Mombasa (TUM). L'obiettivo finale consiste nel suggerire soluzioni energetiche appropriate per l'ammodernamento delle infrastrutture didattiche.
Lo studio rientra nella fase di valutazione preliminare del progetto EU Edulink ENERGISE, finanziato dalla Comunità Europea con il supporto del Programma di Cooperazione in Higher Education ACP-EU. Tale progetto ha lo scopo di promuovere lo scambio di informazioni tra le università di Etiopia, Kenya e Tanzania, sviluppando piani di studio in ingegneria energetica al fine di favorire l'accesso all'energia, l'efficienza e lo sviluppo socio-economico. Il fine ultimo dello staff ENERGISE, avente il Politecnico di Milano come coordinatore, sarà quello di implementare un corso di laurea magistrale innovativo in Sustainable Energy Engineering.
Per comprendere più a fondo il contesto, viene condotta un'analisi preliminare della situazione socio-economica ed energetica del Kenya, includendo anche un confronto con gli altri paesi dell'Africa Orientale e l'Italia.
In aggiunta, viene presentata una panoramica sul livello dell'istruzione in ingegneria energetica nel paese grazie a due diverse metodologie. La prima è riferita all'analisi dei dati ottenuti dai questionari, compilati dagli studenti e dai membri dello staff di diverse università keniote, mentre la seconda riguarda un'approfondita rassegna bibliografica utile per definire le principali debolezze del sistema educativo.
Nello specifico, questa tesi si concentra sulla proposta di rinnovamento dei laboratori delle due università tecniche del paese, cioè TUK e TUM. Per questa ragione, la fase di valutazione è stata completata con l'osservazione diretta e tramite interviste in loco al fine di verificare le condizioni dei macchinari presenti e la disponibilità degli spazi e dei servizi necessari per il miglioramento dei laboratori. Tali incontri sia con lo staff universitario che con alcuni rappresentanti delle più importanti organizzazioni internazionali presenti nel paese sono stati un utile mezzo per capire le dinamiche interne con un'esperienza di prima mano e per completare le risposte mancanti dei questionari utilizzando fonti primarie.
Sulla base delle informazioni raccolte e delle esigenze riscontrate durante gli incontri, si effettua una scrematura della tecnologie appropriate e successivamente vengono esaminati e comparati diversi scenari. In quest'ottica, tutte le alternative considerate sono volte a risolvere i due principali problemi identificati all'interno delle facoltà, ossia l'inefficiente sistema di gestione dei rifiuti alla TUK e i frequenti black-out sperimentati alla TUM.
La scelta finale viene effettuata non solo su una base puramente economica, ma anche tenendo in conto della sostenibilità dell'azione.

Parole chiave: laboratori didattici, TUK, TUM, ammodernamento, progetto EU Edulink ENERGISE, accesso all'energia, tecnologie appropriate, inefficiente sistema di gestione dei rifiuti, black-out, sostenibilità.

Introduction

According to IEA, "Energy is essential to economic and social development and improved quality of life"[1]. From this definition it is evident that access to energy takes the form of an important right of which everyone should make use. However, in this sense, the data drew from the recent publication of the *World Energy Outlook 2014* bring out and confirm an extremely disheartening situation:

- 1.3 billion people in the World do not have access to electricity;
- 1 billion people in the World do not have reliable electricity grid;
- 2.6 billion people in the World rely on traditional biomass for cooking.

Even more alarming, these values derive mainly from developing regions in Asia and from Sub-Saharan Africa. In this light, the *Africa Energy Outlook* (2014) states that more than 620 million people in Sub-Saharan Africa, i.e. nearly half of the African population, lack access to electricity and, among these, 80% live in rural areas. In particular, in Kenya the share of population without access to electricity overcomes the 75%. To be more precise, 35 million people do not have access to the national grid, despite the establishment of the Kenyan Rural Electrification Authority (2006) with the aim of achieving universal access by 2030.

Instead, in the matter of access to clean cooking facilities, in Sub-Saharan Africa nearly 730 million people rely on the traditional use of solid biomass for cooking and almost three quarter of these are rural households [1].

Therefore access to modern energy services is fundamental to guarantee the basic needs, the public services operation and the dissemination of income generation activities with the final goal of assuring sustainable development for all [2].

Following the definition given by the World Commission on Environment and Development (the Brundtland Commission) in the report "*Our Common Future*" (Oxford University Press, 1987), sustainable development "[…] meets the needs of the present without compromising the ability of future generations to meet their own needs."[2] In this sense the concept of sustainability has a multi-dimensional nature and sustainable energy concerns three different dimensions:

- ECONOMIC DIMENSION: self-financing solutions are preferred because they develop an increased awareness about the importance of keeping the system running in the users;
- ENVIRONMENTAL DIMENSION: the exploitation of renewable energy sources is crucial to not damage the ecosystems and to avert the fossil fuels' depletion, already in progress;
- SOCIAL DIMENSION: energy is part of everyday life and hence the technologies must be appropriated for the needs of local communities.

In order to make more immediate the link between energy and sustainable development, some International Organizations have formulated indicators for human and energy dimensions [3].

For example in 1990, the United Nation Development Programme (UNDP) has created the Human Development Index (HDI), so as to measure the socio-economic development of a Nation. It is constructed as geometric mean of Life Expectancy Index, Education Index and GDP Index, thus

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[1] "*United Nations Conference on Environment & Development Rio de Janerio , Brazil , 3 to 14 June 1992*", 1992

[2] "*Our Common Future*" (Oxford University Press, 1987), the World Commission on Environment and Development (the Brundtland Commission)

taking into account the three end products of development, and it assumes values between 0 (low human development) and 1 (very high human development) [4].
On the other hand, the International Energy Agency (IEA) has devised the Energy Development Index (EDI) in 2004 with the aim of better understanding the relationship between energy and human development and promoting measurements about energy poverty [5]. It is calculated considering 4 sub-indicators, each of which monitors a specific dimension of country's energy poverty:

- per capita commercial energy consumption to evaluate the general economic development of a country;
- per capita electricity consumption in the residential sector to analyze the system reliability and the willingness to pay for electric services' users;
- share of modern fuels in total residential sector energy use to assess the improved cooking facilities' diffusion;
- share of population with access to electricity.

These two indicators are one the mirror image of the other and such characteristic emerges in *Fig. 1* that plots the trend of EDI as a function of HDI for different countries.

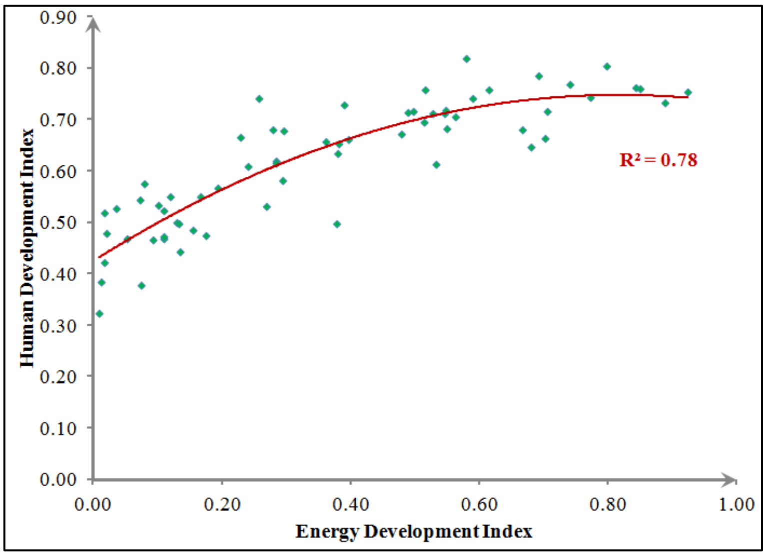

Fig. 1 HDI vs EDI [2]

The resulting trend in *Fig. 1* grows asymptotically: HDI increases more than proportionally with the rise of EDI, but it reaches the threshold of 0.8 when EDI is about 1. Therefore other different factors are instrumental in the determination of HDI, although the relationship is clearly evident.
In order to foster capacity building for sustainable development, the European Commission, assisted by the African, Caribbean and Pacific Group (ACP) of States Secretariat, has supported the implementation of EDULINK programmes (I and II) in the period 2006-2014. They aim at starting cooperative projects between Higher Education Institutions (HEIs) in the ACP States and EU Members States in order to promote balanced investments across the education sector as a whole [6]. Specifically EDULINK II pursues two main objectives that consist in developing an institutional networking and in enhancing the quality of teaching provided by HEIs.
As a part of this comprehensive programme, ENERGISE Project, coordinated by Politecnico di Milano, is addressed to four technical HEIs in Ethiopia (Jimma University), Kenya (Technical University of Kenya and Technical University of Mombasa) and Tanzania (Dar Es Salaam Institute of Technology). Its final goals consist in the foundation of a regional networking among the

Universities above mentioned and in the creation of innovative high quality curricula in Sustainable Energy Engineering, in line with the European Qualification Framework's guidelines.
In more detail, five are the expected results of the project:

1. assessment of the current status of education in energy engineering in the partner HEIs;
2. refresh courses for faculty members to activate the process of capacity building in innovative teaching methodologies and modern renewable energies;
3. organization and running of a new market driven high quality Sustainable Energy Engineering Master of Science;
4. definition of an e-collaborative platform for networking in order to encourage the capacity building within a joint framework;
5. achievement of a South-South knowledge transfer for curricula upgrading in the energy field.

In particular, this thesis focuses on the first expected result, that is the picture of the current status of education in energy engineering in the two Kenyan universities, TUK and TUM.
Thanks to the evaluation of specific questionnaires distributed to students and staff members and through interviews, surveys and planned visits in didactical laboratories and classrooms, an in depth analysis is carried out. It reveals that the two HEIs' common problem is the students' low competence in the renewable energy field. Such circumstance is mainly due to two different reasons:

1. integrative activities are not appropriate to treat renewable energy issues because didactical labs are endowed with obsolete machineries and they are subject to frequent black-out, which undermine the equipments reliability;
2. low presence, or even absence, of special supplies and software that deal with renewable sources, such as sun and wind, even though they are very abundant in the region.

In both cases, the lack of funds that plagues the Universities represents a significant obstacle behind and, on account of this, European Union fosters and finances in the partner HEIs projects regarding capacity building in order to rise the education's quality. In fact, the scarce promotion by technical institutions like TUK and TUM of innovative teachings about renewable energy themes implies outdated curricula, not market-driven, with the resulting difficulties for recent graduates to find a suitable employment.
Another consequence is the low positioning of these two institutions in the national ranking of Kenyan Universities. In fact, the Technical University of Kenya is located at 18th place, whereas the Technical University of Mombasa is 37th [7].
Therefore, the introduction of new technologically advanced and innovative devices could make these HEIs cutting-edge research centers as well as give life to a next generation of African professionals able to manage the local resources. Moreover, such initiative is consistent with the Kenyan national long-term development programme *Vision 2030*. It is founded on values such as Science, Technology and Innovation and it aims at transforming the country "into a newly industrializing, middle income country providing a high quality of life to all its citizens"[3].

[3] *"Vision 2030 | Home*" <http://www.vision2030.go.ke/>

Chapter 1 : Analysis of the context

1.1 Geography

1.1.1 Morphology

Kenya is a country part of the East Africa region. Its total area is equal to 581,309 km^2 (nearly twice the Italian one), of which 13,400 km^2 are occupied by inland waters. It borders on Ethiopia and Sud Sudan in the North, Tanzania in the South, Uganda in the West and Somalia in the North-Est. In the East, the Indian Ocean flows through the coastline of 563 km, as illustrated in *Fig.* 1.1 [8]:

Fig. 1.1 Kenya Map

Along the coast there are forests with a rich biological heritage, as well as autochthon lands with a strong presence of ancient coral reefs and with a regular slope, that gradually rises inwards. Here the Yatta upland extends and somehow it separates the northern lowlands from the Tsavo region. Tsavo is a large semi-desert plain, crossed by ills and monolithic mountains, which reaches the Kilimanjaro Mount, the highest mount in Africa with the peak in Tanzania. North of Yatta plateau the deserts, included in the Somali region, lie whereas in the north-west of Tsavo the central highlands begin. In particular, in the North there is the tableland that culminates with Mount Kenya (the second highest peak in Africa) and in the South the one that includes the vast savannas and wastelands. These highlands have a height varying from 800 to 3,000 meters, with an average above 1,600 meters. Finally, to the North of Mount Kenya a semi-desert area with considerable mountain ranges is located and, also in the Rift Valley region, the mountain chains are numerous.

1.1.2 Hydrography

Besides the Ocean along the coast, Kenya controls a small wedge of Lake Victoria, the largest lake in Africa. Other important inland waters are the lakes alongside the Rift Valley, almost all salted and often affected by phenomena like geysers. Such emissions of steam under pressure are common in many part of the Rift and, for this reason, in the Ol Karia area a thermal power plant, that uses steam for the production of electricity, is established. Noteworthy is the lake Turkana, a freshwater lake, fed by the Omo river, originating in the Ethiopian highlands.
The only two rivers of some importance are the Tana and the Galana, that cross the country with winding paths and then throw in the Ocean.

1.1.3 Weather conditions

The coast is characterized by a tropical climate, which is strongly affected by the monsoons. Inside, below 1,000 m, a warm climate with dry conditions is widespread, whereas above 1,000 meters, the climate is temperate, continental, and even alpine in the high mountains. The capital, Nairobi, is interested by a temperate climate (the temperature rarely rises above 30 degrees), that becomes cold during the short winter in June/August.

1.2 Historical and economic description

1.2.1 Historical background

Kenya is globally recognized as the cradle of the humankind because, since the beginning of the Lower Paleolithic, human settlements were established by populations coming from North Africa. In the 1st century B.C. the first Arab colonies and Nilotic and Bantu people settled in that area, whereas the Arab traders began regular frequenters of the Kenyan coasts in the 1st century after Christ. They founded many cities and entertained strong business relationships with indigenous groups: therefore, the encounter between these two groups gave birth to the Swahili culture, characterized by two elements of unification: the Kiswahili language and the Islamic religion.
The Europeans made their first appearance in 1498 with the arrival of the Portuguese, that want to establish naval bases alongside the Kenyan coasts to control the Indian Ocean. After some decades, they were supplanted by Omani Arabs, that controlled the territory until the end of the nineteenth century, when the British colonization began.
In a first phase, the British government set up the East Africa Protectorate to host the white immigrants engaged in large-scale coffee farming; later, in 1920, the Protectorate was transformed into a British crown colony. In this period, the natives were driven away from the fertile central highlands and all the different tribes were employed in the most wearing activities. These

circumstances led to the formation of the anti-colonial resistance movement called Mau-Mau, that fiercely opposed to British rule in the name of national sovereignty. The independence was achieved December 12, 1963 and the elections of that year brought the leader of the independence Jomo Kenyatta to the presidency. In 1964 Kenya become a republic and the process of political power centralization began thanks to the creation of a single party state model. In the wake of president Kenyatta's death in 1987, the Vice-President Daniel Arap Moi was elected and he officially declared Kenya as one-party state in 1982. However, after local and foreign pressures, in 1991, the Constitution's section on one-party was canceled, so that in the elections of 1992 a multiparty democracy was established. In any case, Moi was confirmed as president both in these general elections and in the 1997's ones, because of the opposition forces' disorganization.

During the 2002 presidential elections, Moi did not compete as candidate because constitutionally prohibited and the new president was Mwai Kibaki. He won by a narrow margin also in the subsequent elections of 2007, that were marked by an ethnic violence explosion. Only the diplomatic intervention of other African countries and ONU restored the order with the agreement that the president Kibaki and his main rival Odinga govern together. Hence the latter was appointed Prime Minister, a position newly created and later abolished.

Currently the president is Uhuru Kenyatta, Jomo Kenyatta's son, winner of the last election in 2013 [9].

1.2.2 Political organization

Kenya is an independent Presidential Republic, where the President is elected by an absolute majority at national level plus the 25% in at least one half of the 47 new counties identified by the Constitution. This constitutional draft was approved on August 27, 2010 and it has created a two-chambers Parliament, that are the National Assembly (Lower House) and the Senate (Upper House). The first counts 290 members elected from constituencies, plus 47 women each elected from the counties and 12 representatives from parliamentary political parties to manage special interests of youth, people with disabilities and workers. On the other hand, the Senate is composed by 47 members, one for each county, besides the 16 women nominated by political parties, the 2 exponents representing the youth and the 2 exponents for people with disabilities [10].

Other provisions of the new Constitution concern the limitation of presidential powers and the fight against corruption, factors that have historically affected the country's development. In fact, according to the Kenyan Ministry of Finance, corruption removes about a third of government revenues and researches of Transparency International (the global coalition against corruption) point out that Kenya ranks 136th in a list of 177 countries in terms of transparency index [11]. The Corruption Perceptions Index (CPI) is equal to 2.1 on a scale from 0 (high corruption) to 10 (high transparency) [12].

1.2.3 Economy

After independence, Kenya supported and incentivized a rapid economic growth through public investments, assistance of smallholder agricultural production and subsidies for foreign private industries. Such initiatives led to an average increase in GDP of 6.6% per year, whereas agricultural production grew by 4.7% per year. However, in the period 1974-1990, Kenya's economic performances declined and even now the country experiences worrying structural weaknesses that limit the development's potential.

Regarding the agricultural sector, it is an important item of the Kenyan economy and it is the second largest contributor to Kenya's GDP, although around one-half of the agricultural output is

constituted by subsistence products. The main cash crops are tea, horticultural produce and coffee, that together with pyrethrum, corn and wheat are grown in the fertile highlands, whereas livestock predominates in the semi-arid savanna. Coconuts, pineapples and sugarcane are cultivated in the coastal region, where also fishery is widespread.
In terms of mining and minerals, Kenya is not properly endowed: this sector contributes barely to the economy, representing only the 1% of the GDP, and it is driven mainly by the soda ash operation at Lake Magadi in south-central Africa.
On the other hand, the industrial and manufacturing sector is obstructed by shortages in hydroelectric power, high energy costs and unsuitable transport infrastructures, that led to its little contribution to the gross domestic product. Nairobi, Mombasa and Kisumu are the principal hubs for the industrial activities, that include the food-processing industries and the fabrication of consumer goods. In addition, the *Kenya Petroleum Refineries Ltd*. transforms imported crude oil into petroleum products, mainly for the domestic market. There is also an expanding informal sector, that deals with the small-scale manufacturing of household goods, motor-vehicle parts and farm implements.
Finally, in the sphere of services sector, tourism is an important activity, which accounts for more than half of Kenyan GDP, although the recent security problems have caused a significant inflection.
However, on a whole, the forecasts about the Kenyan economy are positive: in 2013, GDP has registered an increase of 4.8% and, for the next three years, its growth is planned between 5% and 6%, thanks to a further expansion of banking services and the telecommunication sector [13].

1.3 Socio-economic indicators

1.3.1 Population distribution

With a population of 44,353,691 people, the 68.8% of whom lives in rural areas, Kenya is ranked 30th among the most populated countries in the World. It is sparsely populated, with an average of 76.3 people per every square kilometer and the differences are evident among the counties. In fact, as emerged from literature review, only three counties count more than 1 million of inhabitants, whereas wide areas, especially in the North, are inhabited by less than 250,000 people. Obviously, the population distribution indicates also the resources' allocation in the country and therefore the most densely populated regions are those where the opportunities are greater.
Also the country's age structure is important to understand which investments are needed: for example, a young population requires more investments in education and in medical pediatric facilities than an older one. In this regard, the Kenyan population has a young age on the whole: the 43.1% of people is between 0-14 years old and more than half (53.4%) belongs to the second category (15-64 years old).
Furthermore, considerations on Kenyan population's average age allow the calculation of the ***Total Dependency Ratio*** [14]. It measures the pressure on productive population due to those typically not in labor force because too young or too old and it is obtained with the following mathematical formula:

$$\begin{aligned} &Total\ Dependency\ Ratio = \\ &= \frac{(people\ aged\ 0-14) + (people\ aged\ 65\ and\ over)}{people\ aged\ 15-64} \cdot 100 = \\ &= 81.5\%\ of\ the\ working\ age\ population \end{aligned} \tag{1.1}$$

In *Fig. 1.2* such indicator is investigated: it is equal to 0.815 for the nation and in rural areas it is 1.6 times higher than in urban ones. In addition, the comparison between child dependency ratio (76.6%) and aged dependency ratio (4.9%) underlines that the index's value mainly depends on the large number of children rather than the older people's one, and hence investments linked to childhood are the priority.

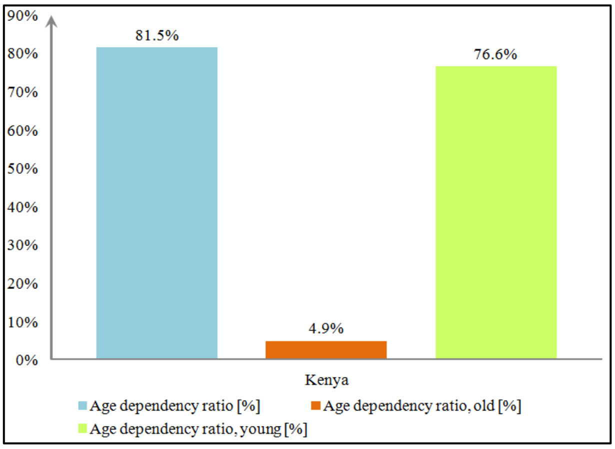

Fig. 1.2 Dependency ratio [%]

1.3.2 Income generation

The Kenyan per capita ***Gross Domestic Product at Purchasing Power Parity*** (PPP) amounts to $1,884.57 (International Monetary Fund, 2013) and this makes Kenya 155th in World GDP's ranking, $13,288.94 below the World's average GDP price equal to $15,173.51 billion. The recourse to this calculation's method shows the relative purchasing power of the average producer and consumer within the specific economy and it represents a good indicator of the living conditions in developing countries, because it takes into account the weakness of these currencies in the global market. In this way, the disparities between high and low income countries are lessened.

In order to give an idea of the deep economic inequalities within the country, it is noted that the 80% of GDP is created in the capital Nairobi and also looking at other indicators this disproportionate situation emerges:

- ***Poverty Headcount Index*** counts the proportion of population which lives below the poverty line and it is constructed considering different types of poverty lines. For comparisons among countries, the absolute or international poverty line ($1.25 per day) is preferred, whereas the national poverty line is suitable for a specific country's analysis, because it is defined according to peculiar economic and social circumstances. In the case of Kenya, the national poverty line per capita per day corresponds to $2.78 (2005 PPP, [15]) and *Fig. 1.3* points out that, at national level, around the 45% of the population, i.e. 15.5 million people, lives below this threshold (World Bank, 2005). The bar chart illustrates also the poverty headcount ratio at national rural and urban poverty lines, set equal to Ksh1.562 ($0.017) and Ksh2.193 ($0.024) per adult equivalent per month respectively.

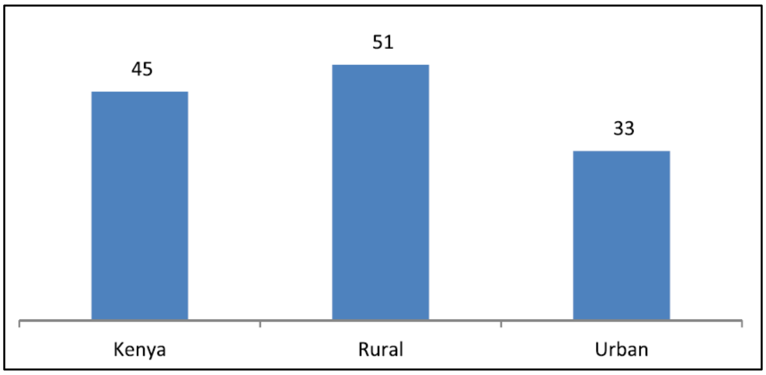

Fig. 1.3 Headcount ratio [14]

- ***Poverty Gap Index*** (PGI) is a meaningful indicator to understand which efforts are needed to bring each household from their current income to the poverty line. It is defined as the ratio between the poverty gap and the poverty line, where poverty gap means the average over all people of the gap between poor people's living standards and the poverty line [16]. It ranges between 0% and 100% and the higher the value, the wider is the discrepancy that separates people from the poverty line:

$$(Poverty\ Gap\ Index)_{\%} = \frac{1}{N} \cdot \left(\frac{\sum_{i=1}^{N} Y_p - Y_i}{Y_p} \right) \tag{1.2}$$

with $\begin{cases} Y_p = \text{ poverty line} \\ Y_i = \text{i-th poor person's income} \\ N = \text{total population} \end{cases}$

Once again the selected poverty line is the international one in the case of comparison among different World regions, whereas the national is used for the single country's analysis. From the latest survey, dated back to 2005, Kenya records a PGI at national poverty line equal to 16.3% and it becomes 17.5% and 11.4% referring to rural and urban poverty lines respectively.

- ***Gini coefficient*** is an aggregate numerical measure of income inequality ranging from 0 (perfect equality) to 1 (perfect inequality). It is based on the Lorentz curve and, for this reason, it is the ratio of the area between the perfect equality line and the Lorentz curve divided by the total area lying on the right of equality line in the Lorentz diagram, as illustrated in *Fig. 1.4*.

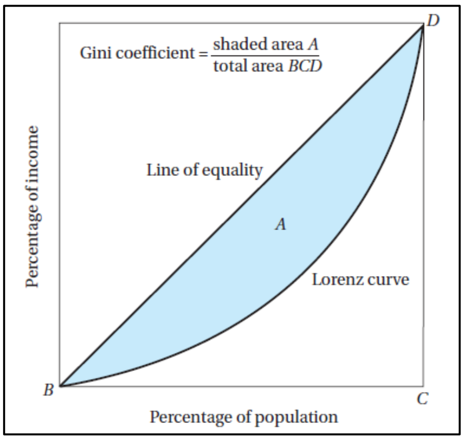

Fig. 1.4 Lorentz diagram [4]

For Kenya the Gini index reaches the value of 47.7%, as indicated by the *Human Development Report 2013* [17] and therefore the income distribution is enough unequal in the country. This circumstance is further corroborated by *Fig. 1.5*, that shows the population divided in 5 quintiles of 20% on the expenditures' basis.

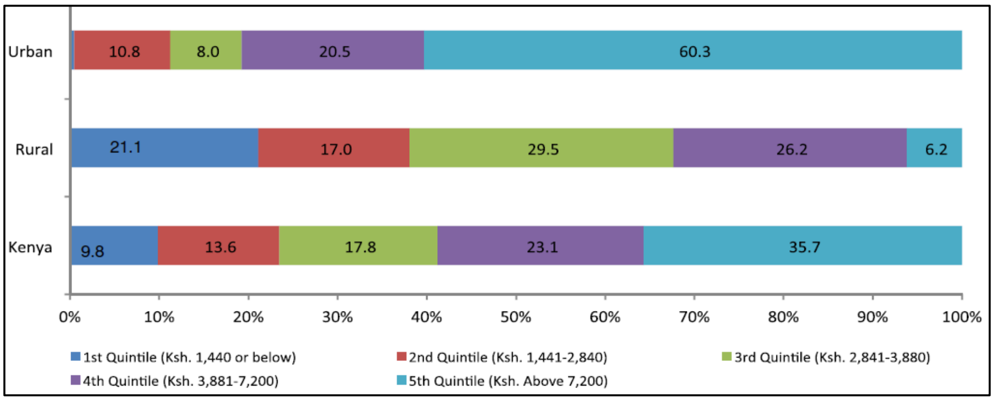

Fig. 1.5 Consumption expenditures share by quintiles [14]

From *Fig. 1.5* it is clear that in Kenya only 35.7% of the inhabitants can incur costs above Ksh7,200 (i.e. about €60), whereas 41.2% belongs to the first three quintiles. Significant differences are found between urban and rural regions: in fact, in cities more than half of households (60.3%) is included in the 5th quintile; on the other hand, the consumption expenditure share of fifth quintile in rural areas is ten time less (6.2%).

1.3.3 Human development

There is not an univocal definition of human development and over the years various aspects have been associated to this concept. However, all the different Human Development Reports drafted by the UNDP draw the attention on the opportunity of realizing the human potential, meaning with this the chance "about having real choices-the choices that come with sufficient income, an education, good health and living in a country that is not governed by tyranny" [17]. For this reason, the ***Human Development Index*** (HDI) has been designed as geometric mean of three different sub-indicators:

a. Income Index (II)

$$II = \frac{\ln(GNI_{\text{per capita}}) - \ln(minimum\ per\ capita\ income)}{\ln\ (maximum\ per\ capita\ income) - \ln(minimum\ per\ capita\ income)} \tag{1.3}$$

b. Life Expectancy Index (LEI)

$$LEI = \frac{actual\ value - minimum\ value}{maximum\ value - minimum\ value} \tag{1.4}$$

(health proxy calculated considering the minimum value equal to 25 years old and the maximum one equal to 85 years old)

c. Education Index (EI)

$$EI = \frac{\sqrt{mean\ years\ of\ schooling\ index} - minimum\ value}{maximum\ value - minimum\ value} \tag{1.5}$$

In *Tab. 1.1* the maximum and minimum values to calculate the three components of HDI are listed:

Dimension	Observed maximum	Minimum
Mean years of schooling	13.2 (United States, 2000)	0
Expected years of schooling	20.6 (Australia, 2002)	0
Combined education index	0.951 (New Zeland, 2010)	0
Per capita income (PPP $)	108,211 (United Arab Emirates, 1980)	163 (Zimbabwe, 2008)

Tab. 1.1 References for the calculation of HDI [85]

Kenya is characterized by an HDI of 0.519, which sets it at the 145th, and although this value is one of the highest among the low human development countries, there are great disparities also within the country: in fact, Nairobi has an HDI of 0.773, whereas in the Northern region it does not exceed 0.5. *Tab. 1.2* depicts also the sub-indicators' values and the difference between GNI per capita and HDI rankings:

HDI rank	HDI (2012)	Life expectancy at birth [years]	Mean years of schooling [years]	GNI per capita [2005 PPP $]	GNI per capita rank minus HDI rank
145	0.519	57.7	7.0	1,541	15

Tab. 1.2 Human Development Index and its components [17]

The positive difference in the last column of the table indicates that, referring to GNI, Kenya is ranked 160th and hence the country experiences a better situation in terms of HDI rather than looking only at the economic aspects.

1.3.4 Comparison with other countries

In order to better understand the Kenya's socio-economic situation, it is worth making a comparison among different countries of the indicators above analyzed. In this way, it is immediately possible to get a sense of the country's prevailing conditions in relation to those inspected in other realities.
Besides Italy, representing the OECD group, the other selected nations are Tanzania and Ethiopia inasmuch also involved in the ENERGISE project. *Tab. 1.3* summarizes the most significant values:

Indicator	Kenya	Ethiopia	Tanzania	Italy
Population	44,353,691	94,100,756	49,253,126	59,831,093
Area [km^2]	581,309	1,104,300	945,203	301,338
Population density [people/km^2]	76.3	85.2	52.1	198.5
GDP per capita (PPP)	$1,884.57	$1,258.60	$1,670.21	$30,094.06
Poverty Headcount Index$_{@\$1.25/day}$	43.4 % (2005)	36.8 % (2011)	43.5% (2012)	1.4% (2010)
Poverty Gap Index$_{@\$1.25/day}$	16.9% (2005)	10.4% (2011)	13% (2012)	1.2% (2010)
Gini index	47.7% (2005)	33.6% (2011)	37.8% (2012)	35.5% (2010)
HDI	0.519 (2012)	0.396 (2012)	0.476 (2012)	0.881 (2012)

Tab. 1.3 Comparison between 4 different countries

As depicted in *Tab. 1.3*, the large gap between the East Africa countries and Italy is clearly evident: the Italian GDP is an order of magnitude larger than all the others and also the poverty indices are widely smaller. However, also among the African countries, some differences are present: Kenya has the highest GDP and HDI indexes, but also the values of PGI and Gini are relevant, meaning that the inequalities are rough pronounced in the country.

Chapter 2 : Kenya Energy Situation

2.1 Energy balance

2.1.1 Energy balance table analysis

It is essential for this work to have a clear vision of the Kenyan energy system in order to both precisely describe the current and past situation and to foresee the possible future development scenarios.

For a complete and comprehensive overview in relation to the country's energy flows the tool of the Energy Balance Table (EBT) is used. The body responsible for the energy balance's preparation is the International Energy Agency (IEA) and it presents the balance in the form of a matrix, in which each column represents a type of fuel (whose acronyms are listed in *Tab. 2.1*), whereas the rows quote the different types of energy flows.

Acronym	Meaning
C&p	Coal&peat
CO	Crude Oil
OP	Oil Products
NG	Natural Gas
N	Nuclear
Hy	Hydro
R	Renewables (geothermal, solar, ecc.)
B&W	Biofuels&Waste
E	Electricity
H	Heat

Tab. 2.1 Acronyms

Specifically the balance (*Tab. 2.2*) can be divided in three different sections:

1. The first part includes the entries about supply and they consist of the production of power in the country with the exclusion of all the items not available for direct use; the imports, which count the amount of inbound energy intended to be consumed (therefore excluding the transits); exports, i.e. the quantities that exit from the country's boundaries, represented as negative flows; fuel stocks, used as damper to cover the demand and supply fluctuations. Finally, the fuels for marine and aviation travels outside the country are treated as bunkers.

   The algebraic sum of the terms described so far gives the ***Total Primary Energy Supply*** (TPES):

   $$TPES = production + imports - exports - bunkers_{\text{marine-aviation}} \mp fuel\ stocks \quad (2.1)$$

   It is worth noting that the item electricity, which appears in the third last column of the matrix, needs to be converted into equivalent primary energy. For this purpose, primary energy is evaluated considering that:

   - for electricity produced by hydro, wind, sun, tides and waves $1TWh = 0.086\ Mtoe$;
   - for electricity produced by nuclear source, it is assumed an average efficiency equal to 33%, hence $1\ TWh = \frac{0.086}{0.33} \cong 0.26\ Mtoe$;

- for electricity produced by geothermal source, it is assumed an average efficiency equal to 10%, hence $1\,TWh = \frac{0.086}{0.10} \cong 0.86\,Mtoe$.

2. The second section lists the transformations undergone by the energy flows, which are processed with chemical or physical treatments (oil-refining or electricity production for example) in order to obtain secondary energy. Also the conversion processes' consumptions are accounted as well as the transmission and distribution losses (given with a negative sign). Furthermore, considering all the other conversions, not strictly related to the energy ones, the ***Total Final Consumption*** (TFC) is achieved.
3. The last portion of the energy balance, shown in *Tab. 2.3*, is representative of the energy demand and it records the energy flows available to the end users. Specifically, the electricity effectively consumed (expressed in Mtoe), the heat consumed and other fuels are included, whereas backflows from the petrochemical industry are not considered in final consumption. In particular, end-use sectors are subdivided as follows:
   - industry, transport electricity production;
   - other sectors, such as agriculture/forestry, fishing, residential, commercial and public services, non specified consumption;
   - non-energy use, that covers the use of other petroleum products.

The energy balance here analyzed, dated back to 2012, expresses all the energy flows with a coherent measurement's unit (thousand tons of oil equivalent-ktoe), in order to guarantee a right accounting and comparison. In particular, the unit used refers to the amount of energy released by burning one ton of oil, calorific power of which is fixed conventionally. Therefore, in general:

$$1\,toe = 107\,kcal = 41.86 \cdot 10^6\,kJ \tag{2.2}$$

$$1\,TWh = 0.086\,Mtoe \tag{2.3}$$

ktoe	C&p	CO	OP	NG	N	Hy	R	B&W	E	H	Tot.
Production	0	0	0	0	0	370	1,376	15,149	0	0	16,894
Imports	211	1,002	3,211	0	0	0	0	0	4	0	4,428
Exports	0	0	-44	0	0	0	0	0	-3	0	-47
International marine bunkers	0	0	-13	0	0	0	0	0	0	0	-13
International aviation bunkers	0	0	-715	0	0	0	0	0	0	0	-715
Stock changes	0	-1	-8	0	0	0	0	0	0	0	-9
TPES	**211**	**1,001**	**2,432**	**0**	**0**	**370**	**1,376**	**15,149**	**1**	**0**	**20,539**
Transfers	0	0	0	0	0	0	0	0	0	0	0
Statistical differences	0	0	0	0	0	0	0	0	0	0	0
Electricity plants	0	0	-590	0	0	-370	-1,376	-91	713	0	-1,713
CHP plants	0	0	0	0	0	0	0	0	0	0	0
Heat plants	0	0	0	0	0	0	0	0	0	0	0
Gas works	0	0	0	0	0	0	0	0	0	0	0
Oil refineries	0	-1,001	992	0	0	0	0	0	0	0	-9
Coal transformation	0	0	0	0	0	0	0	0	0	0	0
Liquefaction plants	0	0	0	0	0	0	0	0	0	0	0
Other transformation	0	0	0	0	0	0	0	-5,072	0	0	-5,072
Energy industry own use	0	0	-50	0	0	0	0	0	-3	0	-53
Losses	0	0	0	0	0	0	0	0	-130	0	-130
TFC	**211**	**0**	**2,784**	**0**	**0**	**0**	**0**	**9,986**	**581**	**0**	**13,562**

Tab. 2.2 Kenyan energy balance (IEA, 2012)[5]

The upper part of the energy balance indicates where Kenya gets the primary energy needed to meet its requirements: it comes evident that most of the energy derives from Biofuels&Waste (about 70% of TPES), but only 91 ktoe of this source are transformed by electricity plants, whereas 5,072 ktoe are subjected to other transformations. Oil products are mostly imported and domestic production is null, despite the recent discovery of significant oil fields (600 million barrels of recoverable resources) in the region of Lake Turkana [1].
Other fuels that contribute to the internal primary energy production are the hydro source and, to a greater extent, the renewable one. In particular, the vast steam reserves in the Rift Valley are a good endowment to develop the country's geothermal potential [18]. On the other hand, the sun, despite its abundance, is not yet widely exploited for the high investment cost.
Finally, it is worth of noticing that the entries "Nuclear", "Natural Gas" and "Heat" do not give any contribution: nuclear electricity generation pilot programmes are in implementation phase, whereas heat applications are common only at households' level, and hence negligible at national level, besides the fact that the measurements of thermal energy are difficult to carry out.
Tab. 2.3 reveals the total final consumption divided by economic sector and it highlights that almost all the Kenyan consumptions are due to the residential sector (10,496 ktoe), followed by the quotas intended for non-energy uses and Commercial&public services.

ktoe	C&p	CO	OP	NG	N	Hy	R	B&W	E	H	Tot.
TFC	**211**	**0**	**2,783**	**0**	**0**	**0**	**0**	**9,986**	**581**	**0**	**13,562**
Industry	*211*	*0*	*504*	*0*	*0*	*0*	*0*	*0*	*317*	*0*	*1,032*
Transport	*0*	*0*	*1,596*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*1,596*
Other	*0*	*0*	*394*	*0*	*0*	*0*	*0*	*9,986*	*246*	*0*	*10,644*
Residential	0	0	332	0	0	0	0	9,986	179	0	10,496
Commercial&public services	0	0	0	0	0	0	0	0	86	0	86
Agriculture/forestry	0	0	19	0	0	0	0	0	0	0	19
Fishing	0	0	0	0	0	0	0	0	0	0	0
Non-specified	0	0	43	0	0	0	0	0	0	0	43
Non-energy use	0	0	290	0	0	0	0	0	0	0	290

Tab. 2.3 Kenyan Energy balance-TFC (IEA, 2012) [5]

2.1.2 Total Primary Energy Supply

The 2012 Kenyan TPES amounts to 20,539 ktoe, which correspond to 238.82 TWh, and a more precise portrait of the energy flows is achieved looking at *Fig. 2.1*, showing the energy balance diagram. To design such diagram some assumptions are put in place:

a) the measurements are expressed in Mtoe;
b) the item RES means Renewable Energy Sources and it is given by the sum of the three columns Hy, R and B&W;
c) I and E are acronyms for "imports" and "exports".

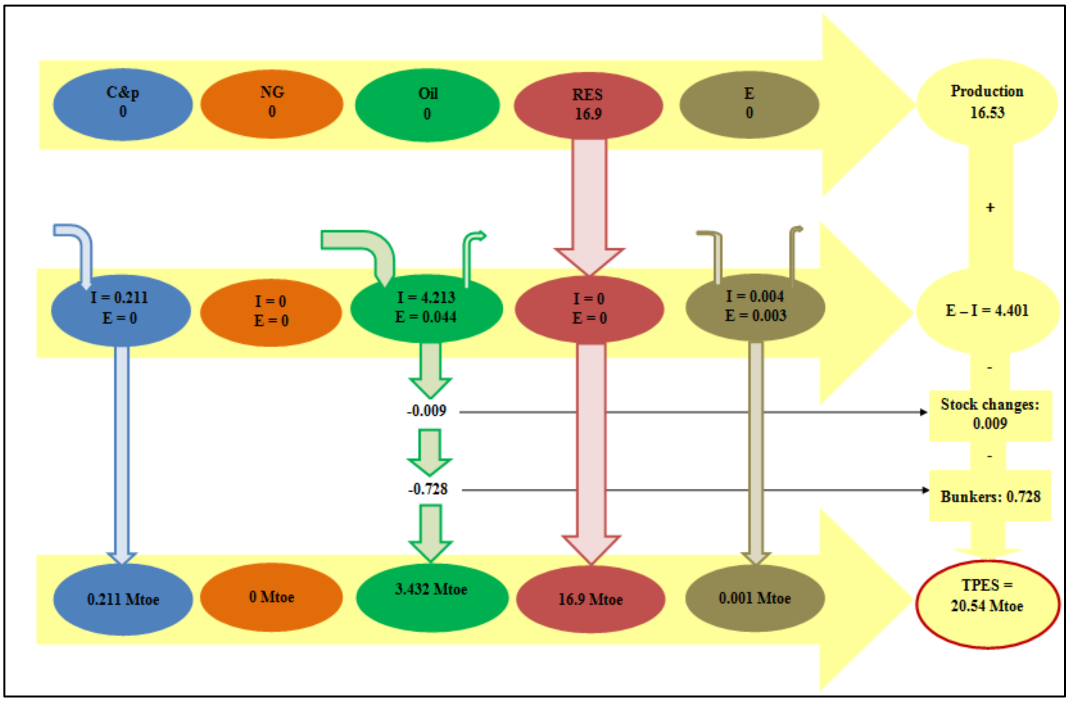

Fig. 2.1 Energy flows diagram - TPES

It is worth of noticing that the sum of the values in *Fig. 2.1* does not return exactly the TPES amount reported in the energy balance, but it is solely due to the approximations used.
The primary energy balance's findings can be more precisely investigated with the aid of *Fig. 2.2*, which points out how much each energy source contributes to the creation of Total Primary Energy Supply, excluding the electricity trade.

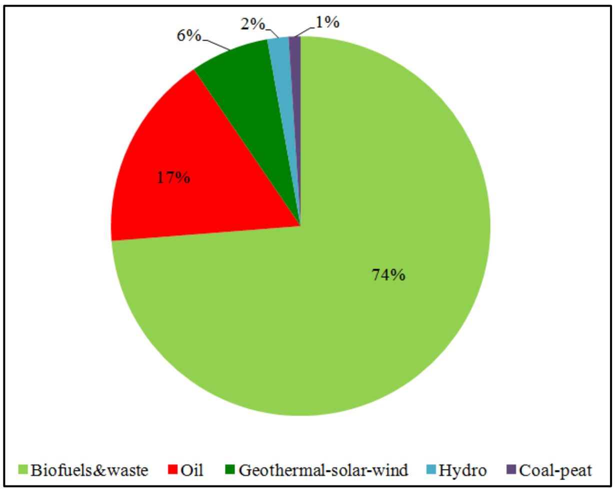

Fig. 2.2 Share of TPES (2012)

Biomass fuels, consisting of wood-fuel (the largest source of biomass in Kenya), but also plant residue from agriculture or forestry and organic component of municipal and industrial wastes, are the most important source of primary energy in Kenya with a share equal to around 74%. In the matter of fossil fuels, they are imported and minimally processed at Mombasa refinery: oil accounts for the 17% of total primary energy consumed in the country, whereas coal provides slightly more than 1%. Finally renewable resources supply the 8% of the total: geothermal and

hydro are the principal responsible, as the percentage of solar and wind energy harnessed for commercial and domestic applications is insignificant relative to their theoretical potential.
Finally, in order to know the trend of Total Primary Energy Supply during the last 40 years, IEA designs a specific graph traceable on its website (*Fig. 2.3*). It should be noted that the electricity trade is excluded from the chart and the following assumptions are made to obtain the values of TPES by source:

a) hydroelectric and renewable are directly converted in EE produced considering that 1TWh corresponds to 0.086 Mtoe;
b) nuclear electricity, in cases in which it is present, is transformed into oil equivalent assuming a national thermal efficiency of 33%;
c) geothermal is characterized by an electrical and thermal efficiencies equal to 10% and 50% respectively.

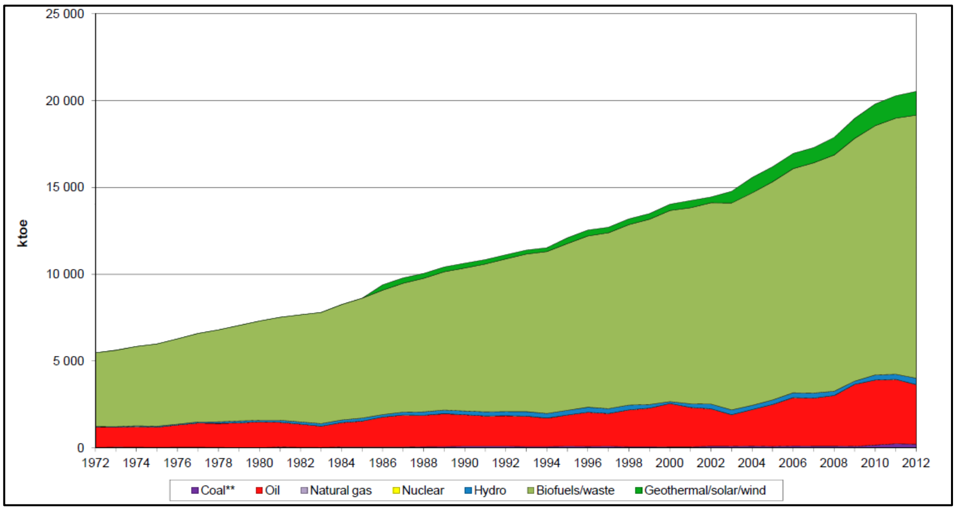

Fig. 2.3 Trend of TPES 1972-2012 [5]

The trend is positive: in just 20 years (1992-2012) the TPES has roughly doubled from 12,000 to 21,000 ktoe and, assuming that the trend's growth remains constant and equal to the one of the last four years, it is possible to estimate the value of TPES for the year 2014, approximately equal to 23,000 ktoe. In particular, the positive tendency concerns almost all sources, with significant growth for Biofuels&waste and Geothermal-solar-wind ones, that in fact show the most leaning trend. This situation is due also to the escalation in crude oil prices, which has implied a significant impact on the country's economy, promoting the recourse to diversified energy sources with more focus on renewable energy that can be produced locally. On the other hand, Oil has risen in a very less marked way, whereas the item Coal, which includes also peat and shale oil when relevant, has also played a marginal role.

2.1.3 Total Final Consumption

Also the energy flows, which conduct to the TFC's determination, can be represented with the aid of a flux diagram (*Fig. 2.4*).

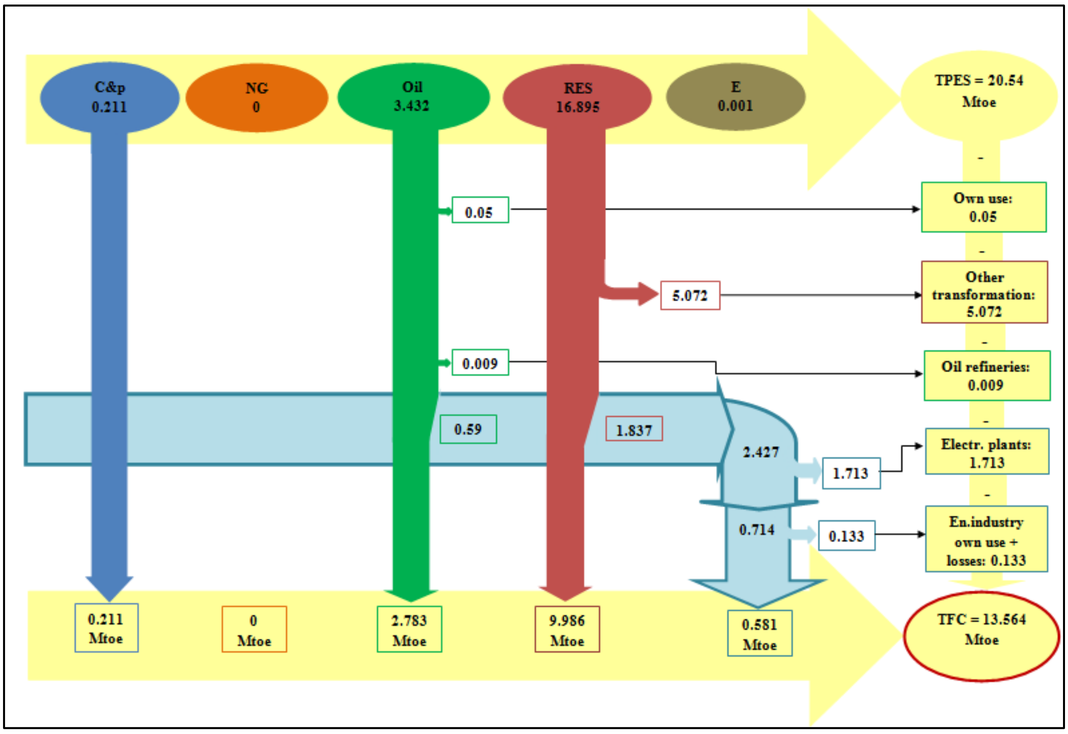

Fig. 2.4 Energy flows diagram-TFC (2012)

All the losses and transformations underwent by the total primary energy supply are considered and the primary energy derived by the electricity's import-export exchanges is small enough to be neglected. The blue arrow indicates the primary energy allocated for the electricity production and it corresponds to 2.427 Mtoe. Since at national level the primary energy's amount not addressed to become electricity is inferior (-1.713 Mtoe), it is easy to find the electricity quota, i.e. 0.714 Mtoe. This is a gross value and by eliminating various losses, the total final consumption from electricity is obtained.

The share of total final consumption by sector (*Fig. 2.5*) brings some evidences out: for example, the prevalence of the other uses (around 80%), which is four times greater than the sum of *Industry* and *Transport* (20% in total). Subsequently, looking more specifically at the item *Other*, it includes almost entirely the residential sector, whereas all the other entries amount together to 1%.

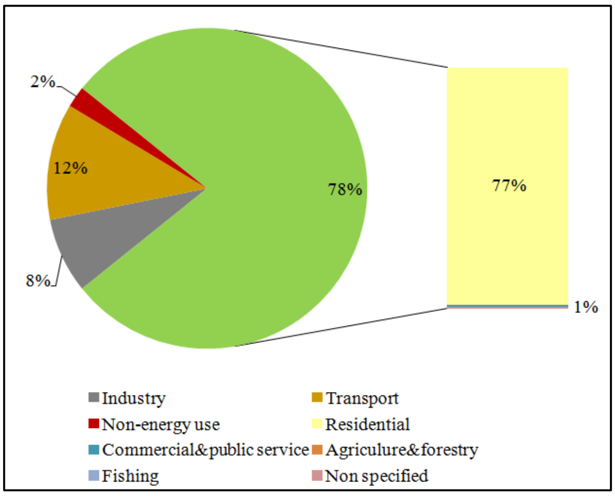

Fig. 2.5 Share of total final consumption by sector (2012)

2.2 Electricity

2.2.1 Analysis of the electricity and heat balance

The electricity balance of Kenya is illustrated in *Tab. 2.4* in which data are picked up from IEA referring to the year 2012, taking into account that the heat's entry is not depicted, because all its values are null.

Production from	**Electricity [GWh]**
coal	0
oil	2,060
gas	0
biofuels	316
waste	0
nuclear	0
hydro	4,299
geothermal	1,599
solar PV	1
solar thermal	0
wind	15
tide	0
other sources	0
Total production	**8,290**
Imports	42
Exports	-31
Domestic supply	**8,301**
Statistical differences	0
Transformation (including electricity used by heat pumps and by electric boilers)	**0**
Electricity plants	0
Heat plants (including waste heat bought from other industries that is generated from combustible fuels)	0
Energy industry own use	**34**
Losses	1507
Final consumption	**6,760**
Industry	3,686
Transport	0
Residential	2,076
Commercial&public services	998
Agriculture/forestry	0
Fishing	0
Other non-specified	**0**

Tab. 2.4 Electricity Balance [5]

Tab. 2.4 points out that hydro, which considers also the production from pumped storage plants, is the leading source for electricity generation and it contributes to the 44% of the total electricity production, as also underlined by *Fig. 2.6*. By contrast, wind and solar PV generation is minimal even though their high potential. Among fossil fuels, oil is the second source exploited with a share of 33%.

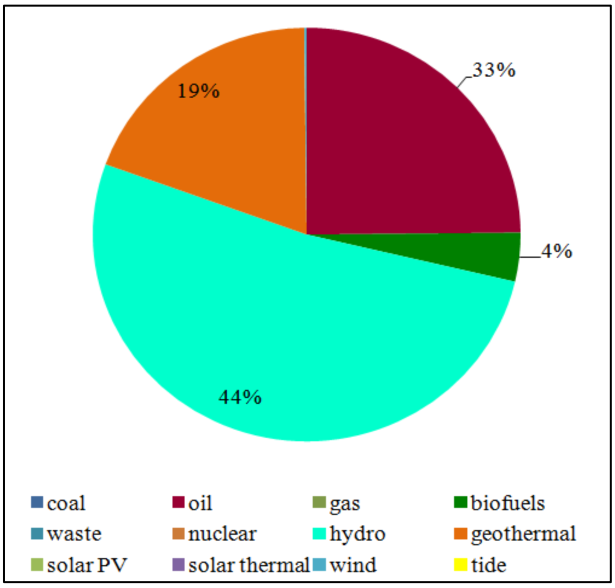

Fig. 2.6 Share in electricity production

Given the total electricity production, the domestic supply can be calculated adding the net import-export item:

$$Domestic\ supply = Total\ production + (Imports/Exports) = 8{,}301\ GWh \qquad (2.4)$$

Finally, it is possible to obtain the final consumption by subtracting to the domestic supply the following entries, considering only non-zero values:

$$\begin{aligned} Final\ consumption &= Domestic\ supply - Energy\ industry\ own\ use - losses = \\ &= 6{,}760\ GWh \end{aligned} \qquad (2.5)$$

To understand the subdivision of TFC by sector, *Fig. 2.7* is constructed and it points out that the largest part of electricity production (over the 54%) is used especially in the industry. To follow, there are the residential sector and the Commercial&public services, which are characterized respectively by a share of 31% and 15%.

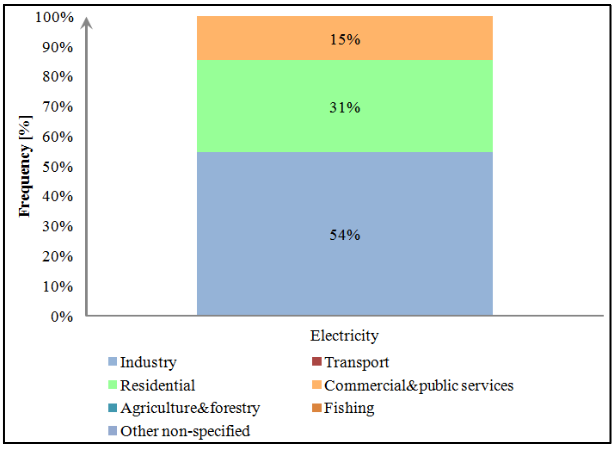

Fig. 2.7 Electricity consumption by sector

Finally, it is interesting to visualize the electricity generation trend during the last 40 years. In particular, *Fig. 2.6* shows the evolution of electricity production considering each energy source: the trend is positive especially for renewable energies thanks to the recent policies adopted by the Government. In fact, in the expectation of rising fossil fuel costs, Kenya is seeking to exploit the potential opportunities in renewable energy production considering also the improvements in technology and its consequent cost reduction.

However oil continues to have an important role in the electricity mix: in fact, in 2000 or in the period 2008-2009, Kenya was affected by intense droughts, that caused the obstruction of the hydropower plants and the increase of the oil's use, as demonstrated by the peaks in the graph.

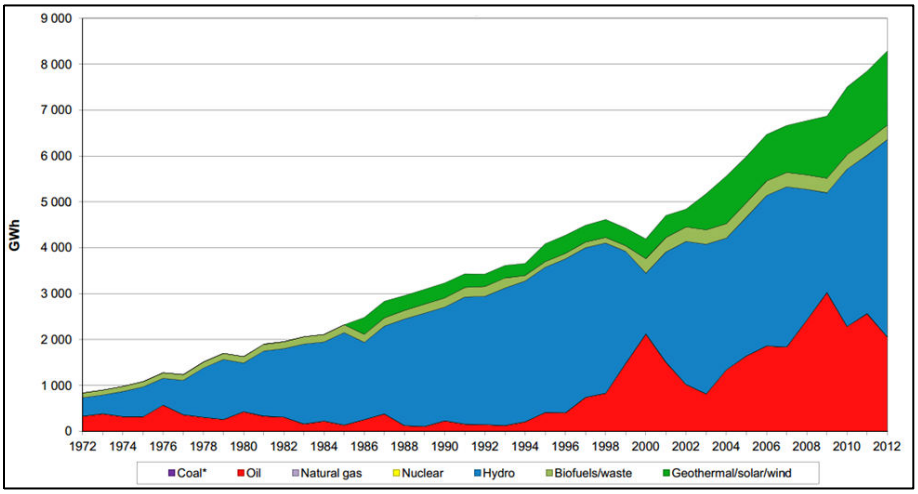

Fig. 2.8 Electricity generation by fuel from 1972 to 2012 [5]

2.2.2 Power installed

A comparison of the total electricity installed capacity between Kenya and the other ENERGISE partner countries is shown in *Tab. 2.5*, referring to the year 2011 [19].

Country	P_{tot} [GW]
Kenya	1.82
Tanzania	0.85
Ethiopia	2.13
Italy	118.22

Tab. 2.5 Total electricity installed capacity, 2011 [19]

From *Tab. 2.5* it is evident that the value for Italy is much higher compared to the others. Instead, considering the Low Income Countries (LIE), Kenya's installed capacity is intermediate between the Tanzania and Ethiopia's ones.

Focusing on Kenya, a road map called the *5000+MW by 2016 Project* to raise the generation capacity by at least 5GW to slightly over 6.7 GW by 2016 is provided in order to meet the growing electricity demand reducing the generation cost. The capacity will mainly be developed from geothermal (1.65 GW), natural gas (1.05GW), wind (0.63 GW) and coal (1.92 GW) [20].

2.3 Access to energy

Access to energy can facilitate the economic development and it can enhance the living standards of the poorest segments of society. Although, energy is not part of the Millennium Development Goals (MDGs), it contributes to reduce poverty, hunger and malnutrition, to improve education, health, gender equality through emancipation and empowerment of woman and to develop water and sanitation conditions [21].

In general, the term access is defined to include not just availability but also affordability, quality and reach. In addition, the supply and use of energy is intended to be efficient and sustainable in consideration of future Kenyan generations [22].

More in detail, access to energy has two dimensions, each of which provides essential benefits for economic and social development:

- access to electric energy;
- access to modern fuels.

Regarding these two aspects, indicators are important for assessing the progress of policies, projecting investment requirements and making comparisons across countries even though the measurements are complicated and the data are not always reliable.

2.3.1 Access to electric energy

Electricity is identified as "one of the prime movers of the modern sector of the economy" [23] in Kenya's Vision 2030. In fact, electricity is essential for basic activities, for instance lighting, refrigeration and the running of appliances; thus access to electricity is normally associated with rising the standards of life.

The World Bank provides the access to electricity's indicator, exploiting electrification data collected by the IEA from industry, national surveys and international sources. *Tab. 2.6* compares the Kenyan access to electricity with Tanzanian and Ethiopian ones referring to the year 2011 [24].

Indicator	Kenya	Ethiopia	Tanzania
Access to electricity [% of population]	19.2	23.3	15

Tab. 2.6 Access to electricity [24]

Tab. 2.6 shows that Kenya presents an intermediate access between the other two countries, taking into account that data are adjusted to be consistent with demographic patterns of urban and rural population. It should be noted that Kenyan indicator is low despite the Government's ambitious target to increase electricity connectivity, especially in rural areas, where the issue is more critical. In fact, rural electrification programmes and national electrification agency have been established to monitor more accurately the needs and the status of rural development.

Electric power transmission and distribution network

The Government, under the *Sessional Paper No. 4 of 2004 on Energy* [25] points out the necessity to fully unbundle the transmission and distribution functions of KPLC (Kenya Power and Lighting Company). For this reason, two entities were established: one for transmission which is 100% Government owned and the other for distribution, which is private sector owned.

- Transmission lines are operated and maintained by the Kenya Electricity Transmission Company Limited (KETRACO), which is wholly owned by the Government and it was registered under the Companies Act, Cap 486 [26]. It operates in line with *Kenya Vision 2030* and its role is to plan, design, build and maintain electricity transmission lines and associated substations.

Tab. 2.7 displays the existing transmission network, which is interconnected with Uganda through a 132 kV double circuit line.

Line	Extension (2013)
220 kV	1,331 km
132 kV	2,436 km

Tab. 2.7 National transmission network [20]

Regarding the installed capacity, it is equal to 1,846 MVA for the nine generation substations in service, whereas it corresponds to 3,076 MVA for the forty-five transmission substations at June 2013. However, the expansion and reinforcement of the transmission network is needed to keep pace with the increase in electricity demand in order to avoid a negative impact on supply reliability and system stability. In fact, KETRACO has identified priority projects for implementation of about 6,270 km of transmission lines comprising 2,081 km of 132 kV, 1,278 km of 220 kV and 2,299 km of 400 kV AC lines as well as 612 km of 500 kV High Voltage Direct Current (HVDC) line between 2011 and 2017. Furthermore, it is estimated that by 2031 KETRACO will have constructed 16,000 km of transmission lines.

- Distribution assets are owned by the Government of Kenya, the Kenya Power and Lighting Company and Rural Electrification Authority (REA). Distribution network involves the reception of bulk supply of electrical energy from generation or transmission network and the transmission of this energy thanks to distribution lines and distribution substations. The capacity of the distribution substations and distribution transformers are 2,800 MVA and 6,195 MVA respectively (June 2013) and distribution lines are represented in *Tab. 2.8*:

Line	Extension(2013)
66 kV	1,097 km
33 kV	16,136 km
11 kV	28,818 km

Tab. 2.8 National distribution network [20]

The purpose of the ongoing Energy Access Scale-Up programme is to increase connectivity countrywide and it implies the expansion of the national power distribution grid to connect one million new customers in 5 years starting from 2009 [20].

Both transmission and distribution lines are affected by losses, which are classified into two components: technical and non-technical. *Fig. 2.9* illustrates the different types of losses that occur from transmission point until consumers [27].

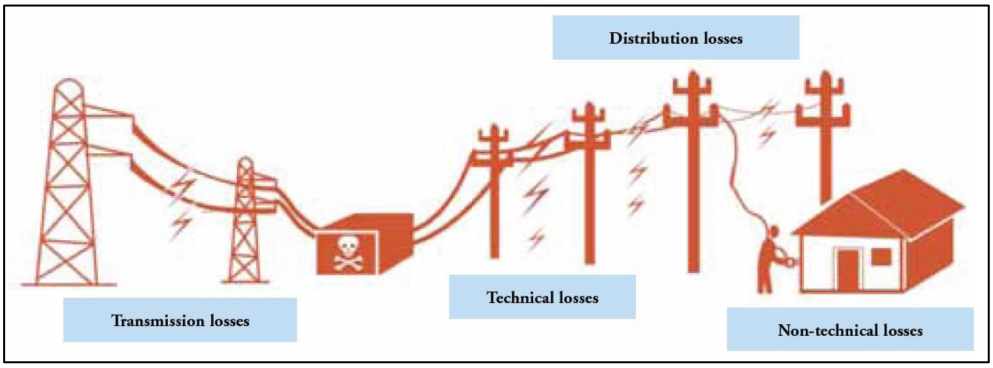

Fig. 2.9 Illustration of different types of losses [27]

Technical losses occur naturally and they are originated by power dissipations in components such as transmission and distribution lines, transformers and measurement systems. Whereas, the non-technical losses consist of actions, external to the power system, referring to electricity theft, non-payment by customers and errors in accounting and record-keeping. These last three categories of losses are respectively sometimes indicated as commercial, non-payment and administrative losses but their definitions vary in the literature [28].
Focusing on electricity theft, the two dominant methods are the illegal hook-ups and the meter tampering: the former mode is most easily detected whereas the latter procedure is a more sophisticated method which is also harder to identify since it can only be confirmed by a random audit [29].
Different researches have demonstrate that technical and commercial losses increase progressively from transmission to distribution, however during the years **Errore. L'origine riferimento non è stata trovata.**losses reduction has occurred as a consequence of the implementation by KPLC of a 5 years strategic plan.

Rural electrification

A rural electrification fund in 1973, an agreement with the East Africa Power and Lighting Company (presently the KPLC), was established under the Rural Electrification Programme (REP) to increase rural electrification. The aims of this programme consisted of promoting socio-economic growth and limiting rural-urban migration through creation of social facilities and employment opportunities. However the rate of penetration was low with not relevant improvements in the quality of life in the rural areas.
Another REP master plan was formulated in 1997 to cover 12 years in duration, but different challenges were encountered such as the limited funds, a high number of rural poor, dispersed human settlements and low return in rural areas [30].
Thereafter, the Rural Electrification Authority (REA) was founded under *Section 66 of the Energy Act, 2006* (No. 12 of 2006) in order to accelerate the pace of rural electrification in the country. Its mandate is to extend electrification services to rural areas, develop rural electrification master plans, manage the rural electrification programme fund, mobilize resources for rural electrification and promote the development and use of renewable energy.
The REA is considered the main driver in realizing the rural electrification targets set by the Government between 2010 and 2020 and it is also expected to implement the Government's policy objectives to extend access to electricity [31].
Despite its work, Kenya shows a share in access to electricity in rural areas very low, less than 10% (*Tab. 2.9*) and therefore further efforts are needed to boost rural electrification programmes.

Country	Electrification rate [%]	Urban electrification rate [%]	Rural electrification rate [%]
Kenya	19	58	7
Ethiopia	23	85	11
Tanzania	15	46	4

Tab. 2.9 Urban/rural electrification rate (IEA, 2013)

Power outages

Another forefront preoccupation of Government of Kenya is related to the problem of reliability of supply. In fact, the increase in population and economic growth has subsequently created an

increase in demand for electricity which cannot be met by the current power supply. The main reasons consist of the severe limitation of existing transmission system particularly during peak hours, the problem of non-technical losses especially due to theft and the sharp increase in vandalism, which aggravate the situation leading to a numerous transformer failures and consequent power outages.
The Africa Infrastructure Country Diagnostic (AICD) estimates an average of 53 days of outages per year in Kenya [32] and this circumstance represents a constrain to Kenya's growth: power outages cost to Kenyan economy an estimated 7% in lost private sector sales revenue, 2% of total GDP and 1.5% of GDP growth [33].
Consequently, the electricity grid's weakness has a negative impact on industries, hospitals, households, educational and tertiary institutions and thus it restrains the economic growth and development, as well as the people's socio-economic welfare. In particular, unpredictable electricity interruptions are an obstacle for business activities in many ways: they affect firm's productivity, they cause the damage of materials and equipment and they also imply huge restart costs. Furthermore, many firms are based on the use of internet to communicate with their customers, to advertise their products, and for electronic payments and all these services can only be efficient if there is effective electricity supply. Therefore the numerous business losses may have considerable effects on people, whose livelihoods depend on these activities. One of the strategies adopted by firms to overcome this issue is the investment in backup generators, but this alternative is not without cost.
For these reasons, the Kenyan Government continues to fund the development of national transmission system and to focus on solving the repetitive breakdown cases reducing the number of incidences and improving repair time.

Cost of electricity

In Kenya, and in general in all African countries, the cost of electricity varies by season, tariff structure and usage. *Fig. 2.10* displays the cost of electricity for domestic (DC) consumers (50-1,500 kWh usage band) over a 5 years period from 2009 to 2014 [34].

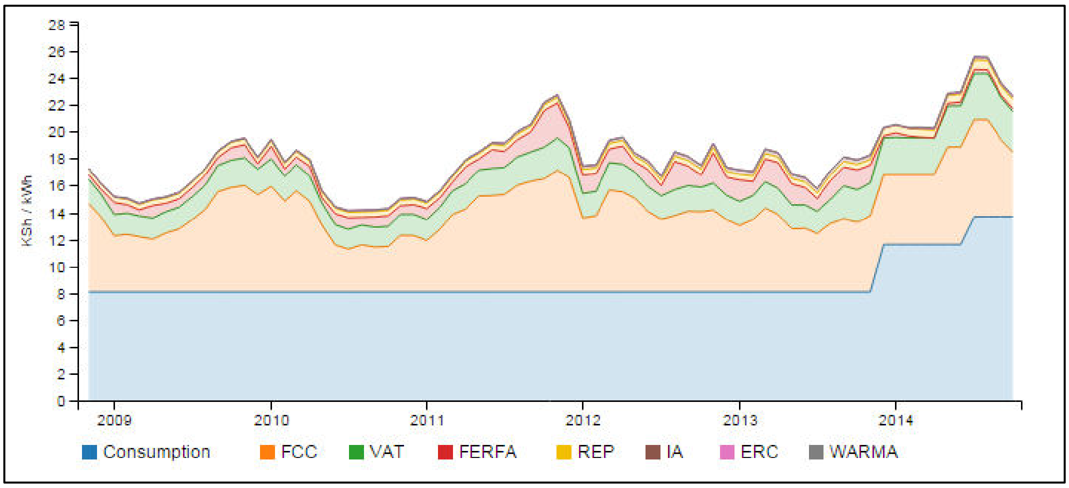

Fig. 2.10 Cost of electricity trend for domestic costumers [34]

The different items depicted in *Fig. 2.10* are described hereafter:

- FCC means Fuel Cost Charge (variable rate per kWh) and it is supposed to be reflective of the cost (to KPLC) of generating electricity during the previous month;

- FERFA (variable rate per kWh) is the acronym for Foreign Exchange Rate Fluctuation Adjustment and it consists of the sum of the foreign currency costs incurred by KenGen and KPLC, other than those costs relating to Electric Power Producer;
- IA (Inflation Adjustment) to take into account the extended increase of the goods and services' average general price (variable rate per kWh);
- WARMA levy corresponds to Water Resources Management Authority and it is fixed equal to KSh5 cents per kWh;
- ERC levy regards the Energy Regulatory Commission's sub-charge and it amounts to KSh3 cents per kWh;
- REP levy is referred to Rural Electrification Programme and it is equal to the 5% of the base rate;
- VAT (Value Added Tax) is 16% on everything except the WARMA, ERC and REP levies and Inflation Adjustment.

From the graph it is possible to find that the electricity bill for a domestic user amounts to around KSh23 per kWh (October 2014), i.e. about €21 cents per kWh.
More in general, except for domestic consumers, tariffs decrease with the increase of energy used and thus, large commercial consumers pay less per unit of energy compared to medium commercial consumers.

2.3.2 Access to modern fuels and modern technologies

Modern fuels

There are a wide typology of modern fuels used for cooking or heating, such as natural gas, LPG, diesel and renewable.
Focusing on cooking fuels, *Fig. 2.11* points out the strong relationship between the kind of sources used and the socio-economic development: in fact, the recourse to modern fuels allows to reduce health diseases and the time opportunity costs of women and children harvesting biomass fuels for use in traditional cook stoves; on the other hand the positive effect on local environment is not to be neglected.

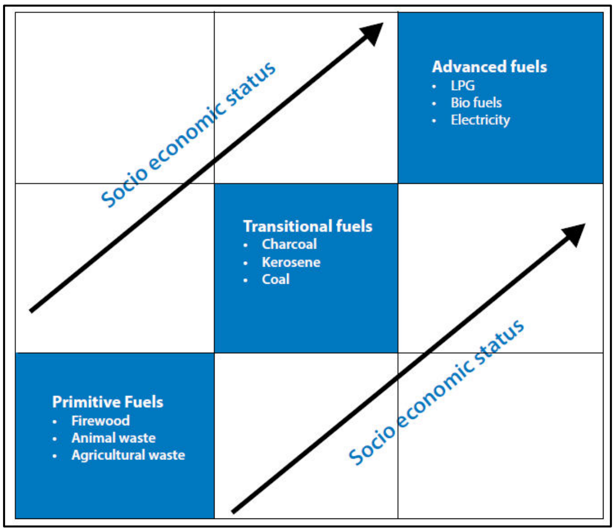

Fig. 2.11 Energy sources and socio-economic status [14]

In particular, firewood is the most widespread fuel used by low income households ,whereas cleaner and more expensive sources, whose cost is afforded only by wealthy families, are liquefied petroleum gas and biofuels. In fact, as depicted in *Fig. 2.12,* the 65% of households in the country exploits primitive fuels, the 29% counts upon transitional fuels and only the 6% purchases advanced fuels.

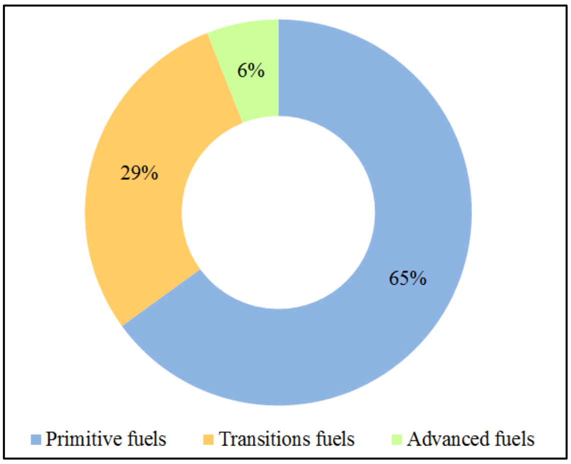

Fig. 2.12 Main Cooking Fuel

In the rural areas, this critical point is accentuated since the 90% of population depends on traditional fuels for cooking, a value almost 4 times higher than the one obtained by analyzing the urban counterpart.

Considering also heating purposes, it is worth of notice that biomass usage represents 68% of total energy consumption. In rural areas, almost all families rely on firewood and 82% and 34% of urban and rural households respectively depend on charcoal. Therefore, in rural and urban areas wood and charcoal are an important sources of income since numerous people are engaged in their production, transformation, transportation and sale. As a consequence, the stocks of woody biomass are diminishing, exacerbated further by the poor management and the utilization in unsustainable ways. Therefore, technological alternatives are required to make use of modern fuels or traditional fuels more efficiently [35].

Modern technologies

The modern cook stoves are one of the options to reduce wastage in fuel and emissions. In fact, the problem of indoor air pollution mainly from smoky kitchens is relevant in Kenya considering that 15,400 women and children die annually. However, besides the technologies, it is important to consider other aspects related to cooking, such as multiple fuel choices, variety of cooking practices, societal and cultural norms.

Improved cook stoves have been promoted in Kenya since the 1980s after the UN conference on new and renewable sources of energy held in Nairobi. By the mid 80’s, one of the first stoves developed was the Kenyan Ceramic Jiko (KCJ, *Fig. 2.13*) and thanks to the improvements on the design over the years, today it has become a widely used stove available in the Kenyan market.

Fig. 2.13 Jiko Cook stove [36]

In the 90's, some driving forces such as GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit), partnering with the Ministry of Agriculture (MoA) and Practical Action, in conjunction with the Ministry of Energy (MoE) tried to accelerate the process of commercialization of wood fuel stoves with the aim of moving people away from cooking on primitive stoves or the traditional three-stone fire [36]. Later, in the 2000's, NGOs and private entrepreneurs have focused on the distribution of stoves (often imported) free of charge or at subsidized prices. Although various initiatives have been made in disseminating cleaner and more efficient cooking technologies, only about the 24% among approximately 6.4 million rural households has been reached.

The principal challenges in the promotion of clean cooking practices and technologies consist of the scarce awareness and limited market development. In fact, cleaning technology is a new concept for many people and it is not recognized as a priority by them. People both in rural and urban areas are not aware of all the negative impacts when using the three-stone fire, compromising the success of different projects related to cook stoves. In addition, the market for cooking devices is rather fragmented: in urban areas households can choice different cook stoves, whereas in rural areas the three-stone fire still remains the most used cooking technology, since many players are not willing to invest due to the risk of not being repaid [37].

2.3.3 Relevant Energy Legislation, Policies and Intervention

The energy policies are design to ensure sustainable, adequate, affordable, competitive, secure and reliable supply of energy to meet national needs at least cost, in addition to protect the environment. The most relevant interventions are:

- the establishment of the Ministry of Energy in 1979 with the aim of formulating and implementing energy policies to conserve oil, explore for oil, promote renewable energies, develop hydropower and procure petroleum products [30];
- the *Electric Power Act No. 11 of 1997* established the unbundling of the Kenya Power and Lighting Company into three entities: Kenya Power and Lighting Company to carry out transmission and distribution functions; KenGen to undertake the generation function and the Electricity Regulatory Board (ERB) to regulate the power sector. The Act aimed at enhancing private sector participation in the provisions of electricity services and it also permitted Independent Power Producers (IPPs) to enter into Power Purchase Agreements (PPAs) with KPLC to add more power into the national grid [38]. The IPPs are private companies which produce power and sell electricity and, as at December 2013, seven were in operation;

- the *Sessional Paper No. 4 of 2004* was developed by the Ministry of Energy in consultation with energy sector's stakeholders. The main objectives of the energy policy were to provide sustainable quality energy services for development, utilize energy as a means to accelerate economic empowerment for urban and rural development, improve access to affordable energy services, provide an enabling environment for the provision of energy services, enhance security of supply, promote development of indigenous energy resources and enhance energy efficiency and conservation as well as prudent environmental, health and safety practices [38].
- the *Energy Act No. 12 in Dec 2006*, considered the guidance of the energy sector, was enacted by the Government and it provided for the establishment, powers and functions of the Energy Regulatory Commission (ERC), the Energy Tribunal and the Rural Electrification Authority (REA) [20].

  Regarding ERC, it is founded by the conversion of existing ERB in 2007 and it is a single sector regulatory agency responsible for economic and technical regulation of electrical energy, petroleum and related products, renewable energy and other forms of energy. Its core role is to facilitate access to energy through regulation ensuring the protection of consumers, investors and other stakeholders' interests [39]. For example, an instrument implemented by ERC to facilitate power producers in generating and selling electricity from renewable sources is the Feed-in Tariff policy (April 2008 and revised in 2010). It is a pre-determined fixed tariff established for a given period of time (20 years) and, in general, tariffs range from US$ 0.08/kWh to US$ 0.2/kWh depending on the typology of sources.

Recently, the Government has created another key institution for the sector, that is the Geothermal Development Company, a 100% state-owned company, formed by the Government of Kenya as a Special Purpose Vehicle for geothermal resource development [40].
Furthermore, in the electricity sector, the principal initiatives are related to the increase of power generation from geothermal and wind sources in order to ensure security of energy in the country and to meet increased energy demand as envisaged in *Vision 2030* [38].

2.4 Energy indicators' comparison

A more detailed analysis can be obtained through a comparison of the Kenyan energy situation with the other nations' one, since a comparative evaluation can be useful in order to assess in a general way the context's state and propose appropriate development's solutions**.** The indicators used are those defined by the International Atomic Energy Agency (IAEA) and they are calculated following the list of the Energy Indicators for Sustainable Development (EISDs), constructed by the same Agency. On a whole, the EISDs are social, economic and environmental and with them it is possible to rank different countries and draw conclusions on the state both in the specific area of interest and globally.
Once again, the basis of comparison is constituted by the other partner countries (Ethiopia and Tanzania) and by Italy, whereas the indicators analyzed and their calculation's method are enumerated in *Tab. 2.10* [41]:

EISD indicators	Name	Definition
ECO1	a) Per-capita total energy requirement	$\mathrm{TPES/population}$
	b) Per capita final consumption	$\mathrm{TFC/population}$
	c) Per capita Total Final Electricity Consumption (TFEC)	$\mathrm{TFEC/population}$
ECO2	d) Energy intensity for the total energy requirement	$\mathrm{TPES/GDP_{PPP}}$
	e) Energy intensity for the final consumption	$\mathrm{TFC/GDP_{PPP}}$
ECO13	f) Renewable energy share in the total energy requirement	$\mathrm{TPES_{RES}/TPES}$

Tab. 2.10 EISD indicators [41]

Besides to these indicators, in *Tab. 2.11* also other energy characteristics are marked:

- the absolute values of TPES, TFC and TFEC;
- Electricity Penetration (EP), defined as the ratio of the primary energy addressed to the electricity production for the TPES;
- Foreign Energy Dependence (FED), that is the share of TPES import/export on the total.

Indicator	Kenya	Ethiopia	Tanzania	Italy
TPES [toe]	20,539,000	45,494,000	22,162,000	158,800,000
TFC [toe]	13,562,000	37,048,000	19,153,000	122,645,000
TFEC [kWh]	6,760,000,000	4,644,000,000	4,441,000,000	296,742,000,000
ECO1.a) [toe/ person]	~ 0.5	~ 0.5	~ 0.5	2.7
ECO1.b) [toe/ person]	0.3	0.4	0.4	2
ECO1.c) [kWh/person]	156.5	~ 51	~ 93	~ 4,984
ECO2.d) [Wh/US$]	19	~ 35	~ 25	~ 7
ECO2.e) [Wh/US$]	12	28.5	21.4	5.35
ECO13.f)	82%	~ 95%	0.65%	14%
EP [%]	12%	~ 1.32%	6%	22%
FED [%]	21%	~ 6%	11% (only import)	84%

Tab. 2.11 Comparison between different countries

The huge gap between Italy, OECD country, and the East Africa Nations immediately emerges looking at the table for the first time: for Italy, all the values of TPES, TFC and TFEC are an order of magnitude greater than their African counterparts. In particular, among these, Kenya shows a total final electricity consumption greater than the Ethiopian and Tanzanian ones and this is evidence of both a greater electricity network's extension at national level and a higher demand from users.

Regarding the per capita TPES and the per capita TFC the results are in line for the three African countries: for example, the amount of primary energy needed by every inhabitant is six time lower than that required by an Italian citizen.

In terms of energy intensity -ECO2.d) and ECO2.e)-, it can be defined as a sort of local economic efficiency, which quantifies the ability in transforming the energy used into wealth. A high energy

intensity, such as that of Ethiopia in particular, indicates a high energy expenditure per unit of wealth produced (in terms of GDP), instead low energy intensities, for example the Italian one, are a symptom of a restrained energy consumption per unit of gross domestic product generated [42].
The share of renewable energies on the total primary energy supply is higher in Kenya and Ethiopia than in Italy, but it is due to the low variety of the other sources available for these countries. In fact, the Italian TPES in abundant measure derives also from fossil fuels and hence the contribution of RES, though significant in absolute value, is spread on a larger and more varied total.
Looking at the electricity penetration, the worst situation is registered in Ethiopia, whereas the foreign energy dependence is very high in Italy, since most of the resources are imported. It is worth of noticing that once again Kenya is the best in the East Africa region and that Tanzania shows a percentage referred to import only, because the export item is null in its energy balance.

Chapter 3 : Status of Education in Energy Engineering in Kenya

3.1 Methodology

3.1.1 Definition of the problem

As noted in Chapter 2, the energy access is certainly one of the thorniest problem that the country has to face. With this in mind, the enhancement of HEIs capacity in promoting energy programs and joint researches seems to be a good solution for developing appropriate strategies for local energy access and for achieving secure, affordable, clean and sustainable energy services. In fact, for the moment, the Technical Institutes and the Engineering Faculties do not present experiences and updated competences in the energy field.

In particular, the students' low competence in the renewable energy field turns out to be a big obstacle for the identification of the future professionals, that could contribute significantly to the national energy development. Therefore the graduates are provided with a curriculum weak and not sufficiently flexible to meet the technological changes and the different needs of the labor market [43].

3.1.2 Data collection

With the final purpose of checking the state of the art of didactical laboratories and other facilities, the teaching methodology and the quality monitoring system, the data collection took place in two distinct phases:

1. questionnaires' analysis during the period March-June 2014;
2. interviewees and meetings in the partner HEIs in August 2014.

Questionnaires analysis

This preliminary survey, addressed to students, teachers, principals and deans and labs' technicians, was conducted through questionnaires distributed to different Universities of the country. In particular, the HEIs analyzed were 12: Technical University of Mombasa, Technical University of Kenya, Dedan Kimathi University of Technology (DKUT), Masinde Muliro University of Science and Technology (MMUST), Jomo Kenyatta University of Agriculture and Technology (JKUAT), Jaramogi Oginga Odinga University of Science and Technology (JOOUST), Kenyatta University (KU), Maseno University, Moi University (MU), Mount Kenya University (MKU), Egerton and Pan Africa Christian University (PAC University). The samples' sizes are structured as reproduced in *Tab. 3.1*:

Universities	n° of teachers	n° of technicians	n° of deans	n° of students
TUK	4	6	2	41
TUM	5	2	1	15
DKUT	6	-	-	16
MMUST	5	5	1	17
JKUAT	4	1	-	24
JOOUST	4	4	1	9
KU	3	-	-	21
MASENO	4	2	1	20
MU	4	2	1	20
MKU	5	-	-	-
EGERTON	1	1	1	14
PAC Univ	2	1	-	12
Total	47	24	8	209

Tab. 3.1 Sample size

The questionnaires focus on two principal macro-areas: on the one hand the evaluation of teaching methodology and quality monitoring system, on the other hand the assessment of the current status of laboratories and other facilities, for example canteens and libraries. Specifically the data analyzed, both quantitative and qualitative, were related to different issues:

1. annual rate of maintenance of each laboratory**:** the presence of a plan of regular checks and how frequently routine maintenance is carried out are investigated;
2. budget available for each laboratory**:** it represents the allocation of a dedicated sum of money for each type of intervention in a specific lab;
3. number of workstations in ICT labs;
4. installation date of computers in ICT labs;
5. academic software: workstations are used mainly for didactical purposes and therefore the principal software are analyzed;
6. access to internet connection in ICT labs: this aspect is analyzed both for the general assessment of country's Universities and for the two partner HEIs in a more detailed way. In particular the reliability of the connection is examined through the speed tests' results (ping, download speed, upload speed). These are obtained as average of several measurements made in different working days during office hours;
7. devices for web conferences: the presence of comprehensive toolkit (microphone, headphones and webcam) for web conference calls is investigated.
8. coherence of teaching qualification with the courses and activities for which they are responsible;
9. upgrading and Training: the utility of delivering upgrading courses and delivering training about innovative didactical methodologies are studied;
10. overall students' satisfaction with the course's implementation;
11. level of students' content regarding different aspects related to teaching situation: if scholars feel to have adequate prerequisites to understand the subjects they are taught, the clarity of explanations they receive from teachers, the absence of useless repetitions in the courses they follow and the availability of well-prepared material;
12. availability of training on the job for students: these question is general about the wide or limited selection of attachments or internships.

All the given responses were transferred to Excel® and the data were summarized and gathered with the assistance of various graphical tools typical of descriptive statistics (bar graphs, pie charts, histograms). In a first step, the study was performed separately for the four types of questionnaires: questions related to similar topics were investigated together, each time eliminating from the sample the omitted replies. By doing so, a strong approximation is introduced because the sample is variable from one subject to another. Therefore, the investigation's statistical relevance may fail, as it is considered valid if the sample does not change, though the phenomena's number and the type range. Despite that, it is worth noticing that the approach followed adopts the maximum possible degree of detail for the incompleteness of the received answers. Moreover, such preliminary inspection is useful mainly to get a general and indicative sense of the current status of technical education in Kenya.

Subsequently, the evidences found from the data analysis have been further collected and manipulated, this time on the basis of the two macro-themes already mentioned, therefore not paying attention to the answers' origin questionnaires. This was done in order to summarize the outstanding results and to provide a general overview on the subject, although it is not strictly correct statistically speaking.

This first phase was completed with the writing of two reports containing the salient aspects of the questionnaires analysis.

In loco mission

The second phase of data collection took place directly in the partner Universities, TUK and TUM.

Here data were verified and integrated thanks to direct visits to the classrooms and the didactical laboratories and through numerous interviews and meetings both with the HEIs' staff and with representatives of the most important International Organizations operating in the country. The interaction with these various institutions proved to be an useful means to understand their internal dynamics with a first-hand experience and to complete the questionnaires' missing information through the organizations' primary sources.

In addition, this chance made possible the provision of the 27 baseline indicators about the country and the Institutions themselves, designated as essential data for setting and evaluating the project and for determining its periodical progresses.

Specifically, at Technical University of Kenya (Nairobi) the institutional figures, illustrated in *Tab. 3.2*, were interviewed:

Institutional figures	Characteristics of the Organization
ICT Director	-
Chief of Mechanical Department	-
Alumni Director	-
Director of Technical and Vocational Education Training (TVET) Programme	TVET is part of the Kenyan education system which provides courses and training programmes related to employment [86]
Director of University-Industry Partnership	-
Chairman of Kenya Association of Technical Training Institutions (KATTI)	Body that coordinates the activities of technical training institutions all over the country
Finance Manager	-
Academic Registrar	-
21 B.Tech. students	-

Tab. 3.2 Stakeholders interviewed in TUK

Furthermore, the following stakeholders were consulted in order to obtain more general information about the country:

- Columbia Global Centre in Nairobi, which promotes and facilitates the collaborative commitment of the University's faculties and students in order to empower the highest levels of knowledge and learning and design a hub for innovative curriculum and scholarly outreach in the region [44];
- UNIDO (United Nations Industrial Development Organization) which launches projects to promote inclusive and sustainable industrial development in the country;
- Chairman of Environmental and Bio-systems Department of School of Engineering, University of Kenya. Such interview has enabled the acquisition of information about the types of equipments available in the laboratory, thus having one more example from which arise for the laboratories' upgrading proposal;

Instead in Mombasa, in addition to the meetings with the personalities listed in *Tab. 3.3*, it was possible to visit the *Mombasa International Agricultural Show*. This event is an opportunity for various national and non national institutions and organizations to exhibit their products and projects, presenting their mission and goals directly to the public.

1) Chairman and responsible of Medical Engineering Department	8) Technicians of Electrical and Electronics Engineering labs
2) Chairman of Applied Sciences	9) 1 technician of Telecommunication Engineering's lab
3) Chairman of Computer Science and Information Technology	10) Chairman of Electrical & Electronic Engineering
4) Chairman of Mechanical Department	11) Chairman of Civil & Building Engineering
5) 2 lecturers of Energy related courses	12) Financial Officer
6) ICTs Director	13) Academic Registrar
7) 2 students of Mechanical Engineering	14) ENERGISE project coordinator

Tab. 3.3 Stakeholders interviewed in TUM

3.1.3 Identification of the most suitable solution

The choice about the best solution for the laboratories' upgrading has been made thanks to the visits at the two campuses. In fact, in this instance, it was possible to inspect the universities' main structures and to ensure the space availability for the installation of the possible new devices. Secondly, the participatory approach of interviewees and meetings has allowed to identify the main problems and to consider the opinion of all the different groups that daily attend the partner HEIs. Furthermore, such means generates some ownership in the affected people and it makes them more willing to accept and take the intervention up during the time.
Once again after that the best fitting resources have been selected, literature reviews and web researches were carried out to examine all possible solutions available on the market. These were then carefully analyzed and ranked in order of decreasing price. However, the final choice was made not only on the basis of a merely economic criterion, but also looking at the sustainability of the action. This term means to figure out if the maintenance is easily feasible, if the spare parts are smoothly available and if the technology can be replicated over time.
In consequence, the definitive resolution was made taking into account a large number of different factors, which favor not necessarily the most convenient option economically speaking.

3.2 Access inequality in Higher Education in Kenya

3.2.1 Overview of status of education in Kenya

The current structure of education in Kenya consists in the 8-4-4 system, launched in January 1985. It considers 8 years of primary school, 4 years of secondary school and a minimum of four years of university education. The Early Childhood Development and Education (ECDE) and the Technical, Industrial, Vocational and Entrepreneurship Training (TIVET) are excluded from the system as shown in *Fig. 3.1* [43]:

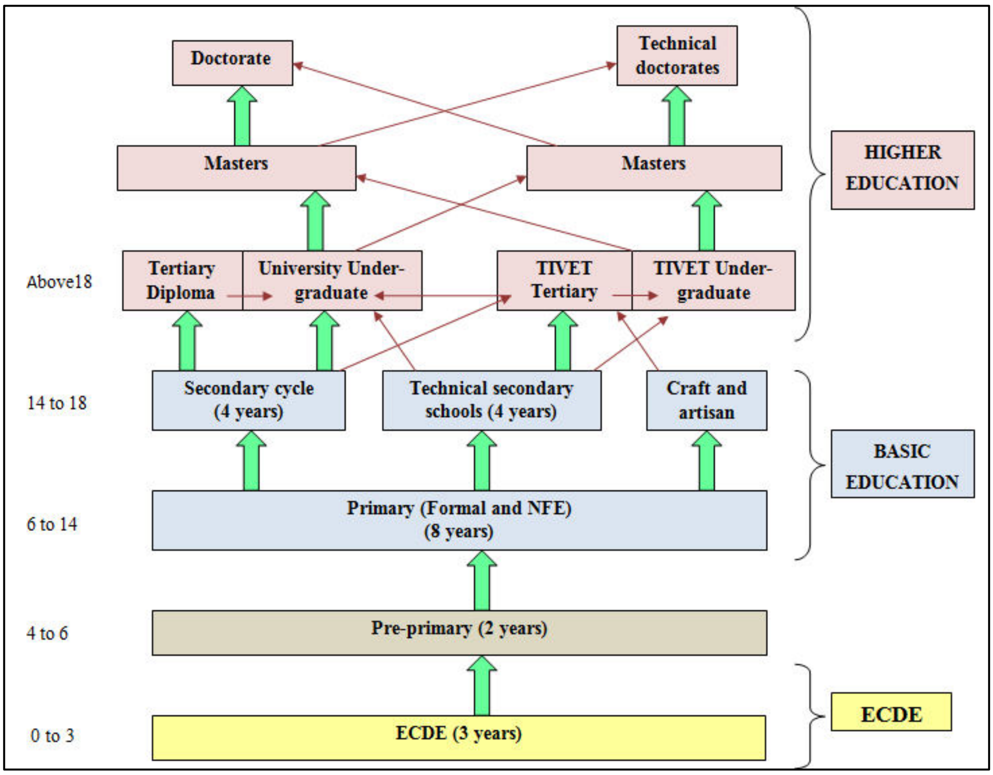

Fig. 3.1 Structure and organization of education and training [43]

Primary school is the first phase and, before it, the children can attend 3 years of ECDE and 1 or 2 years of pre-primary to obtain a basic education. The primary education is universal and free, but not compulsory, and at the end of this step, the students receive the Kenya Certificate of Primary Examination (KCPE), which determines on a merit basis the placement at secondary school.
The secondary cycle, which lasts 4 years, accepts students aged between 14 and 18 and it can meet the needs of the students who want to continue with the university education and of those who want to stop after secondary school. In this second case, the courses are supplied by the Young Polytechnics (YP), i.e. the Craft and Artisan Institutes, and they are more oriented toward vocational subjects. The Kenya Certificate of Secondary Examination (KCSE) is the final document obtained at the end of the fourth year and it establishes the students' future scholastic career [44].
Finally, the tertiary education can be divided in two main groups [45]:

1. Tertiary diplomas and Under Graduate programmes provided by Universities and Higher Education Institutions;
2. TIVET Tertiary diplomas and TIVET Under Graduate programmes, that can last 2 or 3 years and can allow students to access university with appropriate credit transfer and to follow their preferred degree courses.

Nevertheless, it is worth of noticing that TIVET is a wide system, which comprises not only National Polytechnics (TUK and TUM) and Technical Teachers Colleges, but also primary and secondary schools, like Institutes of Technology, Technical Training Institutes, Industrial Training Centers, Youth Polytechnics, Vocational Training Centers and other Commercial Colleges. Hence, the training courses offered are numerous and concerning different areas and they are strictly linked with the regular programmes offered by the 8-4-4 system.
The Ministry of Education, Science and Technology (MoEST) is responsible for almost all the sectors in education, with the exclusion of Youth Polytechnics which are governed by the Ministry of Youth Affairs and Sports. The MoEST's directives are:

- the implementation of Science Technology Innovation (STI) policies;
- research development and organization;
- Technical Education (TE) coordination.

Along with it, the Kenya Institute of Education (KIE) is a semi-autonomous governmental agency liable for educational research and development of the curricula. Finally, the Kenya National Examination Council (KNEC) deals with the implementation and evaluation of national exams at various educational levels.

3.2.2 Access in education and disparities

The national education level is illustrated in *Fig. 3.2*. It points out that one quarter of the population has no education, with rural areas' rate twice than urban areas' one. In addition, slightly more than half of the population has primary education and only the 23% has secondary. In particular, in rural areas the proportion of people with secondary education and above is only of 16% compared to the urban areas' proportion of 38% [15].

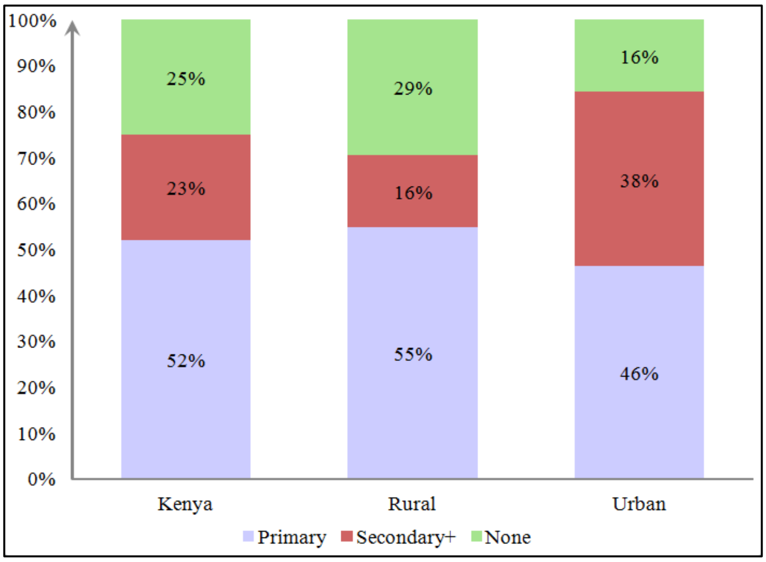

Fig. 3.2 Education level

Focusing on county level, the difference between them are relevant: people in Nairobi county have 17 times more access to secondary education or above than those living in Turkana County, as illustrated in *Fig. 3.3*.

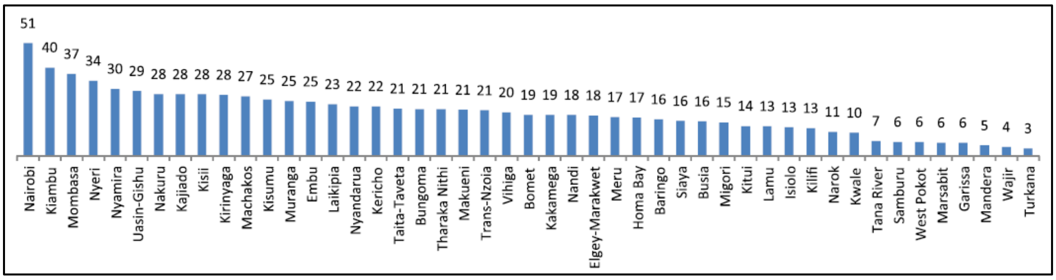

Fig. 3.3 Proportion of the population with secondary and above education at county level [14]

These deep inequalities in primary and secondary education are caused mainly by an economic issue. In fact, "education in Kenya is highly capitalistic" and its quality and quantity depends on families' willingness to pay [46]. Therefore, children from poor families are trained at public schools, which receive few resources and have difficulties in attracting and retaining qualified teachers. This takes from students' preparation, which is inferior compared to private schools' one. Subsequently, researches on the KCPE and the KCSE point out that private academies perform better than public institutes and they provide high quality education. In fact, according to World Bank's survey (2004), at the end of primary school, only 60% of children from low income households reach Standard 8, whereas the private counterparts amounts to 75%.

This limited access to qualified education affects also the university admittance, substantially based on a student's socio-economic background: for instance, at the University of Nairobi, about the 84% of scholars comes from high income areas and only the 0.5% of total female students comes from arid and semi-arid areas. Furthermore, also the university education in Kenya is discriminatory due to the development of parallel programs in public universities. These courses have been created with the aim of expanding higher education access (in fact they admit students with grade C and not B, as requested by public universities) and providing more funds to public colleges, poorly financed from the Government. Therefore essentially the parallel programs are

private because only students from wealthy families can afford the expensive fees, whereas students on regular courses are largely state-funded.
Another important issue is the gender inequality at all education levels: on the whole, female are almost twice illiterate than male and this means that 70% of illiterate people in Kenya are women. Among counties, Nairobi has a rate of literate women 14 times greater than North Eastern Province.
Especially in universities the gender gap is significant, with negative impacts on social and economic development. In fact, in some institutions, female enrollments are the half of male's ones and such aspect is very stark in technical faculties: for instance, engineering faculties have the lowest percentage of female students (10-20%) compared to business programmes (where the percentage is around 50%). *Tab. 3.4* provides some examples of engineering courses in which is evident the ratio.

Programme	Students	Female [%]	Women
Egerton *B.Sc. in Manufacturing Engineering and Technology*	40	3%	1
Egerton *M.Sc. in Engineering Systems and Management*	5	1%	0
Masinde Muliro *B.Sc. in Renewable Energy and Biofuel Technology*	30	15%	5
TUM *B.Sc. in Renewable Energy and Environmental*	28	3%	1

Tab. 3.4 Female students

Also regional disparities are relevant: urban and metropolitan areas are preferred and some prestigious institutes are based in Nairobi. These inequalities are both historical and political (ethnical) because, during the colonial era, educational infrastructures were built near the colonial administrative structures/divisions, with the ethnic groups in the more resourced and centrally located regions profiting from this opportunity.
In conclusion, education system in Kenya is highly capitalist, elitist and discriminatory: students from poor families are disadvantaged by the education system and therefore they have less job opportunities.
To face this problem and to encourage needy scholars to pursue their course of study, the Higher Education Loans Board (HELB) was implemented by the *Higher Education Loans Board Act* of 1995. HELB is the leading financier of higher education in Kenya and it provides loans, bursaries and scholarships to help students whose parents have little or no income. In particular, the priority is given to orphans, students from single parent families and others who come from poor backgrounds. In addition, to meet the rising loan demand, the Loans Recovery and Repayment Department was established in order to recover all matured loans from students after completing their studies.

3.3 Evaluation of existing equipment and available services

3.3.1 Status of laboratories and other facilities

The questionnaires about the facilities' state of the art have been filled out by 9 Universities, for a total of 95 labs.
The energy related didactical laboratories and ICT laboratories are grouped as follows:

- 22 Electrical labs;
- 27 Mechanical labs;
- 8 labs of Chemistry or Thermodynamics;
- 46 ICT labs;
- other labs such as Control Engineering Lab and Communication Engineering Lab.

It is worth of noticing that this classification points out a total number greater than 95 because some labs can be used also as ICTs.

Regarding the maintenance schedule, that is one of the main aspects to consider, the two categories "regular" and "not regular", used in *Fig. 3.4*, refer to how frequently planned maintenance is carried out. It is assumed that the second category also includes laboratories which have a technician dedicated to this task, despite not having a plan of regular checks.

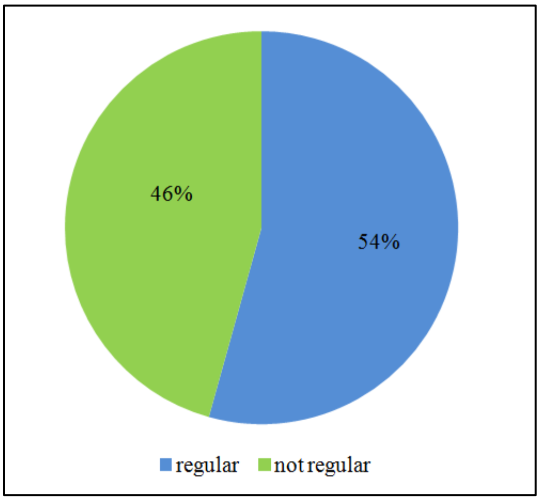

Fig. 3.4 Rate of maintenance

From *Fig. 3.4* it can be seen that the 46% does not regularly monitor laboratory conditions. However the majority (54%) reports scheduled maintenance, even if the frequency is limited to few interventions per year. In fact, in *Fig. 3.5*, the 75% belongs to "low rate" group, which reports a rate of maintenance between 1 and 4 per year. The other two groups ("middle rate" and "high rate", respectively for rates of maintenance between 5 and 9 and from 10 to 14) together constitute about 1/4 of the total.

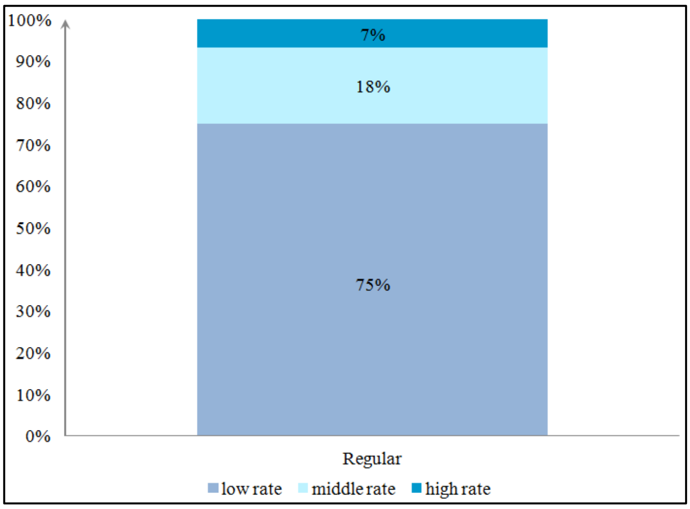

Fig. 3.5 Share of regular maintenance per year

In terms of budget available, the situation is very adverse since more than half (59%) of laboratories does not have a dedicated budget. Furthermore, there is a strong relationship between the availability of budget and the maintenance rate, as it is clearly visible in *Fig. 3.6*. The presence of more funds could allow to verify the correct operation of the facilities through a series of planned checks.

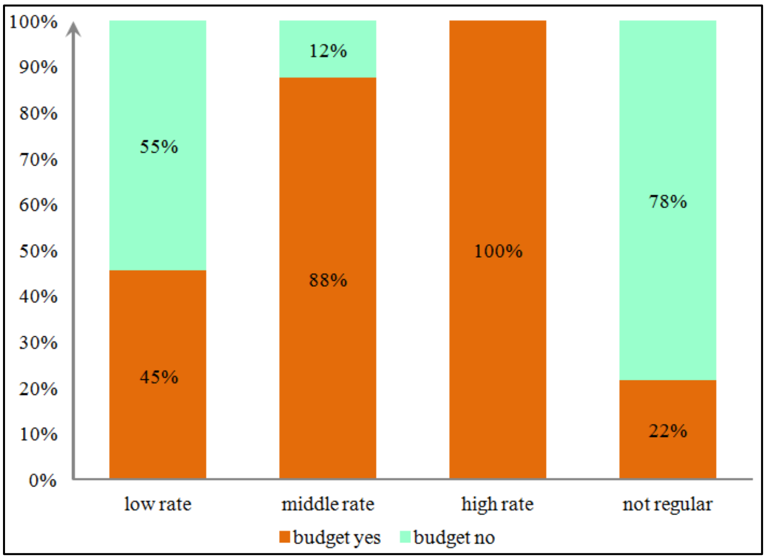

Fig. 3.6 Rate of maintenance & budget

A specific focus on ICT laboratories is required to evaluate the status of computers, the internet connection and other tools with the aim of improving internal communication, collaboration and networking among the involved HEIs through the creation of the project's e-collaborative platform. In addition, some general comments point out that ICT technologies could also support the administration procedure, facilitate research activities and enhance students' achievements.
A sample of 46 labs, consisting of 406 workstations, is considered. To assess the ICTs' capacity, the number of installed computers is evaluated and it turns out to be very low because the 74% of laboratories has less or equal to 10 workstations. Moreover, among these, 67% consist of only 1 or 2 computers (*Fig. 3.7*), underling that only a small number of people can work simultaneously within the same ICT laboratory.

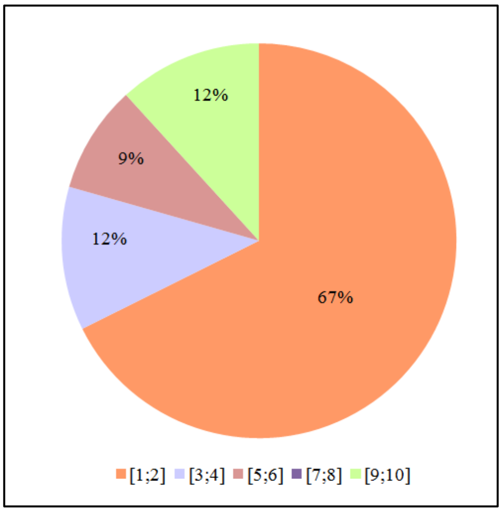

Fig. 3.7 Share of 1-10 workstations

The workstations are used mainly for didactical purposes to run software like Matlab, AutoCAD, Nexa OEM; also web-surfing and word-processing activities are enough frequent.
To understand how modern the workstations are, the installation date is significant, but it does not seem to be a problem: in fact, it emerged from questionnaires that almost all computers belong to the "new" category (89%), which involves devices installed after 2005. In particular, a larger share (38%) includes very modern computers installed between 2011 and 2013, and also the others are fairly recent (period 2008-2010).
In the matter of internet connection, the access is assured for the 70% of the laboratories examined, however the adoption of software for communication and web conferencing systems is not spread. *Fig. 3.8* reveals this issue because only the 15% of laboratories makes use of these programs.

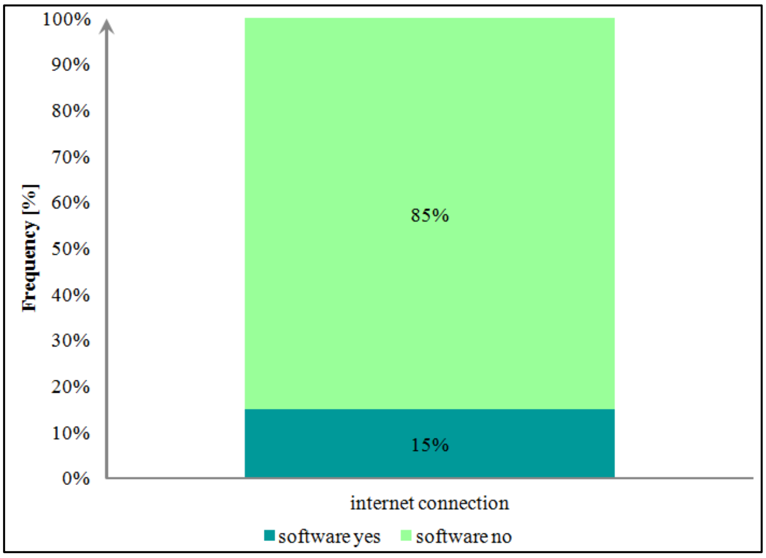

Fig. 3.8 Software use in labs with internet connection

Hence great efforts need to be undertaken in the provision of an adequate toolkit for the definition of the web platform and the figures recorded in *Tab. 3.5* corroborate these findings: only 4 faculties out of 20 report the use of some communication software as Skype, Adobe Connect or Hangout Google. Such a situation could arise not only from the shortage of comprehensive toolkit (microphone, headphones and webcam), but also and mainly by the scarcity of bandwidth and the low reliability of connection.

University	Faculty	Instruments	Skype	Adobe Connect	Hangout Google
TUM	Electrical	×	×	×	×
	Mechanical	×	✓	✓	×
Egerton		×	×	×	×
Jaramogi	Chemistry	×	×	×	×
	Engineering	×	×	×	×
	ICT	×	×	×	×
	Physics	×	×	×	×
Jkuat		×	×	×	×
Maseno	Chemistry	×	×	×	×
	Biology	×	×	×	×
Masinde Muliro	Mechanical	×	×	×	×
MOI	Electrical	×	×	×	×
	Mechanical	×	×	×	✓
Pan		×	×	×	×
TUK	1	×	×	×	×
	2	×	×	×	✓
	3	✓	×	×	✓
	4	×	×	×	×
	5	×	×	×	×
	6	×	×	×	×

Tab. 3.5 Instruments and software for communication

In conclusion, all the category consulted, that is students, principals and teachers, do not evaluate in a positive manner the adequacy of laboratories and other facilities such as classrooms, libraries and canteens. Specifically, principals express the urgency of improving the libraries' status, whereas teachers highlight that infrastructures need to be reengineered, including the classrooms. Finally students complain about the fact that technicians are not properly trained.

3.3.2 Teaching methodology and quality monitoring system

Students

The total number of students interviewed is 209. However, in some parts of the analysis the considered questionnaires are less, since not all have been properly compiled.

On a whole students, which are subdivided among those attending programmes related to Energy Engineering (39 students) and "Others" (148 students), are satisfied with the courses' implementation: in fact, the positive judgements amount to 69% and 78% respectively.

However, more in detail, this promising scenario is partly eclipsed by the opinions of 203 students regarding some issues connected with teaching, such as if they feel to have adequate prerequisites to understand the subjects they are taught, the clarity of explanations they receive from teachers, the absence of useless repetitions in the courses they follow and the availability of well-prepared material (*Fig. 3.9*).

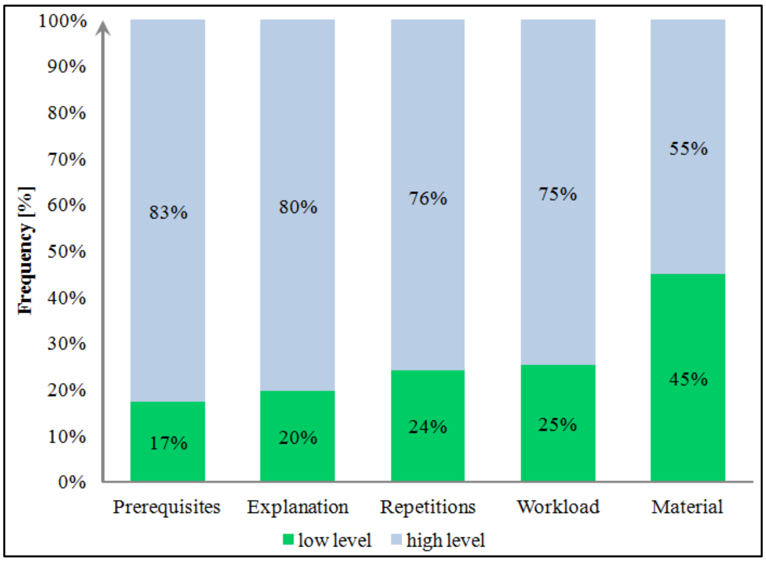

Fig. 3.9 Teaching situation

In general, there is a high level of satisfaction on the matter of prerequisites, explanations, absence of useless repetitions and workload, but students complain about the lack of useful training materials.

Instead, the level of satisfaction with the teaching staff, depicted in *Fig. 3.10*, is evaluated considering different aspects: lecturers' ability to stimulate the learning process, teaching staff's availability for further explanations if required, compliance with the scheduled timetable and effectiveness of preparation for included activities.

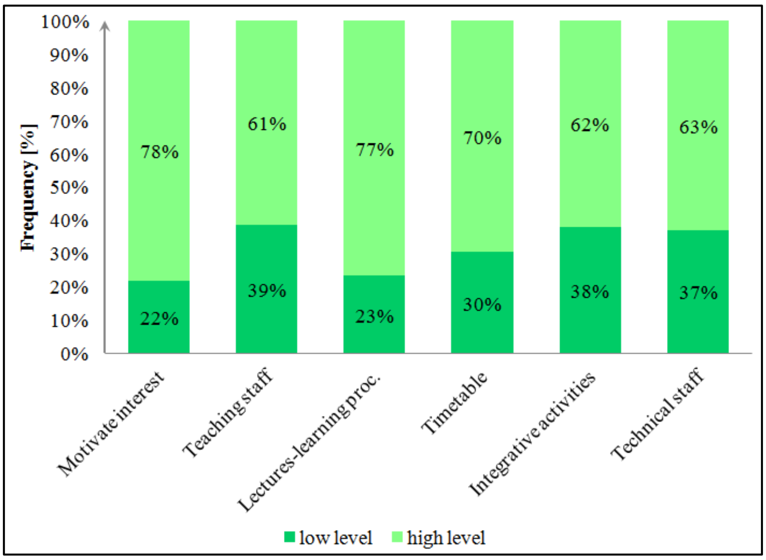

Fig. 3.10 Lecturers' situation

Students report that professors are quite good at motivating interest in the subjects (78%), but criticize the lack of dedication of both teaching staff (39%) and technical staff (37%). Finally, integrative activities are judged not always good, with a percentage of "low level" equal to 38%.

Ultimately, also the limited selection of available trainings on the job is an obstacle that more than half of students denounce.

Teachers

The perspective of the 47 teachers interviewed is slightly different from the students'one, as *Fig. 3.11* indicates. The feedback is positive about prerequisites students already have, but on the other hand, the practice of irrelevant repetitions is reported by 51% of interviewees, in contrast with students'opinion. In addition, coordination between various courses is needed not only to avoid unecessary repetitions, but also to improve teaching. Therefore, even if the global level of teaching is quite good, some aspects still need to be improved.

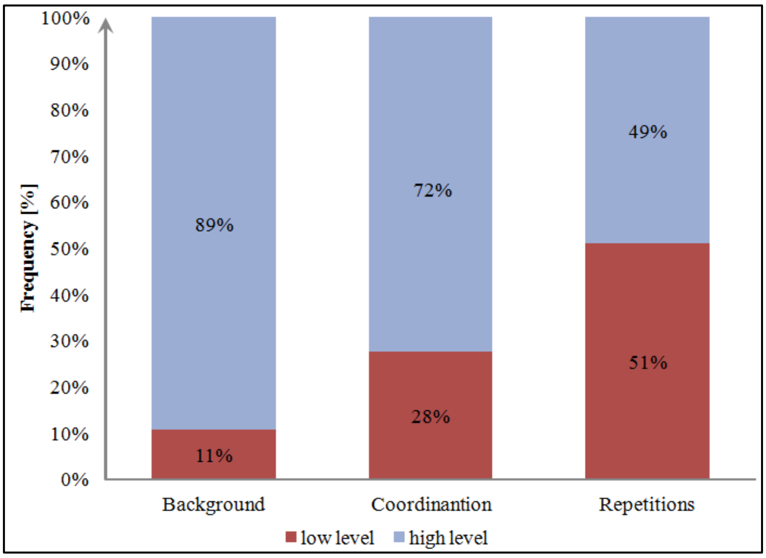

Fig. 3.11 Overall view on programme structure

On the other hand, almost all teachers, regardless of their membership Institute, strongly assert the need of delivering supplementary upgrading courses and training innovative teaching methodologies. Moreover, this is in line with the project's second result, which plans the organization of intensive courses for Faculty staff competence upgrading in innovative technologies and modern renewable energies.

In the wake of such issue, *Fig. 3.12* focuses on subjects taught (yellow histograms refer to the number of lecturers teaching the specific subject reported on x-axis) and number of lecturers who have expertise in each field of study (purple histograms). Green histograms investigate the teachers' suggestions for future trainings.

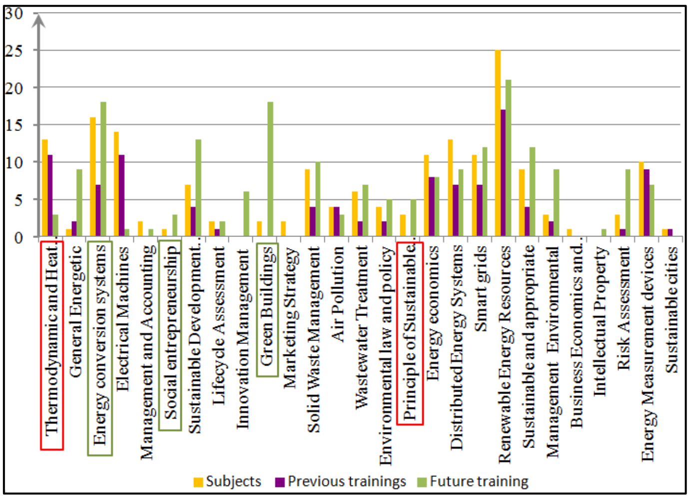

Fig. 3.12 Subjects taught-previous trainings-subjects for future training

As shown in *Fig. 3.12*, “Renewable Energy Resources” is the most diffused among the subjects already taught related to energy, followed by other topics, such as “Energy Conversion Systems” and “Distributed Energy Systems”. Nonetheless, for these matters lecturers themselves state they do not yet have a good preparation because they have not attended previous specific training courses. Indeed the requests for additional future training from lecturers include subjects in the same field. Moreover some professors would like to expand their area of study, asking for new courses mainly in “Green Buildings”, “Sustainable Development and Climate” and “Smart Grids”. However, according to the comments collected, the most influential barrier, which prevents from including these topics in the Universities’ curricula, is the lack of equipments and materials.

Principals and Deans

The principals’ sample consists of only 8 interviewees and consequently this small size cannot be considered sufficient to glean meaningful information. In any case, the investigation of deans’ opinions allows to find similarities and differences compared with the students and teachers’ judgements. For instance, in contrast with what the lecturers have reported, the Universities’ administrators confirm the coherence of teachers’ educational qualification with the courses and activities for which they are responsible.

In addition, the principals have the qualification to indicate the expectation in terms of achievements and abilities that students should have reached at the end of each cycle of studies. Four aspects concerning students’ education were examined:

- ***Application of knowledge and understanding***: students can apply their knowledge and understanding in a manner that indicates a professional approach to their work or vocation, and have competences in devising and sustaining arguments and in solving problems within their field of study;
- ***Making judgments***: students have the ability to gather and interpret relevant data (usually within their field of study) to inform judgments that include reflection on relevant social, scientific or ethical issues;
- ***Communication skills***: students can communicate information, ideas, problems and solutions to both specialist and non-specialist audiences;
- ***Learning skills***: students have developed the learning skills necessary for them to continue to undertake further study with a high degree of autonomy.

The findings, shown in *Fig. 3.13*, are encouraging on the whole, in particular regarding student’s learning skills and their ability to make judgments. On the other hand communication skills are the least developed (30% reports “so&so”) and consequently students are not accustomed to the communication of information, ideas, problems and solutions to both specialist and non-specialist audiences. Therefore, also this analysis points out that some improvements are needed, especially in the teaching methodologies.

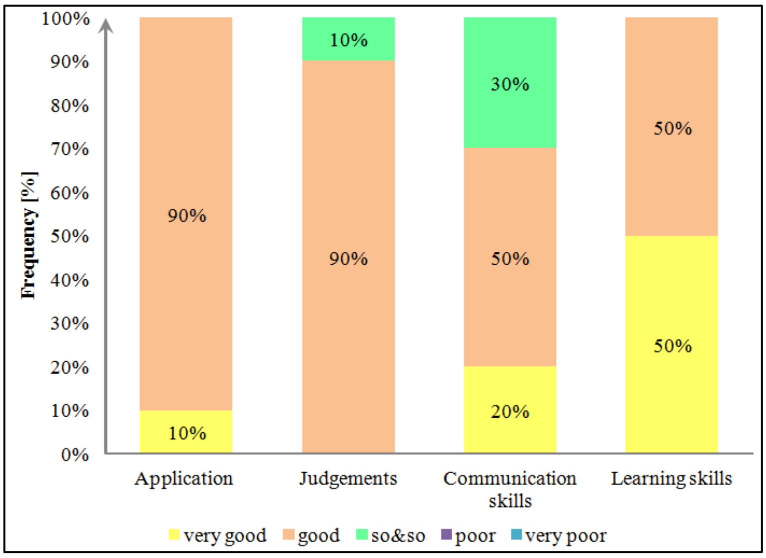

Fig. 3.13 Achievements

Chapter 4 : Assessment of Energy Engineering in TUK and TUM

4.1 Focus on TUK

4.1.1. TUK profile

The Kenya Polytechnic (*Fig. 4.1*) was founded in 1961 with the principal objective to train largely in the technical fields. In 2005 the Government of Kenya established *the Sessional Paper No.1* "*A Policy Framework for Education, Training, and Research*" in order to allow the National Polytechnics to provide degree programmes in their areas of expertise. Immediately after the launch of this official document, the Ministry of Education initiated the process of conversion from Kenya Polytechnic to a degree awarding institution called Kenya Polytechnic University College (KPUC).

Finally, in 2012, through the elevation of KPUC to full university status thanks to the *Universities Act*, the Technical University of Kenya (TUK) was established.

Fig. 4.1 Administration Block

TUK currently has a population of 12,115 students, of which 5,227 are degree students while 6,888 are diploma and certificate students.

The Institute offers a wide range of Bachelor of Science courses within three main Faculties:

1. Faculty of Social Sciences and Technology;
2. Faculty of Applied Sciences and Technology;
3. Faculty of Engineering Sciences and Technology.

The latter comprises some undergraduate programmes related to the energy field, but a programme in Energy Engineering is absent. In particular Electrical and Electronic Engineering, Infrastructure and Resource Engineering, Mechanical and Process Engineering are offered.

More specifically, some courses focusing on energy related topics are "Introduction to Energy Science", "Energy Storage and Distribution", "Combustion Techniques", "Energy and Environment", "Biomass Combustion System", "Solar Energy Technology", "Biomass Technology", "Wind Energy Technology", "Geothermal Energy", "Energy Conservation and Management", "Hydro Power Techniques". In addition, the University provides also TIVET Programmes.

4.1.2. Laboratories related to energy

1. Thermodynamics Lab presents a British steam plant dated back to 1960, composed by a boiler, a condenser and a turbine. This equipment, nevertheless its old age, is reliable with failure's rates every one or two years. Hence the maintenance is performed only when it is necessary. This laboratory holds also a machine for engine testing. For example, Morse test is conducted to determine the power developed in each cylinder in a multi-cylinder engine.
2. Fluid Dynamics Lab includes a venturimeter, channels in which it is possible to study fluids' flow (*Fig. 4.2*), pipe line to experiment losses (*Fig. 4.3*) and Pelton and Francis turbines. Also these tools derive from British colonization era and they are repaired only when the need arises.

Fig. 4.3 Pipe Line Losses Experiment

Fig. 4.2 Flow in Channels

3. Machines Workshop is composed by conventional and advanced mechanical machines. The latest are all new and came from China, through mutual cooperation and partnership.
   An example of this collaboration is the Africa Tech Challenge, a contest organized by the Ministry of Education, Science and Technology of Kenya and sponsored by Kenya Association of Technical Training Institutes, AVIC INTL of China and China House. The goal of this contest is to enable participants gain technical skills to encourage entrepreneurship and facilitate self-employment among the youth in Kenya. It also presents a great opportunity for students to test their skills on something that is directly related to their field of study.
   In particular the laboratory is equipped with the machines listed in *Tab. 4.1*:

Machine	Number
Conventional Shaping machines	10
Lathe machines	40 (20 conventional and 20 advanced)
Cylindrical grinders	7
Surface grinders	3
Milling machines	31 (10 conventional and 21 advanced with numerical control)
Air compressor	1

Tab. 4.1 Equipment of machines workshop

An innovative instrument, obtained by the Chinese partnership, is the 3D printer. It is still under testing and its operation is composed by three phases, that take place in three different rooms:

- Reverse engineering: it is a common process, used for product design, which converts a physical 3D model into a digital computer solid model (*Fig. 4.4* and *Fig. 4.5*);

Fig. 4.4 Reverse Engineering

Fig. 4.5 Reverse Engineering

- Rapid prototyping machine converts 3D data into solid physical models of components and products through a number of rapid techniques without the need for special-purpose tooling;
- Post treatment allows to get the right finish for the 3D printed object.

4. Bench and Metrology Workshops belong to the same mechanical area. Both these laboratories are equipped with few workstations (less than 10) and hence for practical lessons students are gathered in smaller groups. *Fig. 4.6* shows an example of didactical machines included in Metrology Workshop:

Fig. 4.6 Metrology workshop

5. Electrical Labs are constituted by Microprocessors Lab, Analogue Telecommunication Lab and Digital Telecommunication Lab. All labs contain new Chinese equipment useful to conduct electrical measurements. There are also several devices connected to personal computers to perform electronic tests and panels to study circuits, as represented in *Fig. 4.7*.

Fig. 4.7 Microprocessors Lab

4.1.3. ICT Laboratories

Technical University of Kenya is endowed with 7 ICT labs taking into account that this number includes also the laboratories listed above that contain computers used for educational purposes. *Fig. 4.8* depicts an ICT lab: it is composed by 60 computers, installed thanks to a Chinese partnership that replaced old computers with new ones, updated with the latest software. Workstations are used mainly for academic purposes and for this reason they are endowed with didactical software such as Adobe, CS4, ArcGIS, Arcview, AutoCAD.

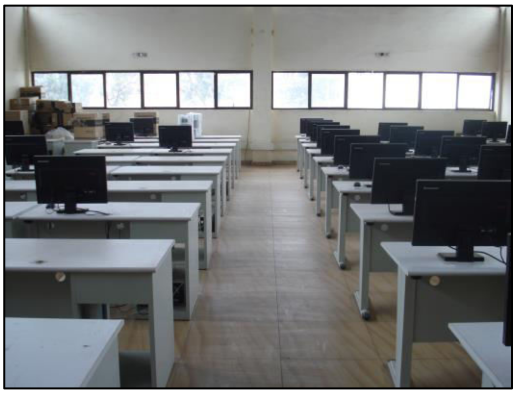

Fig. 4.8 ICT

In the perspective of the project's implementation of an e-learning platform to enhance the HIEs networking, it is worth of noticing that one lab is used as conference room and hence it contains also a projector and two main screens (*Fig. 4.9*):

Fig. 4.9 Conference room (projector and two main screens)

Finally, also administration and financial offices avail themselves of computers equipped with some specific programs. In particular, the management system adopted is TUSOFT, which allows to perform different activities such as user management, student recruitment, student admission and registration, staff medical claims and project management.
Regarding internet connection, the wi-fi is present in almost all the campus but improvements are needed, as illustrated in *Tab. 4.2***Errore. L'origine riferimento non è stata trovata.**:

Ping test [ms]	Download speed [Mbps]	Upload speed [Mbps]
89	0.66	1.27

Tab. 4.2 Speed test for internet connectivity

The values reported are obtained as average of several measurements made in different working days during office hours. Download speed is the most critical parameter since a reasonable value should be around 3-4 Mbps to have a good internet connection. Furthermore, the ping, i.e. the round-trip time for messages sent from the originating host to a destination computer, is too high (an acceptable value is around 30-60 ms).
Ultimately internet connectivity, both wired and wi-fi, needs improvements due to the small bandwidth equal to 56 Mbps.

4.1.4. Innovation and linkages with industries

A proper attitude towards innovation and research is an important aspect that should be trained inside the University and be applied in the labour market in order to accelerate the development of industries. However the technical content of current programmes does not always match the specialized technical requisites of industries.
For instance, regarding renewable energies, an in-depth acquisition of knowledge and appropriate skills are necessary to stimulate innovation, although students are aware of the importance of sustainable energy sources. This is demonstrated by some projects developed by scholars' teams, such as the solar powered seat illustrated in *Fig. 4.10*.

Fig. 4.10 Solar Powered Seat Project

Moreover, an important initiative related to innovation is the already mentioned *Africa Tech Challenge*, the nationwide competition designed for the technical training institutions' students to cultivate the spirit of entrepreneurship.

Concerning linkages with universities, the Institution has a Partnership and Linkages Division that connects students with industries in order to provide them two external attachments of about 3 months. After graduation, there is the further possibility to carry out a 6 months intership, in which alumni can put in practice the theorethical notions learned during their course of studies. Another example of collaboration with industries is represented by the construction of an air-conditioning system, installed in a conference room and supported by agreements with Samsung.
Furthermore, TUK arranges meetings between students and firms'representatives and these events are an opportunity both for scholars and for industries. In fact, the former can understand the most required job profiles, whereas the latter can promote themselves. Besides these initiatives, in TUK there is also the *Alumni Affairs Office* which manages a web platform useful to provide the alumni with networking opportunities to further their carrier.

4.2 Focus on TUM

4.2.1. TUM profile

The origin of TUM can be traced back to the late 1940s, but the Mombasa Polytechnic University College (MPUC) was realized on 23rd August 2007, through a *Legal Notice No. 160*, converting the Polytechnic into a University College.
The University College (*Fig. 4.11*), is located in the Tudor area, but it has opened two strategic satellite campuses in Kwale and Lamu County in line with government policy to increase access to higher Education. These campuses are dedicated for deserving students to access TUM diploma and certificate programmes without necessarily attending the main structure.

Fig. 4.11 Technical University of Mombasa

The University College has three main Faculties:
- Faculty of Applied and Health Science;
- Faculty of Business and Social Studies;
- Faculty of Engineering and Technology.

The three Faculties have developed and rolled out new degree programs in the three thematic areas with a total of 86 programs running from Masters to certificate level.
Also TUM does not provide an Energy Engineering Programme, but a B.Sc. in Renewable Energy and Environmental Physics is carried out by the Department of Applied Physics. It is an undergraduate programme of 4 years followed by 28 students, with a female-male balance of 1:27. It is a new course started one year ago and it includes a mandatory industrial attachment of three

months during the fourth year and a project lasting one semester. In addition, alongside the other courses, also TVET programmes are held.
The student population currently is equal to 7,391, composed of 1,916 females and 5,475 males, spread across all the programmes.
Furthermore, the University College boasts of 210 teaching staff and 437 administrative staff, giving a total of 647 employees.

4.2.2. Laboratories related to energy

Electrical and Electronics Engineering Department

In this Department 9 laboratories are located, almost all equipped with Italian "Elettronica Veneta" machines of 2006, obtained as a grant from the Italian Development Cooperation.

1. Data Communication and Networking Lab aims at training second year students in Integrative Services and Digital Networking field. In particular, scholars learn to be familiar with fiber optics panel (*Fig. 4.12***Errore. L'origine riferimento non è stata trovata.**) and with lan&internet connection (*Fig. 4.13*). The workstations can accommodate 40 students and maintenance is realized by two technicians.

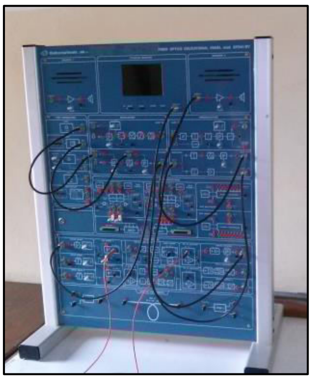

Fig. 4.12 Fiber Optics Educational

Fig. 4.13 Lan&Internet Connection Panel

2. Computer Lab is designed to teach basic application programs and software to students with low skills in computer field. In addition computers are also used to program in Java and Visual Basic and to run electrical software like TINA (simulation of electronic circuits). The workstations were installed 8 years ago, therefore there is the necessity to replace them with 30 modern ones, financed by Government's funds.
3. *Microprocessors Lab* in which the main activities conducted are related to both low level and high level programming codes. Students are encouraged to improve their skills on something directly related to their field of studies through didactical projects.
4. *Electronics Lab* gives to students the opportunity to practice with analogue and digital machines. In general classrooms consist of 60 students which are grouped in smaller team during practical lessons. The most critical problem is related to the lack of enough tools, which are mainly Electric Device Panels, Optoelectronic Devices and Digital Electronic Panels (*Fig. 4.14*) and Analogue Switch Panels.

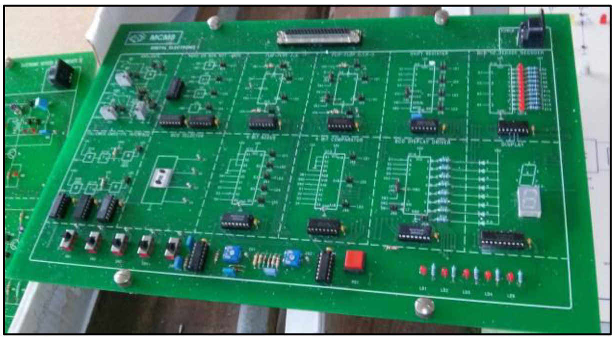

Fig. 4.14 Digital Electronic Panel

5. *Power and Machines Lab* is dedicated to 20 first year's students to measure engine's performances and it is arranged with several practical machines for second and third year's students. The specific devices present in the workshop are: an induction motor braking by plugging/cascade, A.C. squirrel cage induction motor-A.C. salient pole alternator self excited, A.C. commutator motor Schrage-Eddy current brake, A.C. universal teaching-D.C. generator, A.C. synchronous Machine-D.C. compound, some small scale motors (models) and oscilloscopes. Finally, a central unit fitted of A.C.-D.C. converter supplies necessary power for all motors.
6. *Light Current Workshop* covers 2 semesters: during the first six months, students carry out a project on tools using benches (*Fig. 4.16*) and mechanical laboratories. Later they study how to install light and sockets in houses (*Fig. 4.15*). Every practical lessons is conducted for 40 students that are attending the third years of study.

Fig. 4.15 Light Current Workshop

Fig. 4.16 Bench Laboratory

7. *Analogue and Digital Telecommunication Lab*: telecommunication is a important section within electrical field, related to the possibility of moving information from one point to others. In this laboratory, during one session, the 15-20 students can understand how single modules and systems (group of modules) work. For example, transmission lines and antennas, PCM switching & transmission system and AM/FM synthesized receiver (radio) are studied.
8. *Control & Instrumentation Lab* is for practical lessons in automation and control. It contains pneumatic and electro pneumatic process simulator (*Fig. 4.17*) to obtain measurements of temperature, pressure, level and speed. Students of 2^{nd}-3^{rd} year of studies are admitted in this laboratory, which presents 30 workstations in total. The maintenance is carried out by a dedicated technician and a specific budget is allocated for this purpose. The software used is Automation Studio, but it does not run on updated operating systems (Windows 7 and XP).

Fig. 4.17 Pneumatic process Simulator

Mechanical Department

The department includes 6 workshops, all with a scheduled maintenance 6 times per year, of which two are performed by Kenya Bureau of Standard. This is one of the leading certification bodies in the East and Central African Region and it provides systematic actions to calibrate machines and to assure their correct functioning.

1. *Machine Shop 1* contains conventional machineries from England and Germany installed 20 years ago. Specifically *Tab. 4.3* lists all the machines present:

Machines	Number
Lathe machines	12
Milling machines (horizontal or vertical)	5
Drilling machines	3
Shaping machines	6

Tab. 4.3 Equipment in Machine Shop 1

   Using these machines, first year students learn how to operate, maintain and repair them. Each workstation can be used simultaneously by 4 students and the maximum number of scholars allowed is about 30-40. Two technicians are responsible for maintenance and during practical lessons the presence of one of them plus a lecturer is necessary.

2. *Machine Shop 2* (*Fig. 4.18*) is composed by the same machines, but they operate thanks to numeric control, which is programmed in M-code and G-code and ensures the machineries' functioning. Students do practical lessons in this laboratory at the end of their studies and, due to the limited space, they are admitted in turn of maximum 20. Machines' set-up is provided by a local company that assemble different components.

Fig. 4.18 Machine Shop 2

3. *Material Testing Lab* includes 2 machines to test the strength of materials, components and structures and a surface grinder to obtain a desired surface for a functional purpose. All the devices were installed 20-30 years ago during the British colonization era (1960).
4. In *Fabrication and Welding Lab* students manufacture equipment useful in many fields: for example, with the help of technicians and lecturers, students built a manual water pump, a manual machine to cut crops (*Fig. 4.19*) and a mechanized machine to break coconuts.

Fig. 4.19 Manual machine to cut crops

5. *Heat treatment Lab (thermodynamics)* is used to conduct thermodynamics experiments, even if the pressure vessel is obsolete with an efficiency of only 50%. It should be replaced by the end of the year thanks to Government's funds.
6. *Fluid Lab* is equipped with machines, itemized in *Tab. 4.4*, useful to perform fluid dynamics and hydraulic experiments:

Module for heat transfer	Venturimeter
Refrigeration cycle demonstration unit	Machine for testing buoyancy with different type of fluids
Channel for fluids' flow analysis	Small scale turbine
Convergent-divergent tube for measurements of air pressure and speed	Valve for pressure's measurements

Tab. 4.4 Equipment of Fluid Lab

All these tools need to be replaced due to their obsolescence: in fact, they dated back to British colonization era (1960), except for the two channels for fluids that are manufactured locally.

Medical Engineering Department

The four laboratories of the Department (Piped Services Lab, Electronics Lab, Medical Lab and Dental Lab) are equipped with medical systems related to diagnosis, treatment and monitoring of patients and the majority of these machines derives from near hospitals. The maintenance is well planned, although it is not strictly necessary because the machineries are split in their main components to facilitate the learning process for students.
Focusing specifically on Electronics Lab, it is composed of German machines dated back to 1990 and it is equipped with different devices, for example analogue or digital electronic boxes for demonstration purposes and analogue and digital oscilloscopes.
During practical lessons students are gathered in small groups in order to have 20 scholars in each session, whereas the maintenance is performed by lecturer.

4.2.3. ICT Laboratories

Each ICT laboratory contains around 25 computers for a total of 300 computers for students, all with Windows 7, XP or Linux as operating system. Workstations are mainly endowed with some software like Java, C++, AutoCAD, Visual Basic, Matlab, Fortran, Microsoft Office.
The maintenance is performed when the need arises by technicians, one for each lab and, for this reason, the allocation of a dedicated budget is envisaged. However, the budget covers not only the maintenance's costs, but it is also useful to buy new laptops and tools (keyboards and mouse mainly). A good initiative arranged by the Institution is the Digital Room (80-100 workstations), shown in *Fig. 4.20*. Here students which cannot afford to buy a personal computer, have the opportunity to study and practice with didactical software.

Fig. 4.20 Digital Center

Concerning internet connection, it is supplied by Kenya Education Network (KENET), which provides cost-effective internet connectivity to its member institutions. Technical University of Mombasa is one of the six points of presence (POP) and it hosts 3 access points to enable Wireless Infrastructure.
The ping test (*Tab. 4.5*), carried out in a similar way to the TUK's one, reveal that the ping value is too high.

Ping test [ms]	Download speed [Mbps]	Upload speed [Mbps]
95.5	4.85	2.60

Tab. 4.5 Speed test for internet connectivity

As inferred by *Tab. 4.5*, the download speed is not very bad, but improvements are still needed to promote the ICT Directorate's project about the settlement of an e-learning platform using the open source software Moodle. Also small bandwidth, equal to 40 Mbps, must be enhanced in order to accommodate traffic.
In the matter of administration procedure, it is managed with DATA PACK, a data base management system. On the other hand, an innovative ANDROID application is under implementation.

4.2.4. Innovation and linkages with industries
Technical University of Mombasa participates in numerous industrial fairs, exhibitions or academic contests. During these events, like for example, the Mombasa International Show or the Kenya Region Robotics/TIVET Fair, students can show their projects and build networks with sector's companies. Some interesting projects exposed in these occasions consist for example of an automatic solar powered street lighting system or a torque controller for three phase induction motor, as *Fig. 4.21* and *Fig. 4.22* illustrate.

Fig. 4.21 Automatic Solar Powered Street Lighting System

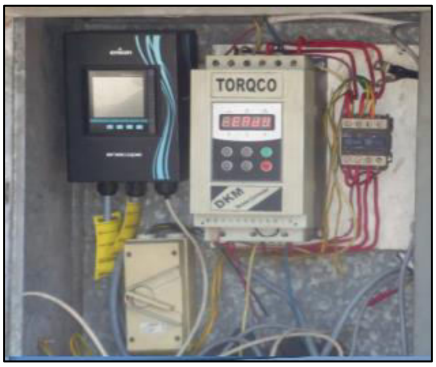

Fig. 4.22 Torque controller connected to a chiller

Moreover in the campus is still under construction a modern building, supported by Government's funds. The structure will contain new laboratories and the Marine Engineering Department to face the growing number of enrollments. For this purpose, the Government allocated KSh6,000,000 to build an innovative Marine Engine Simulator Room, unique exemplar in East Africa Region. This laboratory permits to simulate faults which may occur during the navigation and it is a great opportunity for students to understand which component is damaged and which intervention is necessary to solve the problem. It is composed by three simulating consoles (Electrical Power Plant Console, Main Engine Propulsion Plant Console and Auxiliary Systems & Machinery Console) and a computerize control unit which starts the breakdowns. The simulation program used by computers is supplied by the French TRANSAS Group, in particular by its branch in Dubai, which is also involved in the maintenance's activity.

In conclusion, regarding relationships with industries, the University provides linkages to enhance capacity building in the technical area. Indeed, external attachments are mandatory during the second and fourth years of studies, whereas the academic attachment inside the institution is optional.

Chapter 5 : Laboratories' upgrading

5.1 Focus on TUK

5.1.1. Stakeholders analysis

From the numerous interviews, it emerges that a critical problem, which affects not only the University, but it is extended to whole country and the capital Nairobi in particular, is the abundance of waste and the inability of urban authorities to struggle with this issue.

In fact, with a population of 3.363 million people, the city has a generation rate of garbage equal to 3,121 tons per day and this means that the Total Daily Amount of Solid Waste per capita ($TDASW_{per\text{-}capita}$) is about 0.9 kg/person · day. Hence, the Kenyan capital is experiencing waste management problems, as the increase of population and the consequent rise of urban garbage are not followed by a parallel increment in the urban authorities' initiatives to deal with this issue.

As depicted in *Fig. 5.1* [47], more than half (51%) of rubbish composition consists of organic waste (that is 1,592 tons/day), whereas paper and plastic occupy the second and the third place respectively (18% and 16%).

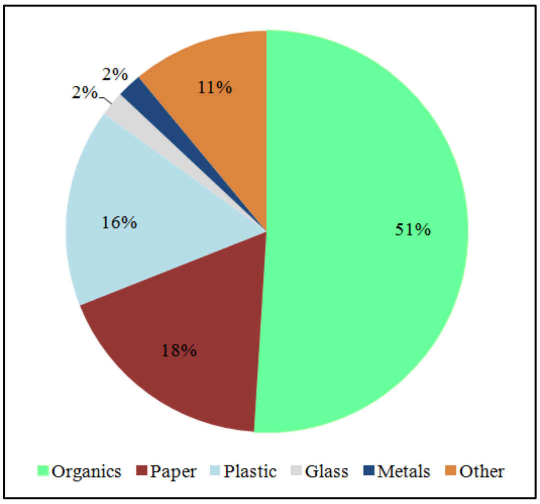

Fig. 5.1 Waste composition [47]

According to literature reviews, the contribution of domestic waste amounts to 2,122 tons/day, i.e. 68% of the total, instead the rest (32%, namely 999 tons/day) is due to non-domestic garbage. The term refers to waste produced by supermarkets and various shops, offices, institutions such as schools, universities, religious venues and non-hazardous waste from health centers. *Tab. 5.1*, constructed following the Technical Document accompanying the Solid Waste Management Plan 2010 [47], summarizes the non-domestic waste characterization by sources.

	Composition [%]		
Waste type	**Retail & Shops**	**Offices & Work place**	**Institutions (Education, Religious and non-hazardous healthcare)**
Organic	43.6	25.9	48.9
Paper	22.0	42.1	19.8
Plastics	19.8	17.1	10.9
Glass	2.3	0.0	3.7
Metal	2.1	0.8	2.7
Other	10.2	14.0	14.0

Tab. 5.1 Non domestic waste characterization by sources

Tab. 5.1 highlights that in Institutions the organic fraction is the most relevant waste type with a percentage of 48.9% and this prevalence is evident more specifically also at educational level. For example, Technical Training Institutions (TTIs), which include National Polytechnics, Institutes of Technology and Technical Training Institutes, "are major sources of waste due to their multiple status of being training, commercial and domestic entities" [48]. For this reason, the per capita amount of organic solid waste (Daily Amount of Organic Waste) is calculated referring to the share of organic waste on the total garbage's generation rate (51%):

$$DAOW_{\text{per-capita}} = TDASW_{\text{per-capita}} \cdot 0.51 = 0.9 \left[\frac{kg}{person \cdot day}\right] \cdot 0.51 \cdot 1{,}000 \left[\frac{g}{kg}\right] \cong \cong 460\ g/person \cdot day \quad (5.1)$$

The basic hypothesis is that any person, member of public Institution (such as those mentioned in **Errore. L'origine riferimento non è stata trovata.**), produces this quantity of waste: such assumption is simplifying and not always verified, but it is useful to obtain a rough estimate.
The importance of finding out the organic fraction consumed by each person attending a public Institution, as may be TUK, is related to the possibility of establishing a small scale bio-digester in the campus in order to deal with the problem of waste management.

5.1.2. Assessment of the appropriate technologies

Relevance of the solution

At Technical University of Kenya, as it emerged from the stakeholders' analysis, the installation of an anaerobic digestion system could entail a number of both economic and environmental benefits. Several reasons ensure that the preference relapses on this technology:

1. biogas, obtained by the anaerobic bio-degradation process, is a proven and widespread source of energy [49] and it is coming to the fore in recent years due to the growing concerns about greenhouse gas emissions and the fossil fuels' high price. The interest in this technology is corroborated by the interviews conducted during the in loco mission: in fact all the respondents have revealed a great enthusiasm for such settlement because it not only could meet the campus energy needs (light and electricity in particular), but it could also have interesting implications in the educational field. Specifically, TUK could be able to implement new lines of research in the field of biogas and its numerous applications. In addition, the University could organize courses and practical lessons, that could involve students from different degree programmes: for instance, Chemical engineering students could analyze the biomass' composition and they could test innovative mix of feedstock. On the another hand, Mechanical engineers could sharpen their

qualification about plants for the combined production of heat and electricity and they could realize original biogas burners;

2. a small scale digester seems to be a good solution because it allows the transformation of organic waste in high quality fertilizer. This possibility should not be overlooked in a city like Nairobi where the 30% of the slums inhabitants relies on urban agriculture to survive. Urban Agriculture Network defines urban agriculture as an "industry that produces, processes and markets food […] on many types of privately and publicly held land and water bodies" [94] and this means represents the only source of sustenance and nutrition for the poor citizens. In fact, according to the background analysis for the preparation of an Oxfam GB Urban Programme "*Urban Poverty and Vulnerability in Kenya*", in the country there are over 4 million urban food poor and a third of these are Nairobi's citizens [50]. Furthermore, the 60% of Kenyan capital's inhabitants, i.e. approximately 2 million people, lives in slums below the poverty line and without the possibility to afford the purchase of food with the right calories for the recommended daily nutritional requirements [51].
   For these reasons, the installation of a bio-digester in the campus could enable the creation of projects for the sustainable development of durable and intensive forms of urban agriculture. In more detail, the output bio-slurry produced at the end of the digestion process could be commercialized by the University in forms easily accessible even to the slums dwellers. In this way, they could cultivate their plots of land and they could promote their own sustenance, reducing in the same time the food security problem;
3. another valid explanation lies in the national diffusion of traditional methods for cooking. In effect, all Kenyan rural households count on firewood and the 84% of urban families and the 34% of rural ones rely on charcoal for cooking and heating purposes [37]. Therefore, the promotion of biogas stoves is crucial to stop the massive exploitation and the unsustainable development of woody biomass. In this context the presence of a bio-digester could allow TUK to become an important research centre for the biogas technology. Thus the benefits are related not only to the University's distinction, but also to the chance for students to specialize in the biogas stoves' sector;
4. the fourth and final reason is linked to the meaning acquired by the system's presence in the campus. The provision of courses and practical lessons on biomass and its plants could train experts more aware and dedicated to waste management problems. Moreover Kenya Polytechnic, starting from this first pilot model, could implement a deeper project of waste collection and recycling (in the wake of American zero waste campuses), becoming a good example for future plans of waste management and recovery promoted by the City Council. Obviously this implies a regular pick up of waste generated through separate collection of rubbish, the placement of different dustbins in opportune areas and the creation of a recycling center and hence only a long-term planning and a substantial funds' allocation could realize this ambitious plan.

Biogas System Design

Technical University of Kenya has a population of 12,115 students [52] and it covers about 40,000 m^2. The campus is endowed with two canteens, one for scholars and one used as catering facility by teachers, as depicted in *Fig. 5.2*. Here also the suitable space for the installation of the bio-digester is visible: it is located behind the Mechanical Department, where there is a fairly wide area (about 372 m^2) close enough to the students' canteen.

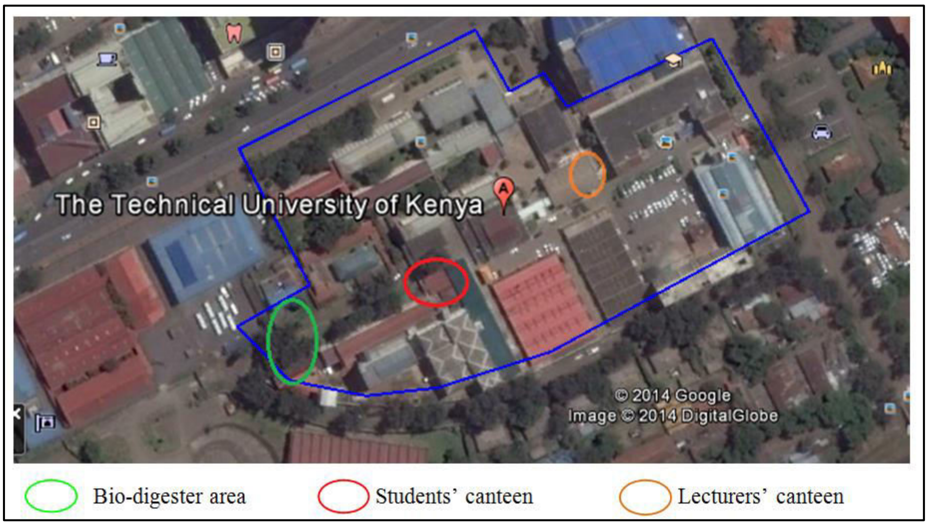

Fig. 5.2 TUK's plant [52]

Generally the sizing of a bio-digester can be carried out with two different logics: the first considers the kinetic parameters that control the substances' degradation in the substrate, whereas the second is based on simplified criteria, such as load factors and operating parameters. For the specific case, the latter approach is preferable as the urban waste's organic fraction is a complex substrate and hence the results obtained with the approximate method are reasonable and acceptable.

The approach consists of an estimated procedure that examines the organic load in order to size the reactor and guarantee the right amount of biomass input. However, in first approximation, the dimensioning is implemented on the basis of the Hydraulic Retention Time (HRT), although this method is not sufficient to ensure the specifications' compliance. It is useful for the compatibility's verification between the geometry of the digester and the type of biomass processed and for this purpose *Tab. 5.2* discloses the HRT values in relation to different digestion processes and different substrates:

	Mesophilic			**Thermophilic**		
Substrate	Wet process	Semi-dry process	Dry process	Wet process	Semi-dry process	Dry process
Organic Fraction mechanically selected	14-30	15-20	17-30	10-18	6-15	12-20
Organic Fraction selected from recycling or from the source	12-18	12-18	17-25	8-16	10-16	12-16

Tab. 5.2 HRT [day] for different processes and different substrates [87]

The choices fall on:

- the mesophilic process, performed by bacteria that work in a temperature range between 35 °C - 40 °C. It is preferable to thermophilic one, which is more expensive, more energy-intensive and more complex, even though the latter requires less residence times;
- the organic fraction selected from recycling or from the source because TUK is not endowed with tools and machinery for the waste's mechanical separation;
- the dry process with dry substance content higher than 20%. In this way, the benefits consist in the absence of internal mixers, the requirement of minimum and cheap pre-treatments and the low heat's demand for the reactor [53].

Subsequently the expected HRT is equal to 17-25 days and with the following calculation procedure it is possible to assess the coherence between the predicted value and the result obtained from the calculations.

1. <u>Characterization of the input mass flow</u>
The Per-capita Daily Amount of Organic Waste and the catchment area are known, meaning with this latter term the approximate number of people producing waste. It amounts to about 6,000 individuals, inspecting that not all students avail themselves of the canteen for breakfast and lunch in an average day. Therefore the Organic Fraction Daily Selected (OFDS) is calculated:

$$OFDS = DAOW_{\text{per-capita}} \cdot catchment\ area =$$
$$= \frac{460 \left[\frac{g}{person \cdot day}\right] \cdot 6{,}000\ people}{1{,}000 \left[\frac{g}{kg}\right]} \cong 2{,}760\ kg/day \quad (5.2)$$

The biomass' input flow shall also be evaluated in terms of Total Solids (TS) and Total Volatile Solids (TVS): for this purposes *Tab. 5.3* is supportive.

	Parameter	**Unit**	**Food Waste** Target MCRT 15-day	10-day	5-day
Feed	TS (Meso)	% AVG (SD)	6.4 (1.47)	9.6 (1.6)	8.2 (NA)
	TVS/TS (Meso)	% AVG (SD)	86.3 (2.7)	89.9 (2.3)	90.2 (NA)

AVG = Average Value
SD = Standard Deviation
NA = Not Applicable because only one data point was observed during stable period

Tab. 5.3 TS and TVS/TS for diverse MCRT [54]

The table is extracted from the journal article of P. Suto and C. Peck "*Anaerobic Digestion of Food Waste*" [54] and it shows the Total Solids' average percentage and the rate TVS/TS for various values of the Mean Cell Residence Time (MCRT). It is the theoretical average time during which bacteria stay in the digester and it is a fundamental specification to manage the process stability and define the right digester volume. The longer MCRTs are, the more stable the process is, but in contrast costs increase because a large scale digester is required. For stable digester operation MCRT varies between 15 and 30 days, however the food waste's organic material comprises carbohydrates, proteins, and short-chain fats, that are easily biodegradable. Therefore, also shorter MCRT is advisable and for the specific case it is set equal to the 10-day's average value. In consequence:

$$TS_{\%} = 9.6\% \quad (5.3)$$
$$(TVS/TS)_{\%} = 89.9\% \quad (5.4)$$

Hence the Daily Total Solids Content (DTSC) and the Daily Total Volatile Solids Content (DTVSC) are calculated:

$$DTSC = OFDS \cdot TS_{\%} = 2760 \cdot 0.096 \cong 265\ kg/day \quad (5.5)$$

$$DTVSC = DTSC \cdot (TVS/TS)_{\%} = 265 \cdot 0.899 \cong 238\ kg/day \tag{5.6}$$

2. Determination of the organic load per m^3 of reactor and calculation of the total volume
The Organic Loading Rate (OLR) indicates the amount of volatile solids daily loaded in the digester with the slurry and it influences the process' efficiency and yield. Two studies ([55], [56]) demonstrate that its optimal value ranges from 1 kg_{VS}/m^3day to 1.4 kg_{VS}/m^3day, but for the case in point (mesophilic, dry process with substrate from recycling) an overestimation is appropriate because the input slurry is rough and not pre-treated (so much so that the values in literature are equal to 3 - 4 kg_{VS}). On the other hand, an OLR not too large is always an additional safety factor, since the system can work in less stressful conditions.
Consequently, OLR is fixed equal to 3 kg_{VS}/m^3day and the calculation of digester's volume is finally attainable:

$$Reactor\ volume = \frac{DTVSC}{ORL} = \frac{238\ kg/day}{3\ kg_{\text{VS}}/m^3 \cdot day} \cong 80\ m^3 \tag{5.7}$$

Since such size of the bio-digester is high for the implementation and management of a first pilot plant, it is assumed a catchment area more restricted, composed by only 2,000 people. In this way, the new final results are:

$$OFDS_{2,000} \cong 920\ kg/day \tag{5.8}$$
$$DTSC_{2,000} \cong 88\ kg/day \tag{5.9}$$
$$DTVSC_{2,000} \cong 79\ kg/day \tag{5.10}$$
$$Reactor\ volume_{2,000} \cong 26.5\ m^3 \tag{5.11}$$

3. Operating conditions' verification
The determined volume could lead to lower HRT's values, although the procedure is correct in principle. In order to test the compliance between the estimated HRT and its calculated counterpart, the Volume of the Organic Fraction Daily Selected (VOFDS) is necessary. It is determined knowing the organic fraction's density [57]:

$$VOFDS = \frac{OFDS_{2,000}}{\rho_{\text{food waste}}} = \frac{920 kg/day}{514\ kg/m^3} = 1.8\ m^3/day \tag{5.12}$$

The Hydraulic Retention Time is therefore:

$$HRT = \frac{Reactor\ volume_{2,000}}{VOFDS} = \frac{26.5\ m^3}{1.8\ m^3/day} \cong 15\ days \tag{5.13}$$

Following this logic, the resulting HRT is low compared to the predicted one, that for the selected process has a typical value of 18 days. Then it is worth repeating the calculation with decreasing OLR, up to the achievement of an optimal compromise. With an iterative procedure, implemented thanks to the *Solver*, an additional Excel® tool, the definitive results are obtained:

$$Definitive\ ORL = 2.5\ kg_{\text{VS}}/m^3 \cdot day \tag{5.14}$$
$$Definitive\ reactor\ volume \cong 32\ m^3 \tag{5.15}$$

$$Definitive\ HRT \cong 18\ days \tag{5.16}$$

Finally the reactor volume shall be oversized with a safety factor between 1.1 and 1.3 in order to consider a certain flexibility degree of the plant:

$$Proper\ reactor\ volume = Reactor\ volume \cdot safety\ factor = 32 \cdot 1.1 \cong \cong 36\ m^3 \tag{5.17}$$

4. <u>Energy considerations</u>
   The Daily Energy Potential (DEP) is calculated as the product between the substrate's Lower Heating Value (LHV) and the Daily Biogas Production (DBP). The latter parameter is evaluated starting from the Specific Gas Production (SGP): it is shown in various research studies and the most recurring value is 0.5 m^3/kg_{TVS} [58].
   As a consequence:

$$DBP = SGP \cdot DTVSC_{2,000} = 0.5 \left[\frac{m^3}{kg_{TVS}}\right] \cdot 79 \left[\frac{kg}{day}\right] \cong 40\ m^3/day \tag{5.18}$$

$$DEP = DBP \cdot LHV_{\text{food waste}} = 40 \left[\frac{m^3}{day}\right] \cdot 22.25 \left[\frac{MJ}{m^3}\right] \cong 890 \frac{MJ}{day} \cong \cong 250\ kWh/day \tag{5.19}$$

The energy expenditure for heating processes consists of two items:
- the input waste's heating;
- the digester's heat losses.

The biggest consumption is due to the input substrate's heating, because appropriate calculations display that the heat wasted for the losses does not exceed the 5-10% of the total heat needed to guarantee the digester's correct temperature. Therefore the Heat Required to warm the Feed Stream (HRFS) from the ambient temperature (25°C) to the operating temperature (35°C) is expressed as follows:

$$HRFS = OFDS_{2,000} \cdot SHC \cdot \left(T_{\text{operating}} - T_{\text{ambient}}\right) = = 900 \left[\frac{kg}{day}\right] \cdot 0.4096 \left[\frac{kcal}{kg \cdot °C}\right] \cdot (35 - 25)[°C] \cong 3{,}768 \frac{kcal}{day} = 4.52\ kWh/day \tag{5.20}$$

where SHC is the Specific Heat Capacity of the food waste.

In conclusion the Net Energy Production (NEP) is given by the difference between the Daily Energy Potential from biogas and the Heat Required to warm the Feed Stream. Actually it should add up to the heat lost in the digester, but this share is small and hence negligible.

$$NEP = DEP - HRSF = 250 - 4.52 \cong 245.5\ kWh/day \tag{5.21}$$

Bio-digester's selection

Currently, on the digester designs' market, different technologies are present, each of which with its own advantages and disadvantages. For this reason, the optimal configuration is singled out by describing briefly all the existing systems and by showing the typical project management matrix, constructed by S. Fackler and J. Violetti in their study "*Digester Selection and Operation for Heybeli Island"* [59].

1) *Batch Digester*: it is fueled with biomass batch, as its name suggests. When a batch is treated, no additional input can be added and it is necessary to wait the process' end for entering another new batch. Consequently it requires abundant input flows and on a whole it is not characterized by high efficiency, although it is cheap and easily maintainable.
2) *Fixed Dome Digester*: this system is simple to build and it requires materials easily available. Generally it is an underground construction and this results in stable operating temperatures and high-pressure gas production. However gas yields are low due to the low concentration input feeds.
3) *Floating Dome Digester*: inside the process, pressure is constant and this produces stable gas yields. Its installation is less complicated than the Fixed Dome Digester's one and the efficiencies are superior. In contrast, the system is more dependent on temperature's variations and on the expensive cost of construction materials.
4) *Lagoon Digester*: this configuration takes up much space, but it ranks first in terms of gas production in mesophilic conditions. One disadvantage resides in the difficult conservation of a stable operating temperature;
5) *Plug Flow Digester*: it also requires wide areas for the establishment, but the gas yields and efficiencies are high, despite the total solids permitted are abundant.

Hence the matrix in *Tab. 5.4* is useful to support the final decision.

Requirements	Relative Importance (1-100)	Single Project Impact Definitions	Score					Weighted score				
			1	2	3	4	5	1	2	3	4	5
Biogas Yield	100	0 ≤ Low Potential 1 ≥ Medium Potential 2 ≥ High Potential	0	0	1	2	2	0	0	100	200	200
Budget/ Maintenance	100	0 ≤ Low Cost 1 ≥ Medium Cost 2 ≥ High Cost	2	1	0.5	0	1.5	200	100	50	0	150
Temperature	70	0 ≤ Low Requirement 1 ≥ Medium Requirement 2 ≥ High Requirement	0.5	1.5	0.5	0	0.5	35	105	35	0	35
Life Cycle	90	0 ≤ Low Potential 1 ≥ Medium Potential 2 ≥ High Potential	1	2	0.5	1	1.5	90	180	45	90	135
Load Space Requirement	40	0 ≤ Low Requirement 1 ≥ Medium Requirement 2 ≥ High Requirement	1.5	1.5	1	0	0	60	60	40	0	0
Gas Output Pressure	50	0 ≤ Low Potential 1 ≥ Medium Potential 2 ≥ High Potential	0	1.5	1	1.5	0.5	0	75	50	75	25
Waste input Volume	60	0 ≤ Low Potential 1 ≥ Medium Potential 2 ≥ High Potential	0	1	1	2	2	0	60	60	120	120
Maintenance Time	80	0 ≤ Low Requirement 1 ≥ Medium Requirement 2 ≥ High Requirement	0	1.5	1.5	1.5	1.5	0	120	120	120	120
Construction Complexity	70	0 ≤ Low Complexity 1 ≥ Medium Complexity 2 ≥ High Complexity	2	1	1	0.5	2	140	140	70	35	140
		Total Weighted Score						525	770	570	640	925
		Priority						5	2	4	3	1

Tab. 5.4 Alternative Design Matrix [59]

This matrix is constructed considering different characteristics and their relative weights, that range from 1 to 100. Therefore every requirement is classified with a score from 1 to 5 on the basis of the literature review about the digesters and then this score is weighted thanks to the relative importance's indicators. Summing the values obtained, the highest score is achieved by the Plug Flow system, which in consequence represents the best alternative.

Once the ranking has drawn up, 4 scenarios are investigated:

A. installation of a digestion system commercialized by a local enterprise;
B. recourse to a small scale digester foreign imported;

C. construction of a fixed dome digester;
D. establishment of two different bio-digester model (plug flow versus fixed dome).

Two main goals are pursued by the options above listed, one related to the organic waste disposal problem and the other linked to didactical purposes. On a whole, all the solutions handle the waste problem because the adoption of an anaerobic digestion system aspires in and of itself to find a new, renewable and sustainable solution for the reuse of high-energy organic fraction.

On the other hand, the impact on teaching is ensured by the possibility for students to become familiar with this new technology and learn practically its operation.

For this reason all the proposed systems are equipped with indicators of flow rate, pressure and temperature to control the process and evaluate its efficiency. In this way students could carry out different interesting activities:

- chemical and physical analysis of the input feedstock;
- process stability controls through temperature measurements within the digestion chamber and variation trend's analysis;
- assessments on the amount of biogas produced and evaluation of its pressure in order to determine the most appropriate final use;
- experiments on how the biogas yield changes by varying the input slurry composition.

Biogas final use

The biogas from the anaerobic digestion process can be employed in principle for different end purposes, which encompass the direct use for cooking, heating and lighting and its transformation into heat and electricity through cogeneration plants. This latter option is immediately discarded, given that the digester's dimensions are reduced: indeed, the implementation of a small-scale cogeneration plant would entail considerable technological complications and would still not be adequate for a university campus.

Hence the direct application of biogas for cooking is preferable also to deal with the diffusion of cook stoves fueled with charcoal and wood, especially in rural areas. For this reason, the students canteen should be endowed with some models of biogas stoves. In particular three products are chosen, the specifications of which are summarized in *Tab. 5.5*:

Product	**Heat Load [kW]**	**Hourly Gas Consumption Rate [m^3/h] (HGCR)**	**Heat efficiency**	**Fire maker efficiency**	**Price [€]**
Biogas stove double burner	2.8	0.45 (for one burner)	> 57%	> 98%	19.05
Biogas stove large burner	-	2-3	> 55%	> 98%	27.42
Biogas rice cooker (18 l)	-	-	-	-	111.35

Tab. 5.5 Products for biogas applications [88]

Then a rough sizing of the gas' needs for cooking is necessary to understand which and how many devices should be provided; later the minimum cost logic allows to direct the attention to the best fitting alternative.

From literature review [60] the per capita Daily Gas Requirement ($DGR_{per\text{-}capita}$) is equal to $0.3\ \mathrm{m^3/(person \cdot day)}$, therefore the Maximum Number of Served People (MNSP) is estimated:

$$MNSP = \frac{DBP}{DGR_{\mathrm{per-capita}}} = \frac{40\ m^3/day}{0.3\, m^3/(person \cdot day)} \cong 132\, people \qquad (5.22)$$

Also the value of the Hourly Biogas Consumption by Burners (HBCB) is useful and it amounts to $6.7\ m^3/h$, considering 6 Functioning Hours (FH) in a typical day:

$$HBCB = \frac{DBP}{FH} = \frac{40\ m^3/day}{6\,h/day} \cong 6.7\,m^3/h \tag{5.23}$$

Furthermore, to harmonize the biogas production's kinetics with those of use, the installation of a storage system is necessary. Its volume and pressure are determined on the basis of a cost-benefit analysis. In order to avoid volumes and costs too high, storage should be limited to the amount necessary to amortize the production tips and it must be carried out at low pressure [53]. For establishing the volume equal to 18 production hours, it results:

$$Hourly\ Biogas\ Production\ (HBP) = \frac{DBP}{24[h/day]} = \frac{40[m^3/day]}{24[h/day]} = 1.67\ m^3/hour \tag{5.24}$$

$$Biogas\ Bag\ Volume\ (BBV) = HBP \cdot 18\ hours = 1.67\left[\frac{m^3}{hour}\right] \cdot 18\ hours = 30\ m^3 \tag{5.25}$$

5.1.3. Selection of components

A scenario: Flexi Biogas Total Energy Solution

This settlement is provided by *Biogas International Ltd*, a limited liability company, founded in Kenya in the year 2009 and operating from Karen in Nairobi.

Fig. 5.3 shows an example of the system, which is fabricated from a flexible reinforced PVC tarpaulin bag, placed on the ground, with plastic pipes for inputs and outputs. This specially treated robust material is designed to last in all weather conditions and the estimated average time of resistance is about 10 years [61].

Fig. 5.3 Flexi Biogas System [61]

The digester is covered by a greenhouse tunnel, that keeps the temperature in the digester fairly constant at 38°C and protects the system against direct UV rays.

An advantage of this digester is the possibility to be powered by any type of organic waste, including kitchen and human waste, and the feeding need to be mixed with water in a ratio 1:1.

The orange tube in *Fig. 5.3* is used to insert the slurry in the system, that hence begins to ferment, allowing the biogas' formation and the displacement of the exhausted dung towards the outlet pipe.

In fact, the gas obtained presses down on the slurry and pushes the exhausted dung out of the orange pipe in the background. Then the biogas is moved through pipes to the places of use.
The company sells three different models, reported in *Tab. 5.6* with their biogas yield and their cost in Kenyan shillings. Sideways the column with the corresponding conversion in € has been added.

Model	Production [l/day]	Production [m^3/day]	Volume [m^3]	KSh	€
DBG	1,000-1,500	1-1.5	-	40,000	~ 350
BG5	1,500-2,500	1.5-2.5	5	55,000	~ 480
BG6	4,000-5,000	4-5	6	70,000	~ 600

Tab. 5.6 Price List of Biogas International Ltd [61]

On the basis of the conducted sizing, the choice lies on BG6 product because it is the best in terms of daily biogas yield. In particular, knowing the expected reactor capacity thanks to the sizing, 6 BG6 digesters would be needed in order to meet volume specifications. Since each model is 4 m long and 1.5 m wide, the total area occupied by the 6 digesters is about 36 m^2, allowing the installation in the selected zone.

B scenario: BIOTECH Biogas Plant

Such solution is inspired by the experience of the Indian NGO *BIOTECH*, based in Kerala, that is very active in the development of innovative and low-cost waste disposal solutions. Specifically the proposed solution envisages the use of prefabricated components: the tank is constructed thanks to the excavation of a pit, bounded by a brick or ferro-cement wall and then lined in order to guarantee the imperviousness (*Fig. 5.4*). A steel drum coated with Fiberglass Reinforced Plastic (FRP) is placed on the top to collect the biogas produced [62].

Fig. 5.4 BIOTECH digester [62]

Biogas plants for institutional bodies present a variable capacity between 10 m^3 to 25 m^3 and each provides the final product for 200 person on average. For the didactical aim of the system, a 20 m^3 tank is sufficient also because it is the most convenient in economic terms. *Tab. 5.7* summarizes all the selected digester's characteristics:

Size [m^3]	20
Biogas production [m^3/day]	23
Capital cost [€/digester]	2,000
Number of digesters	2

Tab. 5.7 Characteristics of the biogas plant [89]

Also here the number of digesters is extracted by the ratio between the digester's volume expected from the sizing (36 m^3) and the chosen one (20 m^3).

C scenario: Construction of a fixed dome plant

In order to pursue educational purposes, the construction of a fixed dome digester by students appears as an useful exercise to learn more about this technology. In fact, this expedient would allow the students to take part in all the project phases during the practical lessons on the field: hence they could take care of the preliminary plant's sizing or they could choose the most suitable materials and conduct economic analysis or feasibility studies.

For this aim, a fixed dome plant is preferred, although it qualifies in the second place considering the "Alternative design matrix" (*Tab. 5.4*), since such technology is very mature and globally known.

As depicted in *Fig. 5.5*, the plant is constructed underground and it consists of a digester with a fixed, non-movable gas holder on the top [63].

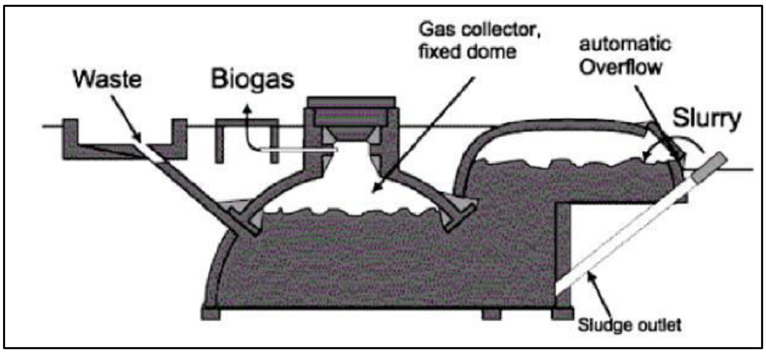

Fig. 5.5 Fixed dome plant, CAMARTEC model [63]

Usually the digester is built with bricks or concrete and the choice between these two materials depends on several considerations:

- technical suitability;
- economic parameters;
- materials' availability and transport costs.

The gas holder is located on the top of the digester and it is made of gas-tight layer (for example Layer or synthetic paints). To limit the possibility of gas-holder's cracking, a weak-ring is arranged in the masonry of the digester and it functions as flexible joint between the lower and the upper part of the system.

Unlike the plug-flow digesters previously analyzed, such system is fed with a slurry consisting of excrement (human and animal) and water and it's sizing is determined in a different way. In particular, the digester's capacity is selected a priori because the system is fabricated mainly for didactical purposes and not to deal with the waste disposal problem. In addition, to create a digester fitting with the organic feedstock daily produced by latrine's users, the University sewage system should be changed in order to connect directly the toilets with the plant's inlet. It would be very costly both in terms of money spent and time for the installation. Therefore the most attractive option is a small-scale apparatus with the specifications underlined in *Tab. 5.8*:

Plant Size [m^3]	Daily Feedstock [kg]	Daily Water [l]
4	24-40	24-40

Tab. 5.8 Plant size & daily feedstock for fixed dome plant [90]

D scenario: Plug Flow Digester + Fixed Dome Plant

While the first three alternatives intend to chase both the didactical and waste related objectives, this one is designed primarily as a teaching support.

The basic idea consists in providing TUK with two different smaller-size digester's models with the aim of making possible comparative studies of their performances. The designs considered are a Plug Flow reactor, selected between the FLEXI Biogas system and the BIOTECH Biogas Plant according to the economic convenience, and a Fixed Dome digester. The digester's capacity is set equal to 6 m^3 for the both models, so that the differences emerged by the comparison concern only the technological aspects and not those related to particular plant's size. Such dimension is opportune for both Plug Flow reactor and the Fixed Dome: in fact, the picked companies market a 6 m^3 digester type and, on the other hand, the construction of a Fixed Dome plant of such dimensions is not very expensive in terms of time and money. *Tab. 5.9* shows all the possible models and their respective properties.

Model	Volume [m^3]	Maximum treatable waste [kg/day]	Daily water [l/day]	Biogas production [m^3/day]
FLEXI Biogas BG6	6	60-70	60-70	5
BIOTECH Biogas plant	6	10-20	60-70	6-10
Fixed Dome digester [90]	6	40-60	40-60	4

Tab. 5.9 Characteristics of digester's models

The information about the FLEXI Biogas system's daily feedstock is not known and therefore it is estimated by calculating the organic fraction daily fed in one digester and by considering that the ratio solid substance waste/water is 1:1.

5.1.4. Economic analysis of different equipment

Selection of biogas burners

The most convenient combination of biogas burners is acquired by a cost analysis that takes into account three different configuration:

a) only stove double burner;
b) stove double burner + stove large burner;
c) stove double burner + stove large burner + rice cooker.

Thanks to the preliminary sizing of kitchen's gas needs and with the help of Excel® *Solver*, the best fitting solution is found and it is assumed that the configuration remains the same for all scenarios later examined.

<u>Case a): Only stove double burner</u>

The characteristics of this product (Hourly Biogas Consumption and price) are specified in *Tab. 5.5* and they are used to calculate the Daily Biogas Consumption (DBC) and the number of stoves required:

$$DBC_{\text{double burner}} = HGCR_{\text{double burner}} \cdot FH = 0.9\left[\frac{m^3}{h}\right] \cdot 6\left[\frac{h}{day}\right] = 5.4\frac{m^3}{day} \qquad (5.26)$$

$$n°of\ stoves_{\text{double burner}} = \frac{DBP}{DBC_{\text{double burner}}} = \frac{40\left[\frac{m^3}{day}\right]}{5.4\left[\frac{m^3}{day}\right]} \cong 7\ stoves \quad (5.27)$$

The associated cost is:

$$Capital\ cost_{\text{case a)}} = n°of\ stoves_{\text{double burner}} \cdot price_{\text{double burner}} = 7\ [stoves] \cdot 19 \left[\frac{€}{each}\right] \cong$$
$$\cong €\ 130$$

<u>Case b): Stove double burner + Stove large burner</u>

This scenario is introduced with the aim of making more efficient the canteen service and faster the food cooking since the stove large burner is typical for restaurant use. In this case, the number of supplied stoves is patterned using arbitrary values in first approximation and the Hourly Biogas Consumption is determined as the product between the first attempt stoves' number and their catalogue specifications. Subsequently, the HBCs for the different products are added up and the Excel® *Solver* is utilized by setting as target cell the difference between this sum and the Hourly Biogas Production. The final results are displayed in *Tab. 5.10*:

Product	Number	Hourly Biogas Consumption [m^3/h]
Stove double burner	2	1.63
Stove large burner	3	4.03

Tab. 5.10 Excel® *Solver* results case b)

Thus two stoves double burner and three stoves large burner are singled out and their capital cost results:

$$\begin{aligned} &Capital\ cost_{\text{case b)}} = \\ &= (n°of\ stoves_{\text{double burner}} \cdot price_{\text{double burner}}) \\ &+ (n°of\ stoves_{\text{large burner}} \cdot price_{\text{large burner}}) = \\ &= 2[stoves] \cdot 19 \left[\frac{€}{each}\right] + 3[stoves] \cdot 27 \left[\frac{€}{each}\right] \cong €\ 120 \end{aligned} \quad (5.28)$$

<u>Case c): Stove double burner + Stove large burner + Rice cooker</u>

The same operations carried out for the case b) are repeated in this third configuration, adding also a 18 l rice cooker. *Tab. 5.11* depicts the final outcomes:

Product	Number	Hourly Biogas Consumption [m^3/h]
Stove double burner	2	1.63
Stove large burner	3	4.03
Rice cooker (18 l)	1	0.93

Tab. 5.11 Excel® *Solver* results case c)

The resulting capital cost is:

$$\begin{aligned} &Capital\ cost_{\text{case c)}} = Capital\ cost_{\text{case b)}} + (n°of\ rice\ cooker \cdot price_{\text{rice cooker}}) = \\ &= €\ 120 + \left\{1[rice\ cooker] \cdot 111 \left[\frac{€}{each}\right]\right\} \cong €\ 230 \end{aligned} \quad (5.29)$$

In conclusion, all the cases and their respective costs are summarized in *Tab. 5.12* and the final choice turns out to be the configuration b), given its economic convenience:

Case	Cost [€]
a)	130
b)	**120**
c)	230

Tab. 5.12 Summary of cases costs

Therefore the economic analysis of different scenarios will be implemented taking into account the biogas burners configuration b).

In addition a 2 m^3 biogas PVC storage bag is needed to decouple the production and use stages of the final product and this component is provided at a price of about €70. In conclusion, the final cost for all the equipment selected is:

$$Equipment\ cost\ (EC) = CC_{\text{case b)}} + storage\ cost \cong €\ 120 + €\ 70 = €\ 190 \tag{5.30}$$

Economic analysis: A scenario + case b) burners

The FLEXI Biogas System is characterized by the ease of installation, which requires only 3 hours, and it necessitates little maintenance, that can be accomplished without additional costs by beneficiaries. Hence such system proves itself sustainable both economically and in terms of durability because, throughout the establishment, end users are involved and they are trained on how to run and maintain the digester. For this reason the Total Capital Cost (TCC), which includes also the assembly, is approximately €3,800:

$$TCC_{\text{scenario A}} = (n°FLEXI\ Biogas \cdot price_{\text{BG6}}) + EC = (6 \cdot €\ 600) + €\ 190 \cong \cong €\ 3{,}800 \tag{5.31}$$

Economic analysis: B scenario + case b) stoves

This option envisages adopting reactors from India where the NGO BIOTECH is mainly operative. However, bibliographic researches [62] underline the spread of ARTI biogas systems (small-scale domestic bio-digesters sponsored by the Organization) even in neighboring Tanzania. Consequently, the importation of these reactors is not unlikely, despite the Transport Costs (TC) represent a significant proportion of the capital cost. On account of this, they are estimated equal to 15% of the total cost, whereas the budget for the installation and the brick fence's construction is the 5% of the total (Installation Cost, IC).

All the contemplated cost items are illustrated in the following calculations:

$$CC_{\text{scenario B}} = n°of\ digesters \cdot SCC = 2\ [digesters]\ \cdot 2{,}000 \left[\frac{€}{each}\right] = €\ 4{,}000 \tag{5.32}$$

with $\begin{cases} \text{CC = Capital Cost} \\ \text{SCC = Specific Capital Cost} \end{cases}$

$$TC_{\text{scenario B}} = 15\% \cdot CC_{\text{scenario B}} = €\ 600 \tag{5.33}$$

$$IC_{\text{scenario B}} = 5\% \cdot CC_{\text{scenario B}} = €\ 200 \tag{5.34}$$

$$TCC_{\text{scenario B}} = (CC + TC + IC)_{\text{scenario B}} + EC = €\ 4{,}800 + €\ 190 \cong €\ 5{,}000 \tag{5.35}$$

This pre-fabricated domestic plant can be installed in two or three days and also in this case training courses are needed in order to ensure the system's periodic maintenance, which should be realized every three months by appropriate technicians. In addition, to address this substantial expense, financing forms could be endorsed, with the direct involvement of external stakeholders or local ministries.

Economic analysis: C scenario + case b) burners

For the construction of a typical underground masonry digester different materials are needed. A web sites exploration [64] allows to acquire specifications about the amount of cement, bricks and sand necessary for the system's realization. All the data are collected in *Tab. 5.13*:

Plant size [m^3]	Cement bags$_{@50\ kg/bag}$	Bricks	Sand [# of cement bags]
4	11-12	1,200	60
6	13-14	1,400	70
8	15-16	1,700	80
10	19-21	2,000	90

Tab. 5.13 List of materials needed on the basis of the digester's size [64]

Regarding the cost, it is reported converting in € the value expressed at the retail US price, despite the fact that these raw materials are less expensive in the Kenyan market:

- €6.7 for about 50 kg/bag of cement;
- 25 cents per brick;
- #34 sand costs €27.5/ton (where #34 sand is about 1 ton).

Therefore, the total cost associated to the 4 m^3 fixed dome digester is calculated as follows:

$$CC_{\text{scenario C}} = \left\{6.7\left[\frac{€}{50kg/bag}\right]\cdot 12\left[bags_{@50\text{kg/bag}}\right]\right\} + \left\{0.25\left[\frac{€}{brick}\right]\cdot 1{,}200[bricks]\right\} + \left\{27.5\left[\frac{€}{ton}\right]\cdot 2[ton]\right\} \cong €\ 435 \tag{5.36}$$

where 2 tons corresponds to #60 cement bag in the last term of the formula.

This value is increased by 20% to account for other materials' costs, but not for the installation ones. In fact, the students are employed in the construction site on behalf of the educational purposes emphasized in this solution.

The final capital cost of scenario C totals:

$$TCC_{\text{scenario C}} = (CC_{\text{scenario C}} + 20\%\cdot CC_{\text{scenario C}}) + EC = €\ 522 + €\ 190 \cong \cong €\ 710 \tag{5.37}$$

Economic analysis: D scenario + case b) burners

This solution consists of two 6 m^3 digesters: the fixed dome is built following the technical specifications yet used for the C scenario, whereas the FLEXI system is selected as alternative since it has a specific cost lower than the BIOTECH one.

$$CC_{\text{FLEXI Biogas 6m}^3} \cong €\ 600 \tag{5.38}$$

$$CC_{\text{Fixed Dome 6m}^3} = = \left\{6.7\left[\frac{€}{50kg/bag}\right]\cdot 14\left[bags_{@50\text{kg/bag}}\right]\right\} + \left\{0.25\left[\frac{€}{brick}\right]\cdot 1{,}400[bricks]\right\} + \left\{27.5\left[\frac{€}{ton}\right]\cdot 2.06[ton]\right\} \cong \cong €\ 500 \tag{5.39}$$

where 2.06 tons are equivalent to about #70 bags of cement useful to construct a 6 m^3 digester.

Also in this case, the Capital Cost of the Fixed Dome digester is increased and the total capital cost appears as follows:

$$TCC_{\text{scenario D}} = (CC_{\text{Fixed Dome }6\text{m}^3} + 20\% \cdot CC_{\text{Fixed Dome }6\text{m}^3}) + CC_{\text{FLEXI Biogas }6\text{m}^3} + EC = € \, 600 + € \, 600 + € \, 190 \cong € \, 1{,}400 \quad (5.40)$$

5.1.5. Selection of the most appropriate solution

In *Tab. 5.14* all the scenarios analyzed are collected and, for each of them, the cost for the realization is shown:

Scenario	Cost [€]
A	3,800
B	5,000
C	710
D	1,400

Tab. 5.14 Cost for different scenarios

The various proposals can be roughly divided in two areas: the options A and B try to solve mainly the waste management problem in the campus, whereas the other two are targeted chiefly for didactical purposes and this justifies the arbitrary bio-digester's sizing.

Looking at the first two scenarios and following the minimum cost logic, the A solution is picked out. In fact, besides being the most convenient in economic terms, it demonstrates several characteristics that ensure its sustainability over time. For example, the Flexi International Ltd's presence in Nairobi makes the maintenance and replacement interventions easily feasible. In addition, the system's portability and the ease with which it operates make it replicable, allowing future developments. Another issue concerns the great versatility of the system which can be powered in theory with any type of organic waste. This could be a useful advantage even for the teaching because it would foster research studies on the most suitable biomass mix to obtain the highest biogas yield.

Instead, in the matter of scenarios C and D, the fixed dome digester's creation by students is great economically speaking, but option D may be more significant at didactical level, despite its higher cost. In fact, having two distinct plants, the students could experience more directly systems' strengths and weaknesses and they could measure numerous parameters in order to sanction the best fitting technology.

On a whole, it is worth noticing that all these alternatives could be adopted, if the available budget was unlimited, as the initial required investment is not prohibitive. However a good compromise seems to be the A scenario: on the one hand it seeks to improve the problem of solid waste's collecting and disposal (for this reason the sizing is conducted from the organic fraction daily produced), on the other hand it represents a well-know and innovative advancement in the renewable energy field.

Moreover, the use of biogas for cooking involves both economic and environmental benefits. From the economic point of view, evaluating the per capita Annual Consumption of Liquefied Petroleum Gas in Kenya ($AC\_LPG_{\text{per-capita}}$) equal to $2 \text{ kg}/(\text{person} \cdot \text{year})$ as the web article "*Kenya Expects LPG Consumption to Triple by the End of the Next year*" asserts [65], it is possible to acquire the amount of LPG needed to run a kitchen used as canteen for 132 people:

$$(AC\_LPG)_{\text{canteen}} = (AC\_LPG)_{\text{per-capita}} \cdot n° \; of \; people = \\ = 2 \left[\frac{kg}{person \cdot year}\right] \cdot 132[people] = 264 \; \frac{kg}{year} \quad (5.41)$$

Since the LPG's Kenyan Average Price ($AP_{\text{Kenyan LPG}}$) is about \$2.50/kg [66], i.e. €1.95/kg, the average Annual Gas Expenditure (AGE_{canteen}) for students' canteen amounts to €515/year:

$$AGE_{\text{canteen}} = (AC\_LPG)_{\text{canteen}} \cdot AP_{\text{Kenyan LPG}} = 264 \left[\frac{kg}{year}\right] \cdot 1.95 \left[\frac{€}{kg}\right] \cong \\ \cong 515 \; \frac{€}{year} \quad (5.42)$$

Bearing in mind that burners should be moved to the LPG stoves when the biogas runs out, biogas replaces approximately the 60% of their Liquefied Petroleum Gas use [62]. Hence, the Annual LPG Saving (AS_{LPG}) due to the biogas' substitute use is:

$$AS_{\text{LPG}} = AGE_{\text{canteen}} \cdot 60\% = 515 \; \left[\frac{€}{year}\right] \cdot 0.6 \cong 300 \frac{€}{year} \quad (5.43)$$

5.2 Focus on TUM

5.2.1. Stakeholders analysis

The numerous technicians and students interviewed point out that the practical activities do not properly support the study and that they are not useful for alumni's preparation. In fact, the work in laboratories is conducted with low rate of productivity and it is characterized by a high waste of time. The most relevant reason that obstructs the practical activities is connected to the issue of weekly interruptions in electricity. In fact, especially in technical faculties, students spend most of their time in workshops and during power failures the activities are interrupted until the power supply resumes. Consequently, their competencies and readiness for work are compromised. In addition, unpredictable power outages lead to a decline of research and development activities.
Furthermore, the voltage fluctuations and the unscheduled interruption of electrical power are also responsible for data loss and they can irreparably damage computers and any other devices.
In particular, in TUM during the 15-day stay, several power black-out were experienced (*Tab. 5.15*):

Day	N°	Duration
Tuesday 19th August, 2014	1	some minutes
Friday 20th August, 2014	3	10 minutes each
Friday 29th August, 2014	1	all the morning
Saturday 30th August, 2014	1	some minutes

Tab. 5.15 Electricity interruptions experienced

To face this problem, TUM presents a backup generator and another one is under construction, due to the low efficiency of the older. Also PV modules (*Fig. 5.6*) have been installed to operate computers and lighting when power outages occur.

Fig. 5.6 PV modules

Another important issue associated with labs is the outdated equipment without technological development due to the shortage of funds, even if this consideration does not affect computers which are relatively modern.
In definitive, all these aspects lead to the disadvantage of failing to assure a concrete approach to didactics and not encouraging research and innovation.

5.2.2. Assessment of the appropriate technology

Relevance of the solution

One of the principal challenge within the laboratories is to obtain a higher reliability of power supply. Consequently, a good way to enhance energy safety could be represented by the exploitation of some renewable energies, like wind and sun, or by the usage of a battery storage system. In particular, a stand-alone PV system, a battery unit or a hybrid system could represent an alternative to conventional power sources (diesel generators) that have the problem of noise and green-house gases, even if their technology is mature and thus the investment cost is rather low. More specifically, three scenarios are analyzed:

1. A scenario: stand-alone PV system with energy storage for computers.

   The stand alone PV system is a configuration that draws upon the exploitation of solar energy resource, very abundant in the region. Moreover, the installation of stand-alone renewable energy system can have also the positive effect on the learning process of students regarding renewable energies, besides trying to solve the problems of black-out. Obviously, due to the fluctuation (seasonal and diurnal) of this source, an energy storage system is required. Indeed, batteries are necessary to provide uninterruptible power and security in order to guarantee adequate activities performed in laboratories.

   The selection of this system compared to a grid connected one is justified by two main reasons:

   - in general, a grid connected system with battery bank for backup implies the installation of more components and the necessity to switch from grid power to solar power, increasing complexity and consequently the cost and the maintenance, even if theoretically it could be selected in order to face the outages' problem;
   - for the didactical purposes mainly pursed by the intervention, the possible earning obtained by the grid connected configuration thanks to the sale of electricity to the grid is not meaningful.

   Furthermore, this alternative is interesting because the system has already been adopted by TUM to supply some laboratories' computers and hence the technology's acceptability does not constitute a problem.

In addition, the option to power computers' electricity needs is in line with the implementation of the project's e-learning and e-collaboration platform as innovative method for teaching and networking. The didactical purpose consists also in the installation of some specific simulation software, with which students can improve their academic skills in designing and developing energy systems. Some examples are:

- PVGIS: it is a specific tool to assess the solar electricity production of a photovoltaic system. It is suited for both stand alone and grid-connected PV systems and plants [67];
- PV SOL: it is a dynamic simulation program to analyze roof-integrated or mounted grid-connected photovoltaic systems with storage [68];
- HOMER: it is a software to design a hybrid renewable micro-grid system. In particular, it is possible to perform an economic-technical feasibility analysis of a system [69];
- TRNSYS: it is a transient system simulation program to evaluate the performance of thermal and electrical energy systems and it is suitable for different applications: for instance, to test wind and photovoltaic systems, power plant (biomass, cogeneration), solar thermal processes [70].

2. B Scenario: UPS system (Uninterruptible Power Supply) + training devices.
   UPS is a special battery unit, that remains plugged into the equipment all time. Hence, it can adequately protect appliances from black-out, since the system becomes active within milliseconds and this property implies that electronic devices do not shut down or reset when the grid fails. In this case, the system is coupled with some didactical trainers in order to allow the provision of courses and activities related to renewable energy technologies. Indeed, these devices could be useful to simulate the operation of renewable energy systems and to test their characteristic parameters.
3. C Scenario: stand-alone hybrid solar-wind system.
   An isolated solar/wind system is independent from the grid and the presence of energy storage allows the system not to be affected by the problem of electricity interruptions. However, for didactical purposes, the presence of an accumulator is not strictly necessary to conduct experiments and tests in a satisfactory manner because solar and wind sources are almost complementary, even though they are intermittent and non-predictable. In this way, the absence of batteries decreases the cost, complexity and maintenance of the overall system despite the slight risk of a cloudy and windless day should be accepted.
   This option could be a good initiative to permit students to learn and analyze the operation of a real multiple technologies' asset. Specifically, the implementation of a mini demonstration hybrid plant for outdoor measurements could be useful to understand the different components and evaluate its performances at different conditions. Furthermore, the system represents a good opportunity to draw the correct data of solar and wind potential in the university area. Finally, this is in line with one of the aim of the project, i.e. the promotion of rural energy access. In fact, hybrid systems are a suitable and cost-competitive solution for electrification in remote areas because they can satisfy the energy demand directly without the necessity of long distribution infrastructure.

Solar potential assessment

The available radiation data vary among the different sources inspected on the web. In particular, databases of NASA [71] and European Commission [72] are investigated and compared.

Since latitude and longitude of the location are the only input parameters required, the European Commission's database has been selected due to its more reasonable value of altitude given in output compared to that displayed from NASA, as shown in *Tab. 5.16*:

	Elevation [m a.s.l.]		
	European Commission	NASA	Datum [91]
Mombasa	22	210	50

Tab. 5.16 Altitude data [71] - [72]

Regarding coordinates, the latitude and longitude of TUM are reported in *Tab. 5.17* considering that the "time zone" is (GMT+03.00) East Africa:

Location	Latitude	Longitude
TUM	4° 2' 19.835" S	39° 40' 6.802" E

Tab. 5.17 Coordinates of TUM

Consequently, it is possible to construct the bar chart representing the locality's Global Horizontal Daily Solar Radiation-I_s (*Fig. 5.7*):

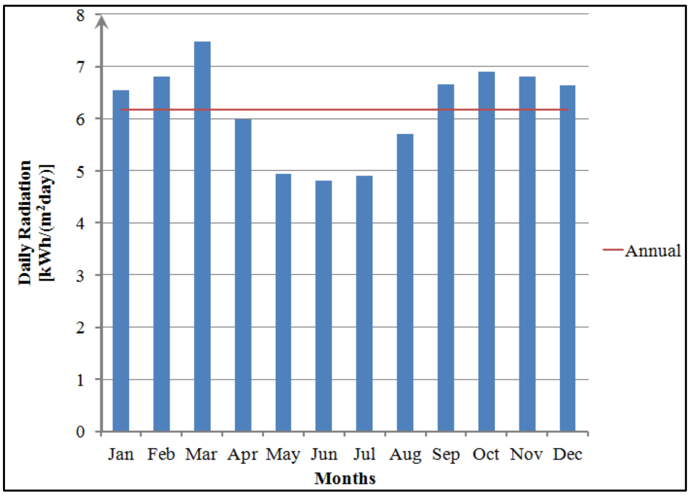

Fig. 5.7 Global Horizontal Radiation

The graph reveals the high potential of solar energy source: in fact, Mombasa receives a solar daily insulation between 4 and 8 kWh per square meter per day thanks to its position near to the Equator (about 4° south of it).

Assuming the maximum irradiance on Earth surface (Solar Radiation Energy Flux, R_s) equal to 1 kW/m^2, achievable at the Equator, it is possible to calculate the daily average solar irradiation hours (h_s) as follows:

$$h_s \left[{kWh}/{(kW \cdot day)}\right] = \frac{I_s}{R_s} \left[\frac{{kWh}/{m^2 \cdot day}}{{kW}/{m^2}}\right] \tag{5.44}$$

These values change for each month and *Tab. 5.18* depicts them for the specific area:

Months	h_s [kWh/(kW·day)]
January	6.54
February	6.8
March	7.48
April	5.99
May	4.94
June	**4.81**
July	4.9
August	5.71
September	6.65
October	6.9
November	6.81
December	6.63
Annual	**5.29**

Tab. 5.18 Daily Average Solar Irradiation Hours (h_s)

Wind potential assessment

NASA database is investigated to assess wind resource present in Mombasa, taking into account that the altitude of the location is not exactly the real one, as yet highlighted in *Tab. 5.16* [73]. Consequently, the wind's speeds are reported in *Fig. 5.8*.

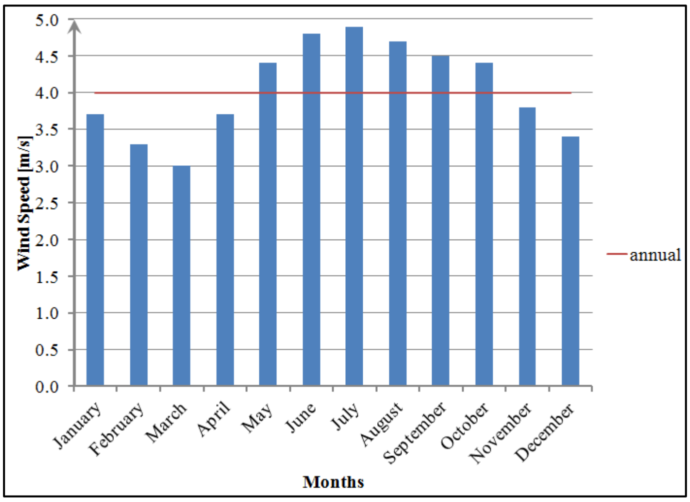

Fig. 5.8 Wind Resource

The picture points out that Mombasa has ample wind resource reaching values over 4.5 m/s for four months in the whole year.

Energy consumption of computers

A preliminary investigation about the amount of energy required by computers and monitors is necessary to define if the idea of supplying them is suitable.

It is worth of noticing that the electricity demand of computers varies with the power needed, with its usage pattern and with users' behavior. In general, an average computer requires between 36 W and 250 W when it is active depending on pieces with which it is assembled. In addition, also monitors use different energy on the basis of the typology: LCD monitors need less energy than CRT ones of equivalent size. In particular, a medium CRT monitor requires between 66 W and 135

W during operation, whereas a typical LCD monitor needs between 15 W and 70 W for functioning. From all these considerations, a reasonable value of the rated power consumed by one stationary computer is estimated around 150 W ($P_{computer}$), which is included in the previous ranges [74].
Specifically regarding ICT labs, in the University there are around 25 computers for each laboratory. Therefore, the request power can be evaluated as follows:

$$P_{\text{computer, ICT}} = P_{\text{computer}} \cdot 25\ computer = 3{,}750\ W = 3.75\ kW \tag{5.45}$$

Workstations are used especially by students for didactical purposes and on average computers are supposed to be used for six hours per day (9 a.m.-12 a.m.; 14 p.m-17 p.m.) from Monday to Friday. In this way, it is possible to calculate the daily energy consumption for each ICT:

$$E_{\text{ICT, day}} = P_{\text{computer, ICT}} \cdot 6\ functioning\ hours\ /day \cong\ 22.5\ kWh/day \tag{5.46}$$

In order to calculate the annual energy consumption, a constant demand is assumed over the year for simplicity, even though in reality this case is seldom. However, the assumption is reasonable due to the alternation of different courses that are attending during all the year.
Hence, considering a number of 253 working days per year, the annual energy consumption of an ICT lab results:

$$E_{\text{ICT, year}} = E_{\text{ICT, day}} \cdot 253 \left[\frac{working\ days}{year}\right] \cong 5{,}693\ kWh/year \tag{5.47}$$

Specifically, the reliable operation of computers could be a key factor for the success of the ENERGISE project since several activities will be carried out via computers. Furthermore, the choice to supply workstations derives also from the examination of the electrical consumption of the mechanical machines installed in laboratories. In fact, these devices consume higher power when they are in operation and they are energy-intensive: for instance, each COLCHESTER Triumph 2000 lathe machine (*Fig. 5.9*), included in Machine Shop 1, is characterized by a value of rated power equal to 2000 W.

Fig. 5.9 Lathe machines

5.2.3. Selection of components

The three scenarios proposed have the aim of reducing the problem of interruptions due to frequent power failures, developing technological know-how and promoting a proper attitude toward research and innovation in the energy field.
The priority is given to local equipment, where possible, to facilitate the maintenance needed for keeping a proper function of devices. In fact it is necessary not only a good education about how the system works, but also a good communication between the planner and the operator in order to guarantee the reliability of machines installed.
In addition, a good compromise between performance and cost is taken into account for the selection of the components.

A scenario: Stand-alone PV system with energy storage for computers

This first option consists of the design of a stand-alone PV system with energy storage to supply a whole ICT lab, i.e. the 25 computers that it includes. *Fig. 5.10* depicts this configuration and its main components, that are the PV panels, the energy storage with a charge controller and a power inverter.

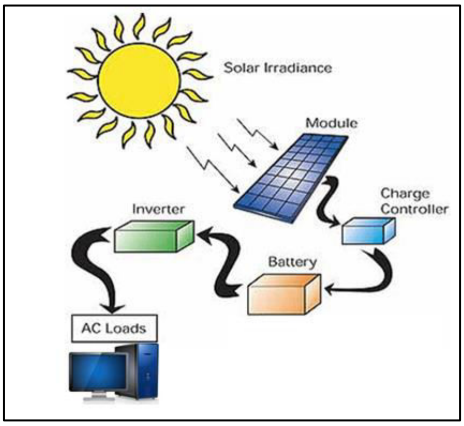

Fig. 5.10 Stand-alone PV System with energy storage [92]

To size the system, the month with lowest radiation (June) and the highest possible load are used, in order to cover the electricity demand for every time of the year.
Then the definition of PV modules' location and installation is needed. PV panels can be mounted on roof tops because they are exposed to higher radiation than on the ground. In particular, the proposed system could be installed on the top of the new department, whose roof has a sufficient extension for the location of PV arrays, as illustrated in *Fig. 5.11*. Concerning this aspect, permissions are not required for academic aims.

Fig. 5.11 New Department

The surface available is indicated in *Fig. 5.11* by the two yellow rectangles and it is equal to 412 m^2. The inclination is horizontal, close to the optimal angle for a fixed solar panel at this latitude which is about 2 or 3 degrees in a North direction.
For the sake of simplicity, a parameter called performance ratio (ρ) is defined to take into account the location and the status of maintenance. In fact, the latter two aspects can influence the level of generation and they are counted in a unique constant, whose value is assumed equal to 0.9.
Finally, it is possible to estimate the power output ($P_{PV\ system}$) as the ratio of the daily average consumption ($E_{\text{ICT, day}}$) and the product between the daily average solar irradiation hours (h_s) and the performance ratio (ρ):

$$P_{\text{PV system}} = \frac{E_{\text{ICT, day}} \left[\frac{kWh}{day}\right]}{h_s \left[{kWh}/{(kW \cdot day)}\right] \cdot \rho} = \frac{22.5}{4.81 \cdot 0.9} \cong 5.2\ kW \tag{5.48}$$

Hence, given the system power output, the panels are selected investigating the proposals of different Kenyan producers. After a deep analysis on the distributors' websites, the polycrystalline panel of 195 W (model SP195-PB) of Sollatek is picked out [75]. Each module contains 72 polycrystalline silicon solar cells and, although they cover a larger surface compared to monocrystalline, in this case the space for the installation is not a constrain. In addition, polycrystalline modules are less expensive and hence they are preferable.
The electrical specifications (irradiance 1000 W/m², spectrum of 1.5 air mass and cell temperature of 25°C) are listed in *Tab. 5.19*:

Specification

Peak Power (P_{pan})	195 W
Nominal Voltage	24 V
Short circuit current	6.01 A
Open circuit voltage	43.2 V
Dimensions	1,485x995x45 mm
Operating temperature	-40°C - 85°C
Maximum system voltage	1,000 V
Weight	17.5 kg
Efficiency Warranty	25 years

Tab. 5.19 SP195-PB [75]

After the selection of the panel, the adequate number to supply an ICT lab is calculated as follows:

$$n^\circ of\ panels = \frac{P_{\text{PV system}}}{P_{\text{pan}}} = \frac{5{,}200}{195} \cong 28\ panels \tag{5.49}$$

The panel's dimensions are 1,485 x 995 mm therefore the total area occupied by the 28 panels is around 41 m^2.
Regarding the accumulation system, it is dimensioned to cover the energy demand required by the 25 ICT computers ($E_{ICT,day}$), assuming one day of autonomy (dd):

$$E_{\text{acc}} = \frac{E_{\text{ICT, day}} \cdot dd}{\eta} = \frac{22.5 \cdot 1}{0.8} \cong 28 \frac{kWh}{day} \tag{5.50}$$

with η = 0.8 (load-reload battery efficiency).
The model singled out is the 200 Ah Solar Battery coming from Sollatek and it is characterized by a voltage equal to 12 V (V_{acc}). Consequently, after the determination of the system capacity, the number of batteries required amounts to:

$$Cap = \frac{E_{acc}}{V_{acc}} = \frac{28{,}100}{12} \cong 2{,}342\ Ah \tag{5.51}$$

$$n°batteries = \frac{Cap}{Cap_{acc}} = \frac{2{,}342}{200} \cong 12 \text{ batteries} \tag{5.52}$$

Another component that shall be selected carefully because it controls the energy flow in the whole system is the charge controller. For this reason, the model chosen is the K12 Charge Controller from Kenital Solar [76] thanks to its high specifications, reliability and quality at a competitive price. It is illustrated in *Fig. 5.12* and its specifications are shown in *Tab. 5.20*:

Specifications	
System voltage	1/24 V
Float Charge Cut Out	18 V
Current max power	13.7/27.4 V
Low voltage cut out	10.5/21 V
Voltage Load reconnect	12.6/25.2 V

Tab. 5.20 K12 SolarCharge Controller

Fig. 5.12 K12 Charge Controller

Finally, an inverter is needed in order to convert the direct current (DC) from the solar panels or batteries into alternating current (AC) required by computers. The solar inverter 2000 W IZZY Power (HT-E-2000, *Fig. 5.13*) from Power Point [77] is adopted on the basis of the maximum requested power from users that is equal to 3,750 W ($P_{computer,ICT}$). Because of that, two inverters are chosen with the features shown in *Tab. 5.21*:

Specifications	
Power	2,000W
Waveform	modified sine wave
Frequency	50/60 Hz +- 3%
DC voltage (input)	12V/24V
Efficiency	>85%
Working Temperature	-15 degrees; + 45 degrees

Tab. 5.21 Inverter HT-E-2000

Fig. 5.13 Inverter HT-E-2000 [77]

B scenario: UPS system + trainer devices

UPS unit is characterized by three main parts, that are batteries in which energy is stored, a charger and an inverter. This last component can include a filter to eliminate noise and distortion from the output wave.
Basically the typologies are classified as follows [78]:

- Off-line/Standby UPS is the cheapest model and it offers a small autonomy. The system comes into operation after about 5-10 milliseconds and it usually has not any kind of protection from unexpected noise or surges, since the equipment is supplied directly from the main grid;

- Online/Double-conversion UPS is the best system thanks to its intervention's readiness and it provides a total protection. In fact, the equipment is powered directly by the battery in order to prevent the noise and, at the same time, to stabilize the current and/or straighten the voltage. On the other hand, it is the most expensive and it has high energy consumptions;
- Line-interactive UPS has intermediate properties between the types mentioned above because it guarantees an intermediate protection in comparison with the offline and online UPSs. The system intervenes after about 5 milliseconds and it represents a good compromise between price and performance: therefore this configuration is selected.

To size the accumulation capacity of the UPS unit, the identification of the didactical equipment for technical and vocational training and the evaluation of their consumption are required. The tools singled out are designed and produced by the Italian De Lorenzo S.p.A. [79], which has already delivered some products to the Ethiopian Jimma University, another partner Institution involved in the ENERGISE project.

In particular, the kit for the study of the photovoltaic solar and wind energies, illustrated in *Fig. 5.14*, is proposed.

Fig. 5.14 DL 3155BRS-PSE [79]

Besides the solar panel, a small fun, a power supply and light for the solar cells, the product comprises a development mother board to hold different sub-modules:

1. two sub-modules with photovoltaic solar cells to exercise with cells in both series and parallel configuration;
2. a sub-module with multifunction display, for the visualization of measurements;
3. a sub-module with charge regulator, that can be connected to an external solar panel;
4. a sub-module with breadboard, for the realization of circuits with components such as photodiodes;
5. a sub-module with battery controller to control the charge of the battery;
6. a sub-module for comparing the efficiency of different light sources;
7. a sub-module with voltage regulators;
8. a sub-module with current regulator and relay circuit to switch between battery and power supply when the battery is out of charge.

Each educational device should be appropriate for a maximum number of 5 students, therefore 6 kits are necessary in order to allow the didactical activities of an average class composed by 25-30 students.

Hence, the total power consumption of the 6 devices amounts to 1.2 kW (P), considering that each one consumes around 200 W.

After this preliminary step, it is possible to establish the maximum output power (S) of the UPS unit, converting the value found from the trainings' total consumption (1.2 kW) into VA unit. The calculation is obtained by dividing the real power expressed in Watt by the power factor cosφ [80]:

$$S = \frac{P}{\cos\varphi} = \frac{1{,}200\ [W]}{0.7} \cong 1{,}700\ VA \qquad (5.53)$$

where cosφ is equal to 0.7, the typical value for electronic equipment.
The power factor is a dimensionless number comprised between 0 and 1; it indicates the effectiveness with which an electrical appliance converts Volt-Amperes to Watts and the higher the value, the more effectively electrical power is utilized.
All these evaluations make possible the choice of the line-interactive UPS system, provided by Sollatek. Specifically, ULTIMA UPS 2000 16% VAT (2000 VA) is suggested and its specifications are listed hereafter:

- fully automatic voltage stabilizer;
- 6 hours to recharge to 90% after full discharge;
- short circuit and overload protection;
- 6 months warranty on batteries.

C scenario: Hybrid solar – wind system

Mini off-grid hybrid system, represented in *Fig. 5.15*, from WindSoleil [81] is selected and it is composed by:

- 20 W solar panel;
- 65 W wind turbine;
- 200 W hybrid controller;
- 300 W inverter.

Fig. 5.15 Solar/wind Hybrid System [81]

To simulate the final use of the energy generated by the asset, a continuous or alternative load should be connected, such as pump or light bulbs. In this way, students can combine different configurations varying the sources or loads, understanding sizing, assembly and maintenance criteria.
Moreover, the presence of the pump can contribute to understand how a pumping system works and this aspect is meaningful in a country like Kenya, where the issue of water scarcity is relevant, especially in rural areas. Therefore, the exploitation of groundwater is a good solution since it is naturally protected from bacterial contamination and reliable during droughts.
Assuming that the space availability for the installation is not a constraint, the following components are added:

- a pump, which works thanks to the electrical power from solar panel or wind turbine and thanks to the presence of the inverter.
  Total head and flow rate are the main criteria to establish which pump is adequate for the didactical purpose of this solution and they are assumed as follows:

$$H \cong 1\,m \quad (5.54)$$

$$Q \cong 0.1 - 0.2\ {}^{l}/_{s} \quad (5.55)$$

Consequently, the pump's operative ranges are illustrated in *Tab. 5.22*:

Flow rate	150 - 800 l/h
Power consumption	3 - 8 W
Pumping head	1-1.5 m

Tab. 5.22 Pump's operative range

- a pump controller;
- 2 tanks, one inferior that simulates the source of water under the ground and the other (transparent to visualize immediately the water level) that accumulates the water pumped. In addition, a valve located in the superior tank could also be adopted for representing the user's consumption. It is worth of noticing that in this case the configuration should be a closed system, in which the water circulated is the same;
- support structure for the superior tank;
- 2 plastic pipes;
- light bulbs;
- valves and switches, that allow to change the type of power supply and the load testing different combinations;
- measuring devices, for instance anemometers, electric energy measurements devices, flow-rate and pressure water measuring tools and wind direction sensors in order to elaborate the acquired data.

5.2.4. Economic analysis of different scenarios

Economic analysis: A scenario

In this scenario, the components' local origin minimizes the shipment costs. Thus, transportation and installation costs are assumed equal to 15% of the total investment cost.

Another assumption consists of neglecting the software's cost because the University could contract some agreements for the expensive ones or adopt those freely downloaded.

After that, it is possible to calculate the A scenario, depicted in *Tab. 5.23*:

	N°of unit	**Price per unit [€/year]**	**Cost [€]**
1. Purchase of Materials			
1.1. A Polycrystalline panel of 195 W(SP195-PB)	28	190	5,320
1.2. 12 V 200 Ah battery	12	250	3,000
1.3. K12 Solar Charge Controller	1	75	75
1.4. 2000 W IZZY Power Inverter (HT-E-2000)	2	300	600
Total Purchase of Materials			~ 9,000
2. Installation and Transportation Costs			1,350
TOTAL			**~ 10,350**

Tab. 5.23 A scenario

Economic analysis: B scenario

In this case, the transport cost is supposed to be equal to 50% of the investment cost because the equipment is imported from abroad. Whereas, the cost of installation is neglected due to the simple and quick installation of devices. *Tab. 5.24* ***Errore. L'origine riferimento non è stata trovata.*** lists the costs related to this alternative:

	N°of unit	Price per unit [€/year]	Cost [€]
1. Purchase of Materials			
1.1. Kit for the study of photovoltaic solar and wind energies (DL 3155BRS-PSE)	6	500	3,000
1.2. Ultima UPS 2000 16% VAT	1	335	335
Total Purchase of Materials			3,335
2. Installation and Transportation Costs			~ 1,670
TOTAL			**~ 5,000**

Tab. 5.24 B scenario

Economic analysis: C scenario

Although the off-grid hybrid kit is not produced locally, the costs are minimized because WindSoleil applies to all products a free shipping worldwide. Also in this case the share of installation and transportation costs is assumed equal to 20% of the total investment, but the predominant term refers to the installation in contrast with the other scenarios. *Tab. 5.25* shows the whole investment cost:

	Cost [€]
1. Purchase of Materials	
1.1. Mini off-grid hybrid kit (WindSoleil)	415
1.2. Other (pump + controller pump + 2 tanks + support structure + plastic pipes + light bulbs + valves and switches + measuring devices)	250
Total Purchase of Materials	665
2. Installation and Transportation Costs	130
TOTAL	**~ 800**

Tab. 5.25 C scenario

5.2.5. Selection of the most appropriate solution

The results from the economic analysis are summarized in *Tab. 5.26* in order to recommend which option is more convenient from an economic point of view:

Scenario	Cost [€]
A. Stand-alone PV system with energy storage for computers	~ 10,350
B. UPS system + trainer devices	~ 5,000
C. Hybrid solar-wind system	~ 800

Tab. 5.26 Cost comparison of different scenarios

Tab. 5.26 highlights that the cheapest alternative is represented by C scenario, whereas the most expensive one is the A scenario.
Regarding A scenario, it exploits the solar source with a technology that is considered commonly the most expensive within the renewable energy systems, due to its high investment costs. In fact, the solar technologies show the highest LCOE (Levelized Cost of Energy), a criterion useful to compare the relative cost of energy produced by different energy-generating sources. It is calculated by dividing the total costs (including construction, financing, fuel, maintenance, taxes, insurance and incentives), by energy generated (kWh), considering all the expected lifetime of the system and bearing in mind that costs and benefits are adjusted for the inflation and that they are discounted to account for the time-value of money [82].

$$LCOE = \frac{Total\ life\ cycle\ cost}{Total\ lifetime\ energy\ production} \tag{5.56}$$

Therefore, an economic and environmental comparison among the different renewable energy assets is conducted thanks to the summarizing table (*Tab. 5.27*):

Technology	**LCOE [$/kWh]**	**gCO_{2eq}/kWh**
Solar PV	0.26-0.75	23-45
Wind Generator	0.15-0.4	5-55
Mini Hydro	0.01-0.4	0.3-13 (run-of-river) 4.2-152 (reservoir)

Tab. 5.27 LCOE and environmental comparison [93]

Despite the high LCOE of the solar PV solution, an aspect in favor of the A scenario is the ability of reducing the electric expense. In fact, the economic benefit of a stand-alone PV system is related to the reduction of the electricity consumption from the grid. Such earning is calculated as the product between the estimated annual electricity consumption and the electricity price, considering the first year after the installation:

$$\text{Income}_{\text{first year}} = \text{E}_{\text{ICT, year}}\,[\text{kWh/year}] \cdot \text{c}_{\text{el}}\left[{}^{€}/_{\text{kWh}}\right] = 5{,}693 \cdot 0.21 \cong \cong 1200\,\frac{€}{\text{year}} \tag{5.57}$$

where c_{el} is the cost of electricity.
However, the profit is not a significant aspect for the selection of the best alternative for the upgrading of technical laboratories, because of it is weakly linked with the didactical purposes of the intervention.
In the wake of it, the solution must be suitable for the specific needs identified within the partner university, taking into account not only the economical factor, but also technical, climatic and socio- economic aspects.
Therefore the C scenario case b), even if it is the cheapest, presents some weak points, concerning for example weather conditions. In fact, during the hot weather in summer or in the rainy season it is complicated to perform different activities outside the room. Another critical aspect is related to the fact that a typical class cannot perform didactical activities in a proper way. In fact, the 25-30 students cannot work simultaneously, but they should rotate, without optimizing laboratory's hours.

Despite that, in a long term vision, this system could be extended with other components: for instance, the introduction of an energy storage or the addition of a pump-as-turbine that simulates a hydro turbine, when the flow is inverted. In addition, when students will improve their know-how about renewable energies, the various components of a hybrid system could be manufactured by them during the workshops also with recycled materials.

However, given these considerations, B scenario represents a good compromise among different aspects:

1. it is simple and easy to maintain because the UPS system is supplied by the local firm Sollatek and, also referring to the electrical devices, they are very reliable with a low failure rate;
2. it is reliable for the reason that it ensures an effective support for performing practical tests and experiments. Furthermore, in case of one component's damage, the didactical activities can be performed without interruptions because 6 devices are provided;
3. it is characterized by a low ecological impact thanks to the silent and the emission-free operation of the UPS system.

Chapter 6 : Conclusions and recommendations

The objective of this study consists of proposing appropriate solutions for the laboratories' upgrading of the two Kenyan Higher Education Institutions, TUK and TUM.
Initially a global assessment of the country has been implemented: the Kenya's economic, social and energy analysis and the comparison with other nations (Ethiopia, Tanzania and Italy in particular) through specific indicators have highlighted that there are deep differences not only among the countries but also within the 47 Kenyan counties.
Regarding the energy sector, despite the great efforts and numerous initiatives undertaken by the Government, some issues remain critical, such as the limited access to electricity and modern fuels, especially in rural areas, the scarce reliability of electricity grid, the insufficient exploitation of renewable sources, although they are abundant, and the high bill's costs incurred by the costumers, just to mention some aspects. Hence, the liberalization of the energy market could be a good strategy to deal with the negative impact of no competition, caused by the almost absolute monopoly of KenGen as regards the power generation. Therefore, enabling private-sector participation in electricity generation should be fundamental to increase efficiency gains and costs reductions. Independent Power Producers (IPPs) should rise in quantitative terms and their generation capacity should be expanded to provide a system more reliable.
Furthermore, several considerations have been taken from the evaluation of the status of education in energy engineering: in particular, the shortage of funds, which affects Kenyan faculties, implies for laboratories outdated equipment without technological development, failing to assure a concrete approach to didactics. Then, in the project's perspective to implement an e-collaborative platform for improving internal communication, collaboration and networking among the involved HEIs, internet connection and the status of ICT labs have been investigated. The findings underline that computers are recent and they get access to the web, but there is urgency to improve internet reliability and bandwidth to accommodate traffic. Instead, regarding teaching methodology, the strong motivation injected by teachers into their students is a positive aspect, whereas the need for more training and advanced courses is stressed by lecturers themselves. Indeed, the necessity of capacity building is essential not only to deliver academic curricula, in line with the ever changing labor market, but also to keep up with the latest technologies. In this sense the upgrading of laboratories equipped with renewable energy technologies could contribute to higher standards and more adequate preparation.
Subsequently, relying on stakeholders' interviews, it has been possible to indentify the most appropriate technology to address the campuses' needs and deal with their critical problems. Although the issues considered involve all the country, it emerges that:

- TUK is affected mainly by the issue of abundance of waste;
- TUM's practical activities are obstructed principally by the weekly interruptions in electricity, compromising the students' preparation.

Therefore, different scenarios has been analyzed and compared to select the best fitting alternative in line with the necessity emerged and with the promotion of renewable energy solutions. The final choice has been made not only looking at an economic criterion, but also considering the action's sustainability. In *Tab. 6.1* the technologies selected are listed, with their equivalent cost and their main components:

Scenario	Components	Cost [€]
FLEXI Biogas system + cook burners	6 bio-digesters + 2 stoves double burner + 3 stoves large burner	3,800
UPS system + trainer devices	1 UPS system + 6 didactical kits	5,000

Tab. 6.1 Solutions proposed

These proposals represent a good starting point to allow on one hand the teaching's continuity and on the other the deepening in renewable energy sources, on which the country should invest for the future. In fact affordable, clean and secure energy is essential to assure long-term economic growth and energy independence and to reduce poverty and inequalities in the country. In particular, in rural areas renewable energies can help in electrification, since it is the cheaper energy option to satisfy energy needs compared to traditional energy solution.

Therefore one of the leverages to be pulled for boosting solutions for access to energy is the enhancement of HEI's initiatives in promoting energy programs and researches. For this reason, it is mandatory that universities are socially embedded, fostering development through direct engagement.

Bibliography

[1] International Energy Agency, *Africa Energy Outlook: On a focus on energy prospects in Sub-Saharan Africa*, 2014

[2] E. Colombo, *Perspectives on the Global Energy Challenge*, 2014

[3] A. Santachiara, *Improved cooking stoves: state of the art , testing and case study of environmental impact for a development project in Malawi*, pp. 1–84, 2013

[4] M. P. Todaro and S. C. Smith, *Economic Development,* 11th Edition, 2012

[5] *IEA - The Energy Development Index* - http://www.iea.org

[6] *About EDULINK | Edulink* - http://www.acp-edulink.eu

[7] *Kenya | Ranking Web of Universities* - http://www.webometrics.info

[8] *Geografia del Kenya - Wikipedia* - http://it.wikipedia.org

[9] *A Brief History on Kenya | Republic of Kenya | The Embassy of the Republic of* Kenya - http://www.kenyarep-jp.com

[10] *Parliament of Kenya: The National Assembly and The Senate* - http://softkenya.com

[11] *2013 Corruption Perceptions Index - Results* - http://www.transparency.org

[12] V. Gallo, *Kenya: Le minacce alla stabilità interna e la ripresa economica*, 2011

[13] *Quadro macroeconomico (KENYA)* - http://www.infomercatiesteri.it

[14] Kenya National Bureau of Statistics (KNBS) and Society for International Development (SID), *Exploring Kenya's Inequality: Pulling Apart of Pooling Toghether?*, 2013

[15] *Poverty - Poverty & Equality Data FAQs* - http://web.worldbank.org

[16] The World Bank, *Poverty Measures*, no. step 3, 2009

[17] United Nations Development Programme (UNDP), *Human Development Report 2006*, 2006

[18] *Kenya: il futuro sarà con l'energia geotermica* - http://www.zeroemission.eu

[19] *U.S. Energy Information Administration (EIA)* - http://www.eia.gov

[20] Ministry of Energy and Petroleum, *Draft National Energy Policy*, 2014

[21] S. Pachauri, N. D. Rao, and K. Riahi, *Access to Modern Energy Assessment and Outlook for Developing and Emerging Regions*

[22] ERC, *Energy Regulatory Commission Strategic Plan 2012/13-2016/17*, 2012

[23] Government of Kenya, *Kenya Vision 2030 A Globally Competitive and Prosperous Kenya*, no. October, 2007

[24] *World Bank Group* - http://www.worldbank.org

[25] Ministry of Energy and Petroleum, *Sessional Paper No. 4 on Energy*, no. 4, 2004

[26] *Kenya Electricity Transmission Co. Ltd. (KETRACO) | Welcome to KETRACO Website* - http://www.ketraco.co.ke

[27] Africa Infrastructure Knowledge Program, African Development Bank Group, The World Bank, and The Infrastructure Consortium for Africa, *Handbook on Infrastructure Statistics Handbook on Infrastructure Statistics*, 2011

[28] P. Antmann, *Reducing Technical and Non Technical Losses in the Power Sector-Background Paper for the World Bank Group ENergy Sector Strategy*, 2009

[29] P. W. Njenga, *Strategies used by Kenya Power and Lighting Company Ltd to reduce non-technical electricity losses*, 2011

[30] S. S. M. Abdullah, *Willingness to pay for Renewable Energy options in Developing Countires: the case of Kenya*, 2009

[31] A. Ngigi, *EAC Strategy to Scale Up Access to Modern Energy Services*, no. April, 2008

[32] Graduate School of Business University of Capetown, *Kenya : enabling private-sector participation in electricity generation*, pp. 1–22, 2010

[33] J. Wendle, *Assessing the impacts of new IPPs at country level? Case study on Kenya*, pp. 18–21, 2009

[34] *Regulus - Web consultancy based in Nairobi, Kenya* - https://regulusweb.com

[35] The Secretary-General’s Advisory Group on Energy and Climate Change (AGECC), *Energy for a Sustainable Future*, no. April, 2010

[36] Winrock International and E+Co and Practical Action Consulting East Africa, *The Kenyan Household Cookstove Sector: Current State and Future Opportunities*, 2011

[37] World Agroforestry Centre and SEI Sotckholm Environment Institute, *From Cleaner Cookstoves to Clean Cooking*, no. May, 2014

[38] Kenya Institute for Public Research and Analysis, *A Comprehensive Study and Analysisi on Energy Consumption Patterns in Kenya*, no. July 2010

[39] *Energy Regulatory Commission* - http://www.erc.go.ke

[40] *GDC | Geothermal Development* Company - http://www.gdc.co.ke

[41] International Atomic Energy Agency, United Nations Department of Social and Economic Affairs, International Energy Agency, and Eurostat and European Environment Agency, *Energy Indicators for Sustainable Development : Guidelines and Methodologies*, 2005

[42] M. Celada and P. Pignatelli, *Analisi di scenario energetico per la Sardegna : situazione attuale , previsione futura e possibili alternative di sviluppo sostenibile*, 2011

[43] J. Nyerere, *Technical & Vocational Education and Training (TVET) Sector Mapping in Kenya*, no. January, 2009

[44] *About | Columbia Global Centers | Nairobi* - http://globalcenters.columbia.edu

[45] G. Wango, *Kenya New Constitution and Education: Education in kenya under the new Constitution*, no. February, 2011

[46] G. Mulongo, *Inequality in Accessing Higher Education in Kenya ; Implications for Economic development and Well-being*, Int. J. Humanit. Soc. Sci., vol. 3, no. 16, pp. 49–61, 2013

[47] A. Kasonzi, H. Von Blottnitz, and U. of C. T. Environmental & Process Systems Engineering Group, *Solid Waste management in Nairobi: A Situation Analysis*, p. 59, 2010

[48] N. K. Gakungu, A. N. Gitau, B. N. K. Njoroge, and M. W. Kimani, *Solid Waste Management in Kenya: a case study of Public Technical Training Institutions*, vol. 5, no. 3, pp. 127–138, 2012

[49] E. and S. C. for A. and the P. ESCAP, *Recent Developments in Biogas Technology for Poverty Reduction and Sustainable Development*, 2007

[50] O. Gb, U. Programme, and N. September, *Urban Poverty and Vulnerability In Kenya*, no. September, 2009

[51] W. Proceedings and R. D. T. H. August, *Stakeholder Forum : The Future of Urban Agriculture in Kenya Stakeholder Forum : The Future of Urban Agriculture in Kenya*, no. August, 2011

[52] *The First Technical University in Kenya | The Technical University of Kenya* - http://tukenya.ac.ke

[53] F. Reale, R. Stolica, M. Gaeta, M. Ferri, M. Sarnataro, and V. Vitale, *Analisi e stima quantitativa della potenzialità di produzione energetica da biomassa digeribile a livello regionale . Studio e sviluppo di un modello per unità energetiche Parte 4 - Studio di un modello energetico*, 2009

[54] P. Suto and C. Peck, *Anaerobic Digestion of Food Waste*, no. March, 2008

[55] A. Babaee and J. Shayegan, *Effect of Organic Loading Rates (OLR) on Production of Methane from Anaerobic Digestion of Vegetables Waste*, pp. 411–417, Nov. 2011

[56] X. Chen, R. T. Romano, and R. Zhang, *Anaerobic digestion of food wastes for biogas production*, vol. 3, no. 4, pp. 61–72, 2010

[57] *Waste Materials – Density Data*

[58] T. Schmidt, *Agro-Industrial Biogas in* Kenya, 2010

[59] S. Fackler and J. Violetti, *Digester Selection and Operation for Heybeli Island*, pp. 1–54

[60] D. Spuhler, *Anaerobic Digestion (Small- scale)*

[61] *Flexi Biogas:* Home - http://www.biogas.co.ke

[62] BIOTECH India and The Ashden Awards for sustainable energy, *Management of domestic and municipal waste at source produces biogas for cooking and electricity generation*, 2007

[63] The GEF Small Grants Programme India, *Types of Biogas Plants*

[64] *How to Build an Underground Masonry Digester | The Complete Biogas Handbook* - http://www.completebiogas.com

[65] *Kenya Expects LPG Consumption to Triple by End of Next Year* - Businessweek - http://www.businessweek.com

[66] The Global LPG Partnership (GLPG), *Kenya Market Assessment*, 2013

[67] *PVGIS photovoltaic software : free tool to assess the PV output power in europe, africa and asia for electrical stand alone or connected to the grid systems* - http://photovoltaic-software.com

[68] *PV Software PV*SOL premium | Valentin Software* - http://www.valentin-software.com

[69] *HOMER Renewable Energy Software | Distributed Power Design Support* - http://www.homerenergy.com

[70] *Welcome | TRNSYS : Transient System Simulation Tool* - http://www.trnsys.com

[71] *ASDC | Processing, archiving, and distributing Earth science data at the NASA Langley Research* Center - https://eosweb.larc.nasa.gov

[72] *PV potential estimation utility* - http://re.jrc.ec.europa.eu

[73] *NASA Surface meteorology and Solar Energy: RETScreen Data* - https://eosweb.larc.nasa.gov

[74] M. Bray, *Review of Computer Energy Consumption and Potential Savings*, no. December, 2006

[75] Sollatek Electronics Limited (Kenya), *Retail Price Liste, effective 1st July 2014 (in KShs)*, vol. 2014, no. July, pp. 1–17, 2014

[76] *Solar Energy... So Simple!!!* - http://www.kenital.com

[77] *Solar Companies in Kenya | Renewable Energy Solutions* - http://www.powerpoint.co.ke

[78] *Come scegliere un gruppo di continuità (UPS) per PC/computer ? | Informatica per* tutti - http://d4rkid.altervista.org

[79] *De Lorenzo Group* - http://www.delorenzoglobal.com

[80] Electronics Quality Power, *Come dimensionare un UPS?*

[81] *WindSoleil* - http://www.windsoleil.com

[82] *Levelized Cost of Energy | SolarPro Magazine* - http://solarprofessional.com

[83] *United Nations Conference on Environment & Development*, Rio de Janerio , Brazil , 3 to 14 June 1992," no. June, 1992

[84] *Vision 2030 | Home* - http://www.vision2030.go.ke

[85] S. Ravizza, *Accesso all' energia : indicatori energetici e strategie di sviluppo*, 2011

[86] *UNESCO-UNEVOC TVETipedia* - http://www.unevoc.unesco.org

[87] Istituto Superiore per la Protezine e la Ricerca Ambientale (ISPRA), *Digestione Anaerobica della Frazione Organica dei Rifiuti Solidi (cap.4)*, 2012

[88] *SHENZHEN PUXIN TECHNOLOGY CO. LTD Catalog of products for biogas application*

[89] *Biotech: Domestic biogas plants. Domestic bio waste treatment, Biogas plant, Biogas plant consultancy, biogas plant kerala* - http://www.biotech-india.org

[90] H. P. K. V. Vidyalaya, *Development and Evaluation of a Fixed Dome Plug Flow Anaerobic Digester*, vol. 16, pp. 225–235, 1988

[91] *Mombasa - Wikipedia* - http://it.wikipedia.org

[92] *Kit stand-alone, module PV* 12V - http://www.solar-rintec.sitiwebs.com

[93] E. Colombo and J. Barbieri, *Technologies for power generation in rural contexts Electrification and Distributed Generation Decentralised and Distributed generation Decentralised Systems (DecS) versus Distributed Systems (DisS)*

[94] Smit, J., A. Ratta and J. Nasr. (2001): "*Urban Agriculture: Food, Jobs and Sustainable Cities. The Urban Agriculture Network*", Inc., New York, NY.