TNA-Project-Yemen

Report I

Technology Needs Assessment for Mitigation and Adaptation

November 2022

List of Acronyms

AREA	Agriculture Research and Extension Authority
BA	Barrier Analysis
BAU	Business-as-Usual
BCM	Bank Cubic Metre
BS	Bus Rapid Transit
BRT	Baseline Scenario
BUR	Biennial Update Report
CAMA	Civil Aviation and Meteorological Authority
CCGT	Combined Cycle Gas Turbine
CFL	Compact Fluorescent Lamp
CHP	Combined Heat and Power
CIF	Climate Investment Fund
CNG	Compressed Natural Gas
CO_2-eq	Carbon Dioxide equivalent
COP4	Fourth Conference of the Parties
CSP	Concentrated Solar Power
DPPR	Development Plan for Poverty Reduction
DTU	Technical University of Denmark
EF	Enabling Framework
EFSNA	Emergency Food Security and Nutrition Assessment
EPA	Environment Protection Authority
EPC	Environment Protection Council
FAO	Food and Agricultural Origination
GCF	Green Climate Fund
GCM	Global Climate Model
GEF	Global Environment Facility
Gg CO_2-eq	Gigagram CO_2 equivalent
GHG	Greenhouse Gas
GJ	Gigajoule
GW	Gigawatt
GWh	Gigawatt Hours
ICZMP	Integrated Coastal Zone Management Programmes
IGOs	Intergovernmental Organizations
INC	Initial National Communication
INDC	Intended Nationally Determined Contribution
IPCC	Intergovernmental Panel on Climate Change
IPM	Integrated Pest Management
LDCs	Least Developed Countries
LED	Light Emitting Diodes
LPG	Liquid Petroleum Gas
LULUCF	Land use, Land-use Change, and Forestry
MAIF	Ministry of Agriculture, Irrigation and Fishery
MCA	Multi-Criteria Analysis
MCM	Million cubic metres

MEE	Ministry of Energy and Electricity
MENA	Middle East and North Africa
MS	Mitigation Scenario
Mt $CO_{2\text{-eq}}$	Megatonne CO_2 equivalent
MW	Megawatt
m/s	Metre/Second
NAMAs	Nationally Appropriate Mitigation Actions
NAPA	National Adaptation Programmed of Action
NASS	National Agriculture Sector Strategy.
NBSAP	National Biodiversity Strategy and Action Plan
NBSAP2	Second National Biodiversity and Action Plan
NCs	National Communications
NCF	National Climate Fund
NDA	National Designated Authority
NEAP	National Environment Action Plan
NG	Natural Gas
NGOs	Non-Governmental Organizations
NMP	National Mitigation Plans
NMVOC	Non-methane Volatile Organic Compounds
NO_x	Nitrogen Oxides
N_2O	Nitrous Oxide
NP	NO Progress
NSREEE	National Strategy for Renewable Energy and Energy Efficiency
NWRA	National Water Resource Authority
NWSSIP	National Water Sector Strategy and Investment Programme
PPCR	Pilot Programme for Climate Resilience
PEC	Public Electricity Corporation
PV	Photovoltaic
RO	Reverse Osmosis
REDD	Reforestation to Reduce Emission from Deforestation and Forest Degradation
SPCR	Strategic Programme for Climate Resilience
SNC	Second National Communication
SO_2	Sulphur Dioxide
TNA	Technology Needs Assessment
TNC	Third National Communication
TAP	Technology Action Plans
TDA	Tehama Development Authority
TJ	Terajoule
UDP	UNEP DTU Partnership United Nations
UNUNCBD	United Nations Convention on Biological Diversity
UNCCD	United Nations Convention on Combating Desertification
UNDP	United Nation Development Programme
UNEP	United Nations Environment Programme

UNEP-CCC	UNEP Copenhagen Climate Centre
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework on Climate Change Convention
UNOPS	United Nations Office for Project Services
US	United States
USA	United States of America
USD	United States Dollar
VES	Vertical Electrical Sounding
WWF	Worldwide Fund for Nature
WWSP	Waste Water Stabilization Ponds
UNOPS	United Nations Office for Project Services

List of Contents

List of Tables

List of Figures

Annexes

Executive Summary

Background

Despite its national circumstances and significant socio-economic challenges, Yemen moved forward to address climate change issues in terms of adaptation and mitigation. Yemen ratified the United Nations Framework on Climate Change Convention (UNFCCC) in 1996 and submitted its Initial National Communication (INC) to the Conference of Parties in 2001. In 2009, Yemen developed its National Adaptation Programme of Action, which proposed a number of measures and interventions to enhance the country's resilience and build adaptive capacities for climate change impacts within the most vulnerable sectors: water, agriculture, and coastal zones. In 2013, Yemen finalized the Second National Communication (SNC), which identified the mitigation and adaptation priority options for all related sectors. Moreover, the SNC set a target for reducing GHG emissions by 23% in 2025 within the energy sector by promoting energy efficiency options, renewable energy, and fuel switching.

In the meantime, Yemen is considered one of the most vulnerable countries to climate change impacts, and it is among the Vulnerable Twenty (V20) Group, which represents the 20 most vulnerable countries in the world. In addition, the unstable political and economic situation has contributed to a significant vulnerability and more threats in several sectors, particularly water, agriculture, and coastal zones associated with, loss and damage to the country's infrastructure. However, the total emissions of Yemen, according to the last GHG inventory in 2010, are very low as the CO_2 metric tons' per capita emission does not exceed 0.4. Furthermore, in the last seven years, GHG emission is expected to be lower because most people have shifted to solar panels to meet their household energy and to natural gas for fueling their vehicles. This policy was a consequence of the war, which destroyed most of the electrical power systems in the country and led to frequent rolling blackouts in the electricity supply for more than 18 hours a day in most of the Yemeni cities.

Moreover, due to the country's unstable political and economic situation, the pathway of addressing climate change was influenced negatively due to the increase of the humanitarian crisis, which meant that climate change activities were not among the most pressing concerns compared with social issues, such as poverty, health, and education. Consequently, Yemen has not received any funds under climate finance for more than five years.

Recently, the Yemeni government started to reactivate its national institutions to carry out their entrusted missions to achieve rapid recovery from the consequences of the war. The government has set climate change as one of the most pressing issues that need to be promptly addressed due to the increasing of its significant impacts in recent years, especially its implications on the key economic sectors, such as agriculture, water, and fisheries. Moreover, in partnership with UNDP, Yemen is preparing an economic recovery Programme to address the effects of the civil war on the economy. One of the topics to be considered is Yemen's climate resilience recovery and Yemen's Renewable Energy Investment Planning and Design as a potential solution to electricity scarcity.

Accordingly, the NDA resubmitted its first readiness project to the Green Climate Fund (GCF) in 2021 and the project was successfully approved. The project aims to enhance the capacity of the National Designated Authority (NDA), represented by the Environment Protection Authority

(EPA), to achieve an effective engagement with GCF. At the same time, Yemen Government, represented by the EPA, has signed an agreement with UNEP/UNOPS Copenhagen Climate Centre (UNEP-CCC) (formerly UNEP DTU Partnership (UDP)) to initiate the process of the Technology Needs Assessment (TNA) project. The TNA process provided an opportunity for Yemen to reactivate the climate change momentum in the country through stakeholder engagement in the TNA meetings and workshops.

TNA is a tool through which Non-Annex I countries could assess and identify the most appropriate technology options required for both key areas under climate change adaptation and mitigation. This report shows the process of technology option identification to help to limit the growth of GHG emissions within the context of sustainable development for the energy and transport sectors and enhance the country's adaptive capacity against the negative impacts of climate change on the two most vulnerable sectors (water and agriculture). Thus, the main objective of this work is to identify and select the most useful and applicable mitigation and adaptation technologies. Accordingly, this first stage of the TNA project has been divided into two main parts. The first part is to identify prioritized sectors and sub-sectors under mitigation and adaptation, while the second part is to prioritize the most technologies suitable and effective in GHG emission limitation and climate resilience enhancement.

Methodology of Prioritization process:

The Multi-Criteria Analysis (MCA) process is the methodology used for identifying and prioritizing sectors, sub-sectors, and areas of interest in mitigation and adaptation. The adopted procedure to carry out the selection and identification processes for mitigation had to meet several criteria, including reduction of GHG emission potential, dependency on fossil fuel, technology availability, attracting investment, market penetration, and mitigation cost. The same process was followed for adaptation, but with different criteria set by the experts and stakeholders, including sector vulnerability to climate change, adaptive capacity, national priority, socio-economic importance, availability of the technology, and adaptation cost. For both mitigation and adaptation prioritization processes, Multi-Criteria Analysis (MCA) was applied, guided, and performed by climate change experts from the relevant stakeholders and policymakers. This process has resulted in the selection of the energy and transport sectors under mitigation and the water and agriculture sectors under adaptation as the two most vulnerable sectors. The prioritization and selection of the technology options were performed in three workshops, one for inception and two consultative for adaptation and mitigation.

For all sectors, the process of technology selection was conducted based on the list proposed by the TNA team and participants from the stakeholders. In the consultative workshops, stakeholders from relevant ministries, organizations, academic centers, and private sectors, in addition to the TNA team were actively engaged in identifying, scoring, and prioritizing of technologies using Multi-Criteria Analysis (MCA). Moreover, the criteria used to assess and evaluate the technology options were also proposed and weighted by the stakeholders with TNA team guidance. Fact sheets were also prepared and shared with the participants prior to the workshops to provide brief description of each technology including the cost of the technology, the application potential in the country, the mitigation of GHG emissions, adaptive capacity enhancement, and other social, economic, and environmental benefits. The results of the prioritization process for mitigation and adaptation were as follows:

Mitigation technologies:

In the energy sector, twelve options divided between energy efficiency and cleaner and renewable energy were proposed by the TNA team and stakeholders. These options were evaluated and prioritized using nine different criteria. The top four potential options for mitigation in the energy sector are (1) Light Emitting Diodes (LED) Lighting, (2) Off-grid, On-grid PV systems, (3) Wind turbines, and (4) Solar water heating. All selected options are reasonable and represent the country's needs for GHG mitigation and sustainable development. LED lighting and solar water heating are considered as energy-efficiency options, and they can reduce the consumption of energy by at least 80% compared to conventional lighting and electrical heaters. On another side, Off-grid, On-grid PV systems, and wind turbines are the most potential renewable energy resources in Yemen. Both options are future-promised technologies to solve the energy crisis in the country.

In transport sectors, fourteen mitigation technology options were initially suggested by the transport consultants and stakeholders, which were clustered as infrastructural options or transport means/fuel used options. After intense discussions and consultations with the TNA coordinator and the TNA team, only eight technology options were considered to be more suitable for Yemen.

The stakeholders, guided by the TNA team, proposed seven criteria options and assigned the initial weight for each criterion for the prioritization process of the technology options. The scores and ranking of the final prioritization process of the technology options for the transport sector were tabulated. The first four mitigation technology options for the transport sector were as follows: (1) Bus Rapid Transit (BRT), (2) Improving By-Roads, (3) Promoting Hybrid Vehicles, (4) Switching to Natural Gas Vehicles. These four options represent the country's needs in the transport sector for GHG mitigation purposes, and are aligned with current national policies and strategies in the transport sector.

Adaptation Technologies:

Since the agriculture and water sectors are interlinked, it was found that some proposed technologies are applicable to both sectors. Also, criteria selected for evaluating the usefulness of technology options were found to be applicable for both sectors as well.

Existing technologies for the water sector are generally conventional and have been practiced for hundreds of years countrywide. Similarly, as for the agriculture sector, during the TNA project inception and consultative workshops, an extensive list of existing technologies for the water and agriculture sectors was identified. The extensive list of existing technologies for water sector consisted of twenty-six technologies, while for agriculture sector it consisted of twenty main technologies and several sub-technologies. To ensure that selected technologies are in line with national and sectoral policies and strategies, all national reports of policy documents were consulted to take stock of the already identified vulnerabilities, adaptation measures, priorities, and efforts related to the focus areas. Such documents include climate change National Communications (NCs), agriculture and water sector strategies, and the National Adaptation Programme of Action (NAPA).

Based on the selected criteria, the technologies have been arranged, and scale limits in percentage for each criterion were decided and elaborated to obtain weights in score points in order to rank the technologies and prioritize them accordingly. Then, per the TNA guidance, participants went through a prioritization and ranking process for technology options and came up with a top list of four ranked technologies in each sector under adaptation. ***For the Water sector,*** the selected technologies are (1) Saline Water Desalination, (2) Rainwater Harvesting Techniques (3) Diversion Facilities and Channels, (4) Wastewater Recycling and Reuse. ***For agriculture***, the final prioritized options are (1) Irrigation saving techniques. (2) Water harvesting and storage technology for agricultural purposes (3) Agriculture soil management and conservation (4) Reuse of treated wastewater and greywater. All selected options under adaptation are suitable for the different climatic zones in Yemen. For example, Saline Water Desalination technology is a priority for the people in the coastal area, whereas rainwater harvesting is more applicable in the mountains, valleys, slopes, etc.

Finally, this report assessed the most prioritized applicable technologies to address climate change issues from both adaptation and mitigation point of view. It is therefore anticipated to take two of the four top technologies identified for each sector to the next step (Step II) Barrier Analysis and Enabling Framework (BA&EF) to identify the barriers and challenges that hinder the implantation of these options in the country and propose an action plan to mainstream them into the national climate change polices.

Chapter 1: TNA Project

1.1 About the TNA project

Based on Articles 4.1(c), (j), and 12 of the United Nations Framework Convention on Climate Change (UNFCCC)(United Nations 1992), countries are periodically required to submit reports to the Conference of the Parties on various topics about their attempts to address climate change issues. Since the ratification of the Convention in 1996, Yemen, despite its critical national circumstances, has taken serious steps to fulfil its obligations to the conventions. In order to fulfil its requirements and to participate effectively with the international community in the climate change process, Yemen developed and submitted its Initial National Communication, Second and Third National Communications (INC, SNC & TNC) to the UNFCCC in 2001, 2013, and 2018, respectively. Although it has fallen into a conflict and unstable situation, Yemen prepared and submitted its Intended Nationally Determined Contribution (INDC) in November 2015, but due to some institutional arrangement's challenges, it has not yet submitted its First NDC to the UNFCCC. Under National Communications exercises, Yemen developed its national inventory of greenhouse gases from 1995 to 2010, assessed and updated its vulnerability to climate change, and proposed appropriate mitigation and adaptation measures. Whereas the INDC presented Yemen's intended efforts to reduce GHG emissions and the specific measures to respond to the impacts of climate change issues on the vulnerable sectors.

Moreover, fulfilling the national obligation to UNFCCC implies that Yemen should have the human, organizational, technological, institutional, and financial resources to develop the required tasks and functions on a permanent basis. Article 4.5 of the United Nation Convention for Climate Change (UNFCCC) states that developed country Parties "shall take all practicable steps to promote, facilitate, and finance, as appropriate the transfer of, or access to, environmentally sound technologies and know-how to other parties, particularly developing country Parties, to enable them to implement the provisions of the Convention." Based on the request made by the Parties to the UNFCCC at the Fourth Conference of the Parties (COP4), the UNFCCC Secretariat conducted a consultative process to help identify and define key elements of a framework for technology transfer under the UNFCCC 2006. Furthermore, Article 4.7 of the Convention alludes to the dependence of developing countries for financial support and technology transfer to enable them to effectively implement their obligations under the Convention. Decision 4/CP.7 of the UNFCCC adopted a Framework for meaningful and effective actions to enhance the implementation of Article 4.5 and also established an Expert Group on Technology Transfer(The Conference of the Parties (COP 7) 2001).

The Technology Needs Assessment project (TNA), funded by the Global Environment Facility (GEF), managed by the United Nations Environment Programme and United Nations Office for Project Services (UNEP/UNOPS) and that will be executed by the Environment Protection Authority (EPA), aims at assisting Yemen in identifying and analysing priority technology needs to mitigate GHG emissions and reduce the vulnerability of sectors and community livelihoods to the adverse impacts of climate change.

The main objectives of the project are:

- To identify and prioritize through country-driven participatory processes, technologies that can contribute to mitigation and adaptation goals of Yemen while meeting the national sustainable development goals and priorities.
- To identify barriers hindering the acquisition, deployment, and diffusion of prioritized technologies.

- To develop Technology Action Plans (TAP) specifying activities and enabling frameworks to overcome the barriers and facilitate the transfer, adoption, and diffusion of selected technologies in Yemen.
- To develop project concept notes for selected technologies in prospect for future funding.

1.1.1 Yemen Institutional Response to Climate Change

Following the unification in 1990, the government created the Environment Protection Council (EPC), an inter-ministerial council that manages the nation's environment. In 2003, the Environment Protection Authority (EPA) was established to replace the EPC with a broader mandate covering setup of environmental policies and strategies, enforcing standards for air and water pollution and land degradation, monitors the environment, implement environmental related activities, programmes, and projects, and coordinates national, regional, and international action on environment protection in Yemen.

Yemen as a Non-Annex I country under the United Nations Framework Convention on Climate Change, ratified -the convention in 1996 and the Kyoto Protocol in 2003, obtaining access to development funding through Kyoto's Clean Development Mechanism. Yemen is also a signatory to multilateral environmental conventions such as The United Nations Convention on Biological Diversity (UNCBD), The United Nations Convention on Combating Desertification (UNCCD), Environmental Modification, Hazardous Wastes, and Ozone Layer Protection. For most of the environmental conventions ratified by Yemen, EPA is the national focal point. As the UNFCCC Operational Focal Point, EPA is responsible for coordinating all climate change-related activities that address GHG mitigation, enhancement of country's resilience to climate change impacts, and building adaptive capacities.

Besides national Communications and INDC, Yemen through EPA implemented several assessments, studies, and projects to address impacts of climate change vulnerability on various sectors, such as the National Adaptation Programme of Action (NAPA) and Pilot programme for Climate Resilience (PPCR).

The NAPA had listed the major vulnerabilities for seven economic sectors which includes the water resources, agriculture/food security, coastal zones and fisheries, and coastal infrastructure (Environment Protection Authority 2009). The primary goals of NAPA which was developed in 2009 were to prioritize measures to adapt to climate change and climate variability and translate them into project-based activities that can address Yemen's urgent needs to enhance the adaptive capacity and resilience to adverse impacts of climate change. This was through a process to identify of an extensive list of interventions that can address the immediate and urgent needs. Yemen NAPA process consisted of two key steps for prioritization of adaptation projects consisted of. Through a scoring, weighting, and ranking process – part of a multi-Criteria Analysis –a discrete set of prioritized adaptation activities was developed for each ecological zone and for each priority sector. The initial list of 95 interventions (obtained through the country-wide consultation process) was thus narrowed down to 22 options, and further to 12 priority options. After considering how they could be integrated into the national planning process, these were then clustered into four major categories:

Table 1.1.1:1 NAPA Outcomes

Sector	NAPA Adaptation Activity
Water	Rainwater harvesting through various techniques including traditional methods. Water conservation through watershed management and reuse of treated waste. water and grey water from mosques, and irrigation saving techniques.
Agriculture	Rehabilitation and maintenance of mountainous terraces. Promotion of research on drought resistant and heat- and salinity-tolerant crops. Development and implementation of sustainable land management strategies to combat desertification and land degradation.
Coastal Zones	Planting and re-planting of mangroves and palms for adaptation to sea level rise. Coastal zones sustainable management of fisheries resources. Development and implementation of Integrated Coastal Zone Management Programmes (ICZM).
Cross-Sectoral	Implementation of an awareness raising programme on adaptation to the potential impacts of climate change on vulnerable sectors. Development and implementation of programmes to improve Yemen's preparedness to cope with extreme weather events. Establishment and maintenance of a Climate Change Database.

The Pilot Programme for Climate Resilience (PPCR I) is an initiative by the World Bank under the Climate Investment Fund (CIF) to provide pilot support for only nine selected countries from all regions of the world (World Bank 2011). For countries to be eligible to participate in the Programme, the world Bank developed a selection procedure, and countries - including Yemen - were engaged through a competition process in which Yemen invested a lot of efforts, worked hard and provided all possible information and justifications, and finally was selected as the only pilot country from the Middle East and North Africa (MENA) Region. The PPCR goal was to mainstream Climate Resilience into development for transformational change to address climate resilience as a core development issue, and as part of a comprehensive response to various vulnerabilities facing Yemen. The specific objectives of the programme were:

i. Mainstream climate change and resilience into national and sectoral development, policies, plans, and programmes including private sector initiatives.
ii. Target the vulnerable stakeholders and communities especially women who are disproportionally affected by climate change.
iii. Raise awareness and strengthen capacity to deal with climate change in government, the private sector, local communities and civil society groups; and
iv. Scale-up successful climate resilient pilot investments to bring about transformational change.

The PPCR was designed to be implemented in two phases. Phase I is for preparing and designing the required priority interventions, and phase II is for implementing the findings of phase I. Funding allocated for phase I was up to USD1.5 million for a period of one and half year, and activities were launched in January 2011. However, due to the unstable situation that started later in 2011, activities could not be completed on time as scheduled and required more time to be completed in June 2014. The four pillars under this phase are:

- Pillar 1: Climate Change Information systems and public Awareness
- Pillar 2: Mainstreaming Climate Change Resilience into National Development Planning
- Pillar 3: Formulation of Yemen's SPCR and Identification of Phase II Interventions
- Pillar 4: Programme Coordination of the PPCR

Key tasks under this phase include assessment and capacity building, awareness raising, and formulation of Strategic Programme for Climate Resilience (SPCR) as a framework of investment strategy and priority interventions.

In the second phase (Phase II), the main objective was to implement the Strategic Programme for Climate Resilience and the allocated fund for this phase was up to USD58 million in Grants. The programme consisted of four investments:

- INVESTMENT I: Climate Information System and PPCR Programme Coordination.
- INVESTMENT II: Improving the Climate Resilience of the Water Sector.
- INVESTMENT III: Improving Rural Livelihood Through Adaptation in Rain-fed Agriculture Project.
- INVESTMENT IV: Climate-Resilient Integrated Coastal Zone Management Project.

However, due to the strong interlinkages between investment two and three, it was - at a later stage - more appropriate to combine and merge the two investments into one investment. Preparatory steps for phase II implementation were initiated even before the closing of phase I, where the SPCR document was already finalized, submitted to the World Bank, and approved.

Unfortunately, implementation of investments under phase II was interrupted and halted due to the dramatic deterioration of the situation and the outbreak of war by the end of 2014. At first, the World Bank suspended the programme (among others in the country), and at a later stage it was cancelled which is unfortunate and considered a great loss after years of efforts and hard work.

Accordingly, since the armed conflict started in 2014, the climate change issues had not become one of the government priorities due to the deterioration of the humanitarian situation. However, climate change impacts are increasing from one year to another. Meanwhile, the country's adaptive capacity has declined and vulnerability to climate change of key vulnerable sectors, water resources, agriculture, and coastal zones has increased. Moreover, in many cities, infrastructure such as energy supply, transportation facilities, water channels and networks, agriculture systems were significantly affected by the conflict.

Recently, the Yemeni government started to reactivate its national institutions to carry out its entrusted missions to achieve rapid recovery from the consequences of the war. The government has set climate change as one of the most pressing issues that need to be promptly addressed due to its significant impacts in the last five years, especially its implications on the key economic sectors, such as agriculture, water, and fisheries. Moreover, in partnership with UNDP, Yemen is preparing for an economic recovery programme to address the effects of the civil war on the economy. One of the topics to be considered is Yemen's climate resilience recovery and Yemen Renewable Energy Investment Planning and Design as a potential solution to electricity scarcity.

Accordingly, the NDA submitted its first readiness project to the Green Climate Fund (GCF) in 2021 and the project was successfully approved [1]. The project aims to enhance the capacity of the National Designated Authority (NDA), represented by EPA to achieve an effective engagement with GCF. At the same time, the Yemen Government represented by the EPA signed the agreement with UNEP & DTU Partnership (UDP)[2] to initiate the implementation process of the Technology Needs Assessment (TNA) project. Therefore, TNA provided an opportunity for Yemen to reactivate the climate change momentum in the country, through stakeholder engagement in the TNA meetings, and workshops.

1.1.2 Rationale of TNA Project

Currently, Yemen, through its Climate Change Unit under EPA, is motivated to effectively address climate change issues and activities through: (i) mainstreaming climate change considerations into national and sectoral development, policies, plans, and programmes; (ii) raising climate change awareness among key stakeholders including government representatives, private sector, local communities, and civil society groups; (iii) explore and mobilize resources to implement activities and projects, and (iv) engaged effectively with the regional and international community.

In order to achieve these targets, Yemen has initiated several approaches to re-establish and re-activate communication channels for cooperation and coordination with international organizations and donor communities. Among other steps, Yemen initiated the process of participating in the TNA programme supported by the Global Environment Facility (GEF). Thus, the TNA project is crucial for EPA and Yemen as the Yemeni government is currently implementing an economic recovery strategy, and addressing climate change impacts and energy issues is one of the new government's concerns. Therefore, the TNA project comes to complement all the efforts of the government of Yemen to combat climate change and aims to provide new and additional information that responds to concerns, generates new findings for policy reform, and shapes action plans for interventions.

1.2 Existing National Policies Related to Technological Innovation, Mitigation of GHG and Adaptation to Climate Change, and Development Priorities

1.2.1 National Circumstances

1.2.1.1 Geography & Topography

Yemen is an arid Middle Eastern country, occupying an area of 527,970 square km at the southern end of the Arabian Peninsula. It is bordered to the north by Saudi Arabia, to the East by Oman, and to the South and West by a 2,200 km coastline along the Gulf of Aden, Arabian Sea and the Red Sea. As seen in figure 1.1, Yemen controls Bab-Elmandeb, the strait between the Red Sea and the Gulf of Aden, a heavily used shipping lane.

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[1] https://www.greenclimate.fund/document/strengthening-national-designated-authorityin-yemen-and-enabling-strategic-frameworks

[2] This agreement was superseded by the agreement with UNOPS after the transition of UDP to UNEP-CCC in 2022.

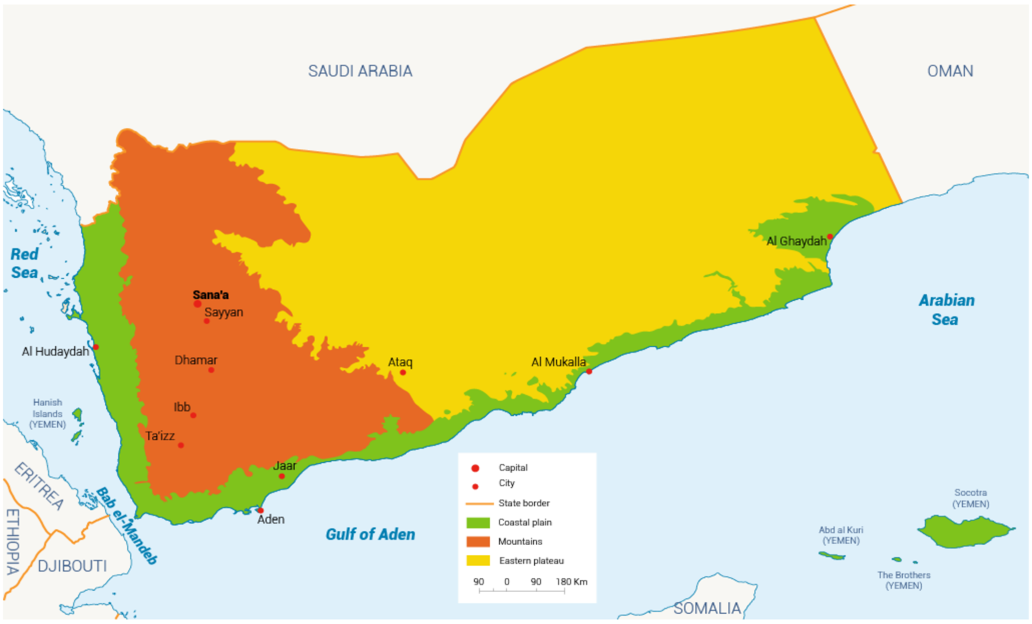


Figure 1.2.1.1:1 Yemen’s Regional Map

The country as shown in figure 1.1 are characterized by five major land systems:

1) A hot and humid coastal plain, 30-60 km wide, along the Red Sea and the Gulf of Aden.
2) The Yemen Highlands, a volcanic region with elevations between 1,000 and 3,600 m parallel to the Red Sea coast, and with temperate climate and monsoon rains;
3) The dissected region of the Yemen High Plateaus and the Hadramout - Mahra Uplands, with altitudes up to 1,000 meters.
4) The Al-Rub Al-Khali desert interior; with a hot and dry climate
5) The islands, including Socotra in the Arabian Sea and more than 112 islands in the Red Sea.

Yemen's coastal and marine ecosystems which include extensive mangroves, coral reefs, and sea grass areas are of major economic importance for fisheries and tourism. Some of Yemen’s ecological zones are confined to small areas (e.g., islands), with human communities, animals and plants highly adapted to subsist within them. Other zones are much larger (e.g., Temperate Highlands) and support most of the country’s agricultural production. In both cases, climate change poses a major threat.

1.2.1.2 Population

The current population of Yemen is around 30 million as of October 2021, based on World meter elaboration of the latest United Nations data. According to a recent study, 38.4% of the population is urban (11,465,414 people in 2020) and the majority, about 71%, live in rural areas.
Although the country’s population is currently predominantly rural in nature, urban populations are increasing rapidly. Between 2000 and 2016, the percentage of urban population increased from 26% to 29%. The continuing urbanization trend is attributable to increased immigration to urban cities along with a proliferation of unplanned settlements. High urbanization rates have led to environmental degradation in cities. Recently, due to the aggravating of climate change impacts on agriculture and water sector in the last ten years, which coincided with the armed conflict in

last seven years, the migration from rural to urban areas is noticeably increased, but it needs to be quantified.

Table 1:2 Expected population increase[3]

Year	Population	Yearly Change
2020	29,825,964	2.39 %
2025	33,140,296	2.13 %
2030	36,406,888	1.90 %
2035	39,602,684	1.70 %
2040	42,670,011	1.50 %
2045	45,522,739	1.30 %
2050	48,080,021	1.10 %

1.2.1.3 Climate

Yemen's climatic conditions vary from a hot and dry climate in the coastal plains regions and low mountain slopes, to a temperate climate in the highlands. Between these two extreme climates, there is a transitional arid subtropical climate. This variation leads to wide differences in climatic conditions and consequently to the formation of different agro-climatic zones.

In addition to its location on the margins of the tropics, Yemen is characterized by a diverse physical and topographical feature, it has a diverse and uncertain climate which is quite hard to predict. These extreme differences in elevation and significant topographical variations are largely responsible for the great variations in temperature and climate over the country.

Moreover, there is insufficient daily temperature data available to determine trends in the frequency of hot and cold days and nights, as well as insufficient daily precipitation data available to determine trends in heavy rainfall events (Environment Protection Authority 2001).

There are well-recognized data quality concerns associated with the daily and monthly meteorological records. Meteorological data are not held by a central authority but are collected by several authorities which include the Civil Aviation and Meteorological Authority (CAMA), Ministry of Agriculture, Irrigation and Fishery (MAIF), National Water Resource Authority (NWRA), Agriculture Research and Extension Authority (AREA) and the Tehama Development Authority (TDA).

Historically, the mean annual temperature has increased by 1.8°C since 1960, a rate of around 0.39°C per decade. The rate of increase is most rapid in summer, with increases at an average rate of 0.56°C per decade and slower in winter at a rate 0.21°C per decade. The rate of warming in Yemen is more rapid than the global average, and this is consistent with what the Intergovernmental Panel on Climate Change (IPCC) projected in its Fourth Assessment Report of higher rates of warming over East Africa and the Arabian Peninsula than the global average(Haidera et al. 2011).

A series of studies has sought to reduce the uncertainty of climate projections for Yemen. In the absence of consistent climate change projections amongst various models and lack of adequate historical climate data, these studies concluded that without homogeneous rainfall and

[3] https://www.worldometers.info/world-population/yemen-population/

temperature records, it is difficult to benchmark future climate variability and change, or the associated impacts. Results of three simplified climate change scenarios used to illustrate the range of possibilities up to the end of century are as follows:

- A *"hot and dry"* scenario of higher warming of 2 to 4.5 °C, with aridity dramatically increased due to the combined effects of low rainfall and high evapotranspiration.
- A *"mid"* scenario, with considerable warming of 1.6 to 3.1 °C but no significant change in rainfall.
- A *"warm and wet"* scenario with lower warming of 1 to 1.6 °C and an increase in rainfall.

While three models used for other studies suggest an increase in rainfall variability and heavy precipitation events. Two of the models project significant increases in rainfall (of 10% and 21% in the spring months), whilst the third suggests a decrease of 13%. These large uncertainties are partly related to differences amongst models in the future behavior of the Inter-Tropical Convergence Zone (ITCZ) over East Africa and the Middle East and the complexity of the modeling process (World Bank 2010).

Based on an ensemble of 21 Global Climate Model (GCM) simulations, the Intergovernmental Panel on Climate Change (IPCC) in its Fourth Assessment Report projects higher rates of warming over East Africa and the Arabian Peninsula than the global average. It is considered 'very probable' that heat waves and heavy precipitation events will become more frequent throughout the region (IPCC, 2007) but the range of uncertainty related to future rainfall is large.

There is an agreement among all models that all areas of Yemen will get warmer. Across the entire country, mean annual temperature is projected to increase by 1.2 to 3.3°C by midcentury, and 1.6 to 4.5 degrees by the end of century. The range of projections by the end of century under any one emissions scenario is around 1.5 to 2.0°C (Mcsweeney, New, and Lizcano n.d.).

Analyses done for the UNDP Yemen Climate Change Country Profile, using an ensemble of 15 climate models and three emissions scenarios, confirm this prediction. The results (Figure (1.2) presented rises in mean annual temperature of up to 5°C by 2100 (Mcsweeney et al. n.d.).

Results of a study undertaken under the TNC of the temperature simulations as illustrated in Figure (1.3) also indicate that all areas of Yemen will get warmer, with the greatest change projected to occur during the winter months. Across the entire country, annual mean temperatures show the greatest rise under the A1B scenario, between 1.7 °C and 2.4°C by the 2050s, with an average annual increase of 2.0°C. Seasonal mean temperatures are also projected to increase by 2050. For each of the emission scenarios, the largest seasonal temperature increases occur during the winter months and the smallest seasonal temperature increases occur during the summer months.

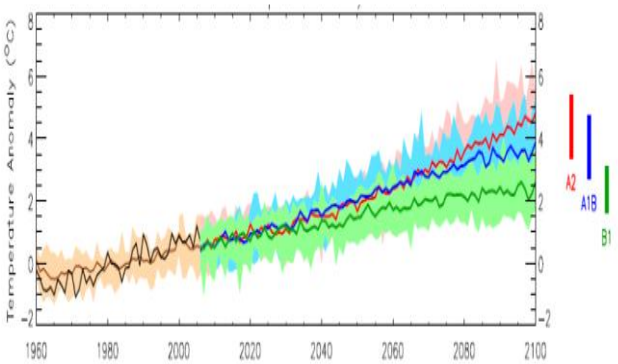


Figure 1:2 Temperature projections up to 2100
Source: UNDP Yemen Climate Change Country Profile 2008

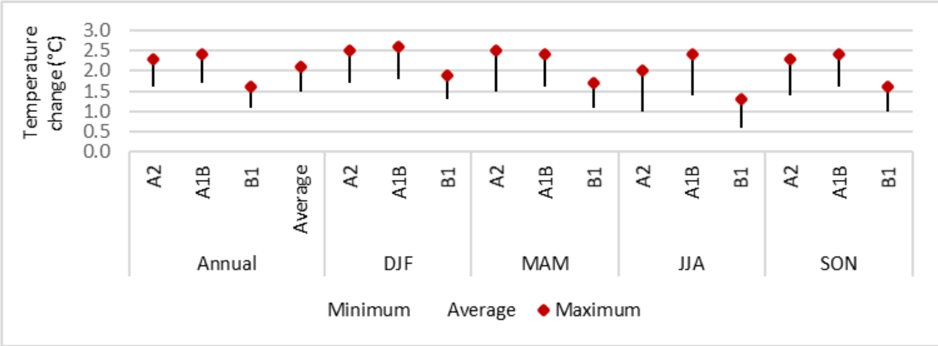


Figure 1:3 Projected change in temperature for Yemen, 2050. (Source: Yemen TNC 2018)

For precipitation, there is greater uncertainty of projections from different models in the ensemble that suggest a wide range of both positive and negative changes with annual rainfall as some season-scenario combinations show a future increase and others show a decline in rainfall. The dominant characteristic of Yemen's climate in terms of rainfall is the high variability, erratic, and unpredictable from year to year. While uncertain, the regime of Yemen is also characterized by short-lived, intense storms that generate flash floods, interspersed between the long dry periods of severe drought (Environment Protection Authority 2018).

Thus, projections confirmed that national and local predictability of climate is low for Yemen. While there is little agreement on the direction or magnitude of changes in rainfall other than to confirm the likelihood of increasing unpredictability and of concentration of rainfall in more intense events, there is, as mentioned above, the strong agreement that temperatures will increase. Results of the precipitation simulations of the same study under TNC, as illustrated in Figure (1.4) confirmed that there is greater uncertainty with annual rainfall change projections as some season-scenario combinations show a future increase in rainfall and others show a decline in rainfall. Across the entire country, annual mean precipitation change shows the greatest rise under the A2 scenario, between 21 mm/year and 306 mm/year by the 2050s, with an average annual increase of 129 mm/year. Seasonal mean rainfall shows both increases and decreases by 2050. For each of the emission scenarios, the largest seasonal rainfall change occurs during the summer months, ranging between a decline of 14 to 47 mm/season and an increase of 131 to 179 mm/season across all emission scenarios. The smallest seasonal rainfall change occurs during the winter months, ranging between a decline of 1 mm/year and an increase of 27 to 45 mm/season across all emission scenarios (Sadek and Al-Nabhani 2016a).

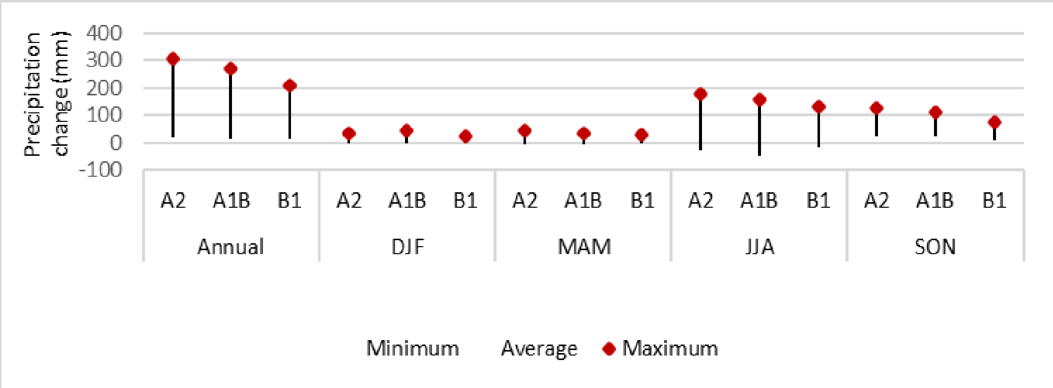


Figure 1:4 Projected change in precipitation for Yemen, 2050. (Source: Yemen TNC 2018)

1.2.1.4 Economy

As a Least Developed Country (LDC), Yemen is one of the poorest countries in the Arab region facing multiple challenges and crises. Its population growth rate is one of the highest in the world and outpaces its economic growth rate, and nearly three-quarters of the population lives in rural areas and rely on land resources and agriculture-related activities.

The poverty rate has increased significantly since 2011 and most of the disproportionately affected poor groups include women, children, small scale farmers and sharecroppers, landless labor, nomadic herders and artisanal fishermen who are spread over 133,000 small rural settlements.

The daunting political and socio-economic unrest that erupted in 2011 has created challenges and adversely minimized human development and economic stability. The rapid decline of humanitarian and livelihoods conditions, increasing poverty rates, lack of employment opportunities, inequalities, lack of justice, and competition over scarce natural resources, especially water, have been among the key triggers for such situation. The unstable situation has spiraled into a full-scale war and armed conflict covering the majority of the country since 2015 which caused destruction of the economy across the different sectors, basic services largely collapsed, and supplies of food, fuel and medicines are dangerously low or not available throughout most of the country.

Under the current unstable situation, poverty is expanding, and food insecurity is worsening. Increases of poverty add additional mounting pressures on the already degrading natural resources upon which the livelihoods of the most vulnerable communities and excluded groups rely.

The water sector already faces formidable challenges, and water table is declining on average by about 2-7 meters annually due to groundwater over-exploitation. The increasingly growing water crisis in Yemen will have severe socio-economic and environmental consequences including, decreased agriculture productivity, reduced food security, increased conflict over resources, accelerated land degradation, and increased livelihood vulnerability. Agriculture, which sustains the rural poor, contributes only 9.7 percent to the GDP while uses more than 85 percent of available water resources. Current projections on climate indicate that rising temperatures, rainfall fluctuation, and frequent droughts will increase the incidences of land degradation and desertification.

Furthermore, Yemen's economy depends in large part on foreign aid and remittances from workers in neighboring Gulf States. Currently, there are no accurate statistics and updated information, however, based on old statistics, the economy is dominated by the oil sector, which used to account for 27 % of the gross domestic product (GDP) and 70% of export revenues. Agriculture also forms a very important sector as it employs over 50% of the population. Before 2010, the government had engaged in efforts to diversify the economy from dependency on oil, and as a result, there was a surge of investment in the development of infrastructure for natural gas extraction. Yet, the political instability in 2011 has undermined development efforts, resulting in damage to infrastructure, rising unemployment, high inflation, depletion of oil reserves and ongoing disruptions at oil production facilities. This has led to a decline in exports of oil and gas, which stopped completely in 2015, leading to a loss of revenues and severe fiscal difficulties. During the last two decades, GDP per capita (in constant 2010 US$) increased from US$ 973 in 1990 to US$ 1,101 in 2014. (World Bank, 2018). Although GDP Annual Growth Rate in Yemen averaged 2.9% from 2001 through 2013, reaching an all-time high of 7.7% in 2010, it recorded negative growth of 37.1%, and 34.3% in 2015 and 2016, respectively, due to the 2011 domestic political crisis and war since 2014[4].

1.3 National GHG Emission Mitigation Policies and Targets

To address the GHG mitigation issue, Yemen has not yet developed and implemented Nationally Appropriate Mitigation Actions (NAMAs) to reduce GHG emissions from various sectors. This situation is partly because the NAMA is not compulsory but rather a voluntary process, and more importantly because it is a very demanding process in terms of financial requirements and the complicated institutional structures needed for NAMAs implementation. This lack of NAMAs, however, does not imply that Yemen is not committed to a transition towards a greener economy, but conversely the government has already taken fundamental steps to mainstream the mitigation concept into sectoral policies. These efforts have led to incorporation of renewable energy and green climate change into several policies and documents like the National Adaptation Programme of Action (NAPA) of 2009, the National Strategy for Renewable Energy and Energy Efficiency (NSREEE) of 2009, the Second National Communication (SNC) of 2013, the National Biodiversity Strategy and Action Plan (NBSAP) of 2016, the Intended Nationally Determined Contributions (INDC) of 2015, and the Third National Communication (TNC) of 2018(Environment Protection Authority 2009, 2013, 2017a, 2018; Ministry of Energy and Electricity 2009).

The Yemen NAPA through three baseline studies calls for mitigating GHG emissions through the adoption of National Mitigation Plans (NMP) for energy, transport, household, and industry with specific focus on introduction and enforcements of norms, bench marks and standards; fuel switching to natural gas in energy generation and transportation; switching to renewable energy; promotion of bio-energy production from wastewater and solid waste; application of efficient lighting system and efficient heating and cooking systems; increase of Liquid Petroleum Gas (LPG) use for cooking and improved biomass and LPG stove performance (Environment Protection Authority 2009; Ministry of Energy and Electricity 2009). Moreover, the NAPA has

[4] https://reliefweb.int/report/yemen/climate-crisis-exacerbates-humanitarian-situation-yemen-enar

identified key actions both to enhance adaptation to climate change and to contribute to GHG emission reduction. Examples are as follows:

- Promotion of modern irrigation technologies to increase water-use efficiency and reduce fuel use in irrigation.
- Promotion of water desalination using renewable energy sources, especially on Yemeni islands and coastal areas, where drinking water is not available or subject to seawater intrusion to ensure continuity of life.
- Promoting alternatives for fuel wood to control woodcutting and preserve plant cover through promotion of LPG use for cooking.

In 2009, the government of Yemen developed and approved the National Strategy for Renewable Energy and Energy Efficiency (NSREEE) to provide clean, reliable, and secure energy supply for economic development and poverty reduction, improve fuel security, enhance the competitiveness of the national economy, protect the local environment as well as contribute to international efforts to combat climate change. The Strategy includes five specific targets aiming to mitigate GHG emission through introducing renewable energy (Ministry of Energy and Electricity 2009):

1. Concentrated Solar Power (CSP) systems integrated into existing steam and single cycle power plants.
2. Off-grid solar PV promoted in rural areas.
3. Wind-farm power plants developed and interconnected into existing national grid.
4. Geothermal power plants developed and interconnected into existing national grid.
5. Biomass power plants developed and interconnected into existing national grid.

The NSREEE also aimed at increasing energy efficiency by 2025 in power generation, transmission, and distribution by 15%, compared to 2010. Specific mitigation measures identified by the strategy to achieve this target include the switch to efficient Combined-Cycle Gas Turbine (CCGT) plants and switching to Combined Heat and Power (CHP) generation systems. Additionally, the NSREEE aims at improving energy efficiency through fuel switch to natural gas in energy generation, the shift to NG fuel in transportation, introduction of solar pumps in irrigation and Energy production from wastewater treatment plants for heating, lighting, and cooking. Furthermore, the strategy calls for improving energy efficiency by 2025 in demand side by 15% through the promotion of CFL (compact fluorescent lamps) & LED in lighting, solar water heaters, power factor correction in government installations, industrial energy audits, standardization and labelling and introduction of time-of-use tariffs.

In the Second National Communication (SNC) 2013, Yemen provided an analysis to limit and reduce the GHG emission with no measures to enhance GHG sinks. The national emission target - as given by the SNC - calls to curb GHG emission incurred by the current Business-As-Usual case (BAU) policy with the aim of promoting energy resilience and achieving 14% reduction of energy-related GHG emissions in 2020 and achieving 23% reduction in 2025 compared to the emission in 2000. These targets are proposed to be realized through three strategic options respectively dealing with energy efficiency, fuel switching and a shift to renewable energy (Environment Protection Authority 2013).

In November 2015, Yemen submitted its INDC which proposed a conditional 14% and unconditional 1% GHG emission reduction by 2030 below BAU level. The INDC target corresponds to an estimated total cumulative GHG reduction of about 35 Mt CO_2-eq from 2020 through 2030, and also includes an overview of mitigation priority measures, as shown in Table 1.3(Environment Protection Authority 2015a, 2017b).

Table 1:3 Potential mitigation reduction proposed as Intended Nationally Determined Contributions

Years	2010	2020	2025	2030	Total (2010-2030)
Emissions-BAU (Mt **CO_2-eq**)	24.18	35.94	39.68	43.81	437.30
Emissions Unconditional Scenario (Mt CO_2-eq)	24.18	35.90	39.50	43.35	434.97
Emissions Conditional Scenario (Mt $CO_{2=}$eq)	24.18	35.25	36.74	37.67	402.33
Expected Emission Reduction-Unconditional Scenario	0.00	0.04	0.18	0.46	2.33
Expected Emission Reduction-Conditional Scenario	0.00	0.68	2.94	6.13	34.97

The second National Biodiversity and Action Plan (NBSAP2) calls for achieving a 14% reduction of GHG emissions from energy-related sectors in 2020, and 37% in 2025 (Environment Protection Authority 2017b). The measures identified to be implemented for GHG emission reduction and improving climate change mitigation based on restructuring EPA to host the National Climate Fund (NCF) and the adoption of nationally appropriate mitigation actions (NAMAs) with specific focus on reducing GHG emissions through multiple actions including the shift to renewable energy, the promotion of smart agricultural practices and the introduction of bio-energy production especially from solid waste and wastewater in main cities. The promotion of smart agricultural practices is to be achieved through carbon sequestration activities such as the expansion of protected areas, restoration of "Blue Carbon" ecosystems (mangroves and sea-grass beds), reforestation to reduce emission from deforestation and forest degradation (REDD) (Environment Protection Authority 2017a).

In the third national Communication (TNC) 2018, the GHG mitigation analysis updated the baseline scenario (BS) and mitigation scenario (MS) created in the SNC and estimates national emission reductions for the Time Horizon Years (2010 - 2040) and the overall energy related GHG emission reductions are expected to be 19.7 million tonnes of CO_2 equivalent by 2040, which is 33.5 % lower than the Baseline Scenario's emissions (Environment Protection Authority 2018)

1.3.1 State of Implementation

In terms of implementation state of all the mentioned polices, strategies and plans, Yemen has taken a few steps to reflect proposed measures into actions or projects contributing in GHG emission mitigation. As shown in table 1.4, national mitigation actions resulted in a total projected decrease in GHG emissions of 2,274 thousand tonnes of CO_2-eq from 2010 to 2013, with the only source of emission reductions being a shift to natural gas plants in electricity generation. Due to the inclusion of natural gas plants into the present national grid, total yearly energy savings from the switch to natural gas was 2,059 GWh (Environment Protection Authority 2017a).

Table 1:4 Highlights of Status of Implementation of National Mitigation Policies, Targets and Measures[5]

Intended outputs	Quantitative Achievement due to Mitigation Measure up to end 2013		
	Annual Electricity Saving (GWh)	Ann. Emission Reduction	Emission reductions through 2013
		tonnes CO_2-eq	tonnes CO_2-eq
Introduction of Concentrated Solar Power (CSP) into national grid	NE	NE	NE
Promoting solar PV in households	NE	NE	NE
Promotion of Wind farms power plants	NE	NE	NE
Promotion of Geothermal power plants	NE	NE	NE
Promotion of Biomass power plants	NE	NE	NE
Promotion of Natural gas-based power plants	2,059	568	2,274
Improvement of Energy Efficiency on Demand Side	NP	NP	NP
Promotion of Solar water heaters in Household & commercial sectors	NE	NE	NE
Promotion of Solar Pumps in Irrigation Systems	NP	NP	NP
Promotion of energy Efficiency in transportation	NP	NP	NP
Promotion of wastewater energy for heating, lighting and cooking	NP	NP	NP

However, it is worth recalling that the list of measures is not comprehensive due to the unavailability of data needed to quantify the environmental impact associated with the shift of the Yemeni people to natural gas in road transportation along with the nationwide application of household solar PV for meeting their household energy needs during the continuing political

[5] Notes: NE Means Not estimated due to lack of Data, though significant progress made, NP means No significant achievement produced

unrest since 2011 and the subsequent war time of 2015 to date. During the political crises and war time, the Yemeni people have suffered from frequent rolling blackouts, which extend sometime to more than 12 hours a day before the war and this status has been escalated by the war, leading to full closure of all national power plants. More drastically, Yemeni households could not even access energy from prevailing small diesel-based generators due to fuel shortage incurred by fuel monopoly and the breakthrough of black market of fuels, which have collectively led to unprecedented and unaffordable of rise in prices of fuel, including transportation cost.

To this purpose, the Yemeni people have devised an innovative coping strategy that includes switching to solar panels for residential energy and switching to natural gas for car fuel. According to national experts, this strategy has resulted in the installation of solar systems in more than 80% of urban houses and 90% of rural households (Ansari, Kemfert, and Al-Kuhlani 2019; Ersoy et al. 2022). This move has resulted in the creation of a self-sufficient society in terms of energy demands, as well as the displacement of black-market prices, which have dropped from 20,000 Riyals per gallon to 5,000 Riyals per gallon. Furthermore, people no longer line for significant periods of time at fuel and diesel stations. Accordingly, it is expected that the coping strategy have certainly led to unprecedented GHG emission reduction in such a relative short time. In order to measure the reduction level, an immediate countrywide survey is needed to quantify the emission reduction from these sources (Environment Protection Authority 2017a) .

Therefore, the planned readiness project under GCF will develop a surveys of household solar systems voluntary introduced by people and transportation modes utilizing NG. These will form important steps for quantifying emission reduction from these sources, which is anticipated to exceed the intended target planed by national strategies by 2025.

1.4 National Strategies, Policies and Actions Related to Climate Change Adaptation

Through a quick scan and review of national and sectorial policies and plans, it was found that some plans and policies have indirect references to the required technologies to address the potential impacts of climate change and/or to contribute to enhancement of adaptive capacities and building resilience. While in other strategic national reports (including NAPA, NCs, INDC) there are straight forward statements and proposed adaptation as well as mitigation measures that are directly linked to technology needs. However, within the sectorial policies and plans, there are several areas in which activities and interventions mentioned are of high potential for adaptation technologies, and could be considered as concrete bases and foundation for the TNA process.

The following few paragraphs may provide brief summary and examples of such statements that address key problems in each sector as well as proposed measures and interventions that are linked (directly or indirectly) to technology needs that aims to overcome these problems and contribute to climate adaptation and resilience. The list of reviewed national as well as sectoral relevant plans include:

- The Third Socio-economic Development Plan for Poverty Reduction (DPPR) for 2006 – 2010,
- The National Water Sector Strategy and Investment Programmed (NWSSIP) for 2005 – 2009 and its update for 2009 – 2014 (World Bank 2010)
- National Fisheries Strategy. (NFS, 2012-2025) (Ministry of Fish Wealth 2012)
- National Agriculture Sector Strategy. (NASS, 2012-2016) (Ministry of Agriculture and Irrigation 2013)

- National Biodiversity Strategy and Action Plan, 2005(Environment Protection Authority 2017b)

These sectoral plans and national reports as well as case studies on some selected sites revealed that there are several gaps related to climate resilience and adaptation measures. However, given the current unstable situation and the continued war and armed conflict in the country, most of these plans have neither been updated nor implemented.

1.4.1 Water Sector

Water crisis has developed in Yemen and characterized by the over-abstraction and 'mining' of groundwater, water shortages and limited access to safe drinking water. The rising demand for water is a result of population growth and a large increase in agricultural production in the absence of an adequate framework for promoting water efficiency and sustainable levels of water use.
The National Water Sector Strategy and Investment Programme (NWSSIP) for 2005 – 2009 and its update for 2009 – 2014 were created to address three main problems in the water sector:

(i) Low water resource availability, groundwater overdraft and irrigated agriculture vulnerabilities.
(ii) Inefficient service, inadequate coverage and high fiscal subsidy of water supply and sanitation in urban areas; and
(iii) Low coverage and poor sustainability of water supply and sanitation in rural areas.

In order to target the above three main problems in the sector, the strategy highlighted the following interventions:

(i) Sector restructuring and institutional development;
(ii) decentralized water resources management (e.g., through assistance to NWRA and basin and local-level initiatives);
(iii) water resources management and water use efficiency through irrigation improvement;
(iv) urban water reform and investment to expand coverage; and
(v) rural water and sanitation reform and investment.

The water section of the Third Socio-economic Development Plan for Poverty Reduction (DPPR) for 2006 – 2010, the NWSSIP for 2005 – 2009 and the NWSSIP update for 2009 – 2014 do not have direct references to potential impacts of climate change or resilience measures, but based on the above points and as a point of departure for key issues of climate change adaptation technology the following measures within the strategy could be highlighted:

- Improve the quality of hydro-meteorological and climate services provided to end-users through improved forecasts resulting from improved observation networks.
- Introduction of new technologies, and access to higher resolution global weather and climate product.
- Availability of early warning systems- Ability to predict and interpret climate information by local communities.
- Robustness of weather data collection, analysis, and long-time series of data and information dissemination.
- Level of uncertainty about the probabilities of various possible changes occurring in specific locations.

- Access to information by local community- Number of end-users using climatic information and products for decisions.

The National Adaptation Programme of Action (NAPA) identified water resources as the top sector among other vulnerable sectors to climate change. Also, it has been clearly highlighted in the NAPA and other climate change-related documents that climate change is projected to increase rainfall variability (timing, frequency, and intensity) and bring about major changes in basin hydrology. Moreover, there has been no integration of climate change or resilience concerns into national water strategies, policies, plans and programmes.

However, NWSSIP highlighted other driving forces behind water crises in Yemen, these include:

- Clear evidence that underground water is being mined at an alarming rate.
- The random drilling of underground wells and the limited low enforcement of the water law as well as the role of influential people has negatively contributed to the mining of underground water.
- Fuel subsidies have negatively contributed to the misuse of water in irrigation and the low adoption of localized irrigation techniques which are known to be more efficient in utilizing water for irrigation purposes.
- During the last few decades there has been a massive construction of spate irrigation structures to better utilize seasonal floods by government agencies and development projects. However, currently most of the spate irrigation infrastructure is deteriorating due to poor maintenance caused by budgetary constraints in the public sector.
- The construction of different water structures without environmental and social assessment has led to a chaos in construction of water structures. Lack of National Master Plan for construction of different water structures for different purposes contributed further to aggravating the situation.

Experiences generated locally and addressed in several policy documents and strategic recommendations clearly noted that diversification of rural water supply can be an ideal strategy to meeting the continuous demands for water supply. Water harvesting from the roofs of houses and from the nearby watershed in villages can be reliable sources for securing additional sources of water harvested during the rainy season which could be sustainable if properly designed and legislated. Closed and open cisterns proved to be ideal structures for drinking and other household purposes. Reuse of brackish and grey water after proper treatment is also among the potential sources. Similarly, desalination of sea water can be a potential source for water supply in coastal areas provided the technology for producing these types of water is affordable and feasible.

1.4.2 Agriculture Sector:

The National Agriculture Sector Strategy (NASS) has identified and illustrated several problems in the agriculture sector, these include:

- Deterioration of landraces as a result of improper maintenance of traditional land races of food crops.
- Low yields of traditional food crops in rain-fed areas as a result of total or partial abandoning traditional growing methods
- Deterioration of terraces and partial abandoning of rain-fed agriculture
- Erratic rainfall and change in the pattern of rainfall.

- Deterioration of community efforts in maintenance of natural resources because of intensive migration of male farmers to urban areas and abroad

Also, the NASS and other national documents on agriculture sector as well case studies on some selected agricultural sites revealed that there are several problems, challenges, and gaps related to climate resilience and adaptation measures in the agricultural sector that require to be looked at and addressed through identifying and implementing available and applicable technologies including traditional ones. These include among others the following key problems/issues:

- Lack of information on the vulnerability of watersheds to climate change;
- Lack of national mitigation and adaptation plans for climate change;
- Weak recognition of the climate change issue relative to other development priorities;
- Poor understanding of the science of climate change domestically;
- Absence of an institutional structure aimed at integrating climate change issues into national plans.
- Degradation of natural resources is evident in terms of soil erosion, increased pasture degradation, the deterioration of vegetation cover, and the declining of soil fertility.
- Deterioration of traditional seed maintenance practices which were adopted by farmers to sustain the use of traditional local varieties and landraces has led to severe erosion of precious varieties and landraces.
- The increased degradation of crop varieties which could be addressed through diversification of cultivated crops and conservation of local varieties and landraces.
- Deterioration of fodder production as well as deterioration of grazing lands as a result of overgrazing.
- Livestock productivity loss as a function of conserving local fodder species and varieties and promotion of integrated crop-livestock production system.
- The random/uncontrolled importation of different plant varieties and animal breeds that are susceptible to climatic conditions of the country, coupled with weak law enforcement of quarantine laws have led to wide spread of crop and animal diseases which are new to the country.
- The random use of chemicals in plant and animal protection has contributed to the wide spread of crop and animal diseases at an alarming rate.
- Moreover, climate change impacts on agriculture is also evident in crop production losses as a result of fluctuation of rainfall in quantity and seasons. This phenomenon can be targeted by improving crop diversification, rainwater harvesting and improving irrigation efficiency and develop disseminate climate resilient crops.

Farming communities in Yemen have already begun witnessing impacts such as more frequent drought, erratic rainfall patterns, and decreasing agricultural production for some types of subsistence crops. The focus on climate resilience of agriculture sector needs to be through an integrated watershed management approach and through agricultural diversification. Although climate change is unpredictable, it is expected to bring a generally hotter, drier climate, and increased incidence of drought and floods, which require farmers to consider possible technologies to adapt farming systems and planting materials. Farmers need to be aware of trends and risks, and make constructive and practical contributions to address climate change through the strategic agenda of TNA.

1.4.3 Coastal Zones and Fisheries:

Key issues of climate change related to the sector as referred to and highlighted in the National Fisheries Strategy (NFS) as well as other sector-related reports are summarized in the following few paragraphs (Ministry of Fish Wealth 2012).:

Yemen's marine ecosystems are complex and diverse. Abundant marine habitats include coral reefs, mangroves, and sea grasses. Yemen's sea grasses include *Posidoniaceae, Zosteraceae, Hydrocharitaceae, and Cymodoceaceae*. There are four species of turtles: Green (*Chelonia mydas*), Hawksbill (*Eretmochelys imbricata*), Loggerhead (*Caretta caretta*) and Leatherback (*Dermochelys coriacea*). Dugongs and several species of dolphins and whales are found in Yemen's waters. There are over 416 fish species recorded with a high number of endemics.

The Red Sea is home to distinctive coral ecosystems comprising Regional Centre of Endemic Fish and Invertebrates. It hosts a unique flora and fauna, a number of marine turtles, and several endemic birds and other unique species. Seventeen per cent of fish are endemic; more than 90% of Dottybacks (Family *Pseudochromidae*) and Triplefins (Family *Tripterygiidae*) are endemic. The Arabian Sea hosts highly productive habitats that reflect biophysical regimes and endemism among algal communities. It has coral reefs with over 75% cover in selected areas and sea grass beds that provide important breeding and nursery habitats especially for mollusks. It hosts several endemic species of marine fauna, a wide variety of invertebrates and algae as well as characteristic fish species .

The effects of climate change on fisheries will impact both at sectoral and national levels. Climate change will probably affect production volumes, species mix, as well as methods of fishing. This will have consequences on the livelihoods and earnings of fisher-folk and on other actors operating in the fisheries sector. Moreover, a decline of fisheries due to the overexploitation of resources and climate change may have wider negative impacts.

Yemen's coastal zones are considered as one of the most vulnerable sectors to climate change impacts. Models predict that decreasing primary production in the seas and oceans due to climate change are likely to lead to changes in physiology of fish in short term (within few years); the recruitment success, changes in species composition, abundance and fish population distributions in the medium term (few years to decade) and the long-term changes in net primary production of the oceans (multi decade) (Kadri AbdulBaki Ahmed and Gamal Bawazir 2016).

All these impacts would be felt in fisheries sector, through changes in capture, production and marketing costs and possible increases in risks or damage or loss on infrastructure, fishing boats, and housing and less stable fisher's livelihood.

In these lines, the strategy should focus on building the resilience of the communities and sectoral adaptation investments towards the compounding effects of the climate change through community and ministerial capacity strengthening initiatives and pilot adaptation programmes.

As mentioned above, climate change is noticeable in Yemen, and its impacts on the coastal and fishery sector is plausible. The vulnerability of the coastal areas in Yemen is for instance compounded by the existing weak coastal management structures and poor infrastructure and inadequately institutionally functioning capacity, and less empowered stakeholder.

The tremendously sensitive livelihoods of poor fishery communities further worsening the vulnerability context under which any unfavourable climate conditions such as increased sea level rise, extreme events, storm surges, high wave activity, increased acidity etc. will certainly lead to deterioration of wetlands, coral reef failure, coastal mangrove migration, erosion, infrastructure damage, seawater-groundwater intrusion affecting groundwater aquifers in coastal areas and flood low-lying areas, and eventually declined biological productivity of fish communities and loss of opportunities and increased poverty (Alsaafani and Alhababy 2015). Altogether, it can be presumed that climate changes may affect fisheries and aquaculture through posing a number of threats including changes in temperature, precipitation, frequent and stronger weather events such as storms leading to deterioration of sensitive habitats influencing fish productivity and stocks. Other health risks expected is food poisoning attributable to increased consumption of toxic marine organisms.

Given the uncertainty presented by current climate scenarios and impacts at the local level, the precise extent of the vulnerability of fishery is not known and needs to be further assessed to factor in while developing the sector policy and strategy to ensure sustainable development under changing climate. Therefore, it can be noted that previous studies are broad and provide generic insights but less specific knowledge on the impacts of climate change on the fishery sector.

The basic data allowing understanding of the vulnerability of the country's fisheries sector to climate change and other environmental challenges is currently lacking. Therefore; bases for prioritizing adoptive strategies through policy formulation and planning are severely constrained. It can be deduced and derived from the strategy and other related documents that they aim to (Abubakr et al. 2013; Alsaafani and Alhababy 2015; Kadri AbdulBaki Ahmed and Gamal Bawazir 2016):

- Reduce the vulnerability of fishermen community to climate change risks, including storm flows and flooding, through the sustainable management of its natural resources.
- Build community capacity to manage coastal resources by assisting village groups to identify appropriate technologies, design and develop alternative income generating initiatives that reduce climate change risks while protecting natural coastal defences such as mangroves, beaches, and coral reefs.
- Reduce erosion from farming practices and improve tidal flushing through the removal of maladaptive coastal infrastructure to improve the resilience of climate-threatened coastal ecosystems by reducing climate-related sedimentation risks.
- Develop and implement awareness raising activities to respond to climate change on coastal zone with all relevant agencies and institutions.
- Assess impacts of climate change and sea level rise on sectors administered by the relevant authorities (e.g., Ministry of Fish Wealth and EPA)
- Identify measures to respond to climate change and sea level rise for sectors administered by the Ministry of Fish Wealth.
- Mainstream and integrate climate change issues into strategies, programmes, plans.
- Implement other related tasks including research and propose measures in term of employment security; poverty reduction for the most vulnerable areas caused by climate change; research and propose solutions and plans on migration, re-settlement and life security for residents in the most vulnerable areas caused by climate change and sea level rise; issues on gender, population, and livelihood.
- Develop and implement action plan to respond to climate change on coastal zone.
- Develop and implement disaster preparedness and recovery programmes, including forecasting, early warning systems and rapid response strategies to cope with extreme weather events.

- Planting and re-planting of mangroves and palms for adaptation to sea level rise.
- Use of improved quality control techniques.

1.5 Vulnerability Assessments in the country

Vulnerabilities and impacts of climate change in Yemen have been clearly identified and addressed in Yemen's policy documents such as National Communication (NCs), National Adaptation Programme of Action (NAPA), and further confirmed in sectoral assessment studies. Key vulnerabilities and impacts of climate change on the vulnerable sectors have been obtained, extracted from those documents, and accordingly rephrased and presented here for the purpose of this report as follows.

The main root causes and drivers behind increased vulnerability are the unsustainable management as well as unsustainable use of natural resources of water, agricultural, land, and coastal and marine resources. These challenges are underpinned by climate change, the magnitude of which will inevitably and quickly increase. Weakened ecosystems, including land degradation, compounds climate change vulnerabilities for people and natural systems. Although such problems and challenges are caused by several factors, the basic issue is the limited access to the knowledge, technologies, and capacities required to identify, incentivize, and adopt pro-conservation, nature-based solutions. In many cases, this is further complicated by inadequate or poorly enforced parameters for access and use.

It is fundamental that Yemen has low adaptive capacities. Yet, a majority of Yemenis depend upon rural economies. Fisheries, livestock and agriculture each require healthy and functional ecosystems to thrive. These ecosystems are now weakened and highly vulnerable to climate change. Marine systems are being overexploited. Rangelands are marginalized. Agricultural lands are highly degraded. As a result, rural Yemenis face immediate climate challenges that will result in substantial food security and livelihood impacts. There is little resilience and/or elasticity under the existing situation to safeguard biodiversity, associated ecosystem services, and highly vulnerable rural households from climate change impacts.

The climate crisis is exacerbating the humanitarian situation in Yemen. Vulnerability to natural hazards, floods and droughts have led to the destruction of shelters and infrastructure, restricted access to markets and basic services, wrecked livelihoods, facilitated the spread of deadly diseases and caused fatalities, as well as contributed to population displacement in what is already the world's fourth biggest internal displacement crisis, with over 4 million internally displaced people. The annual rainy season brings heavy rainfalls, high winds and flooding, particularly to coastal areas. In 2020, at least 13 governorates were impacted by adverse weather, affecting over 62,500 families, while thousands more families have already been impacted in 2021. The NAPA and other climate documents identify Water, agriculture, and coastal zones/fisheries as key sectors most vulnerable to climate change. Major vulnerabilities of main sectors to climate change as illustrated in the NAPA are summarized in table: 1.5 (Environment Protection Authority 2018).

Table 1:5 Major vulnerabilities of the main sectors (Source: NAPA, 2009)

Sectors	Major Vulnerabilities
Water	Water availability and quality difficult situations due to changing patterns of rainfall, impact directly on the livelihoods of the communities. Groundwater sources are at risk from sea level rise induced sea water intrusion.
Agriculture & Food Security	Drought, temperature variability, and changes in precipitation regime can lead to disastrous consequences for agriculture and food security. Climate changes may imply degradation of agricultural lands, soils and terraces, desertification, which negatively affects agricultural incomes for local communities and leads to national food insecurity as food production levels change.
Biological Diversity	Frequency in drought, temperature fluctuation, and changes in precipitation patterns due to climate change, will lead to the deterioration of and changes in the habitats of endangered and endemic species. The intense wave activity of storms already damages near shore coral reefs in the Red Sea and Gulf of Aden, as sea levels rise and storms become more frequent Yemen may see an increase in intense wave activity.
Coastal areas Communities	Flooding of low-lying areas and coastal erosion threaten local communities and their livelihoods. Communities may experience damage to household assets and property, constraints on services such as water supply and quality, and damage to agriculture.
Coastal environment/ infrastructure	Deterioration of wetlands, mangrove forests along the shoreline as well as in islands in the Red Sea. As a result of sea level rise, Yemen can expect damage of infrastructural assets in coastal cities as well as to cultural heritage assets.
Health	Changes in climate will create more suitable conditions for the occurrence and spread of vector borne and water borne diseases such as malaria.
Tourism	Impacts include loss of beaches, degradation of coastal ecosystems, saline water intrusion, damage to infrastructure, and coral reef loss and bleaching.

Climate change projections for Yemen include temperature increases accompanied by erratic periods of intense precipitation and drought. Average temperatures in Yemen are forecast to increase. Estimates of increase vary from 2-3°C by 2050 to 1.2 - 3.3 °C by 2060. This would mean that days exceeding current heat records would increase by 10% or more. Desert areas will likely see very severe temperature increases. Coastal and highland areas will likely have extreme weather events, including prolonged periods of drought punctuated by abnormally intense precipitation events (Environment Protection Authority 2018). This will result in a shifting of climate zones impacting growing seasons and production choices.

The negative influence of future climate change scenarios is indicated by several recent events. The 2008 floods killed 180 people, displaced 10,000 and caused damage and losses to infrastructure, shelter, and livelihoods. Agriculture accounted for nearly 64% of the total losses. Cyclones Chapala (2015), Kyarr (2019) and Maha (2019) each resulted in severe human and ecological impacts. In 2020, heavy rains lasted from March through August. As a result, heavy floods coincided with both harvesting and planting. Destruction of water infrastructure alone (not including impacts on crops) were estimated by Food and Agricultural Organization (FAO) to between US$ 763 million and US$ 932 million (Omran and Schwarz-Herion 2018; Red cross and Red Crescent Societies 2018; Yemen Red Crescent Society (YRCS) 2018).

1.5.1 Water Sector

In addition to the significant development challenges, Yemen is particularly vulnerable to climate change, and is highly water dependent given the relative importance of the rural economy. Of the many sectors that are vulnerable to climate change in Yemen, water resources are considered the most and the top vulnerable sector, with potentially grave environmental and social effects. The sustainable exploitation of Yemen’s water resources is supposed to be a high priority under national environmental and agricultural policies, as well as multilateral environmental agreements to which Yemen is a signatory (i.e., the UNFCCC, UNCCD and UNCBD).

Yemen is considered to have one of the lowest rates of per capita freshwater availability in the world. As local data for Yemen are scarce, particularly for rainfall, it severely hampers efforts to quantify long-term changes in climate and to assess renewable natural resources such as water. Based on current high-water consumption for irrigation and water supplies, groundwater reserves are headed for exhaustion regardless of climate change, and the rate of groundwater overdraft is twice the recharge rate, and is increasingly depleting water reserves with negative socio-economic consequences. Although, this depletion is due in large part to agricultural use, but will have implications for all water users. Looking at what the likely outcome would be in mid-century if the climate became warmer and wetter in line with the range of predictions from global climate models. If that occurred, then groundwater availability would be about half the present extraction rates. If, on the other hand, the climate becomes hotter and drier then groundwater availability would be about a quarter of the current rates of extraction.

FAO estimated that overall water availability dropped by nearly 50% between 1990 and 2010 likely worsened over the last decade. The government estimates that total annual renewable water resources are 2.1 billion m3 (1.1 billion m3 of groundwater and 1 billion m3 surface water) while water consumption stands at 3.565 billion m3, reflecting a groundwater depletion rate of 1.465 billion m3 (170%) a year. Therefore, groundwater reserves are likely to be mostly depleted in another two to three decades, irrespective of climate change. However, rapid increases in water abstraction and use have affected the water balance. As a result, the current dependence of agriculture on dwindling water resources is not sustainable. Groundwater depletion could reduce agricultural output by up to 40%. This will have serious repercussions on the rural economy given that the growth of irrigation has been the principal source of work and incomes in rural areas.

Erratic and variable rainfall is a dominant feature of Yemen's climate, a situation made worse by high evapotranspiration rates. The low humidity and high temperatures cause high rates of evapotranspiration loss - ranging from 1800 mm to 2500 mm a year leading to reduction of the amount of rainfall that can be utilized. The amount of rainfall that is retained in the soil profile for beneficial use by agriculture is no more than a small fraction of the total 37,000m^3 which falls as rainfall (Noman Abdullah 2016; Sadek and Al-Nabhani 2016b).

Variability in the timing, frequency and intensity of rainfall is likely to be a significant risk, and spate and flood flows may increase in volume and frequency under both the 'mid' and 'warm and wet' scenarios (2008 floods is a real example). Despite the indication under the 'hot and dry' scenario that torrential rains and flood flows would be smaller and rarer, there has been recurrent events similar to the 2008 floods and even more severe since then.

Although, it is well understood that agriculture plays a leading role in Yemen's economy and employs more than half of the labour force, it accounts for more than 90% of available surface and groundwater use – about 400,000 ha or 35% cultivated area depend on groundwater alone. Unsustainable irrigation results in increased evaporation levels and water temperatures. On top of that, whatever happens to rainfall patterns, rising temperatures (which is agreed by all scenarios) will increase agriculture water demand. This will affect water supplies for domestic and municipal use as they are in competition for the same water resources. In most areas of Yemen water supplies are from groundwater and increased demand from all sources will increase the costs of accessing groundwater(Sadek and Al-Nabhani 2016b) .

While it is of high importance to take fundamental steps and be engaged in a range of national efforts to manage its scarce water resources under known climatic conditions, Yemen's vulnerability to increased climatic variability and future climate change threatens may ultimately thwart such efforts if climate change is not mainstreamed into such efforts.

1.5.2 Agriculture & Food Security

Agriculture remains the country's most important productive sector, contributing about 25% of the country's GDP and employing over 45 % of the country's work force mainly those living in rural areas of approximately more than 65% of the population. However, as a result of low productivity and emerging water shortages, rural incomes are stagnating and poverty is increasing. The fact that this sector and the rural economy have fared well compared to other countries in the region can be attributed in large part to the intense mining of groundwater.

Although over half of Yemen's work force depends upon agriculture, less than 3% of the land considered suitable for agriculture and agricultural lands are predominantly smallholder. Less than 0.3% of the country is planted with permanent crops and only 550,000 hectares are irrigated (Anon n.d.-a; Sadek and Al-Nabhani 2016b).

Nearly all rural dwellers are food-insecure. Livestock, agriculture and fisheries productivity is very low. FAO estimates that over 80% of all food is imported, including 70% of all cereals, 90% of wheat and 100% of rice. Prior to the conflict period, it was estimated that agriculture and fisheries provided 25% to 30% percent of the annual food requirement (Food and Agriculture Organization (FAO) 2013).

Although there is limited agricultural production with some cereals, vegetables, and fruits cultivated - Due to water and soil constraints - growing seasons and production choices vary widely as a result of Yemen's diverse topography and agro-ecological systems. Many of terraced systems, hang dramatically along Yemen's rugged mountains, are often used for both soil conservation and water harvesting.

Agriculture is now a major driver of vulnerability, land degradation, and biodiversity loss. Food systems in Yemen are poorly prepared for climate change impacts with both environmental degradation and food insecurity already at extremely high levels.

The most important climate risks affecting agriculture in Yemen are: temperature, drought, and changes in precipitation regime which can lead to disastrous consequences for agriculture and food security. Climate change will endanger agricultural systems and the livelihoods of those relying on them as such livelihoods are highly vulnerable to climate-induced hazards and disasters such as floods, cyclones, storms and prolonged drought. Additionally, desertification of agricultural land is further exacerbated by sand dune encroachment ranges from 3 to 5% per annum, where the area of deteriorated land due to soil erosion is estimated to be 12 million hectares and another 3.8 million hectares due to salinity. The dependence of rural communities on land for their livelihoods means the adverse effects of the deterioration of land resources and desertification affect rural populations more than the urban populations[6].

It has become evident that farming communities in Yemen have been already witnessing impacts such as more frequent drought, erratic rainfall patterns, and decreasing agricultural production for some types of subsistence crops.

1.5.3 Coastal Zone and Fisheries

Yemen enjoys a quite long coastline which make its marine and coastal environment a unique, rich, and very diverse of resources, ecosystems, and habitats including wetlands, mangrove forests, sandy and rocky beaches, coral reefs etc. The Red Sea and Gulf of Aden region of Yemen represent a complex and unique tropical marine ecosystem with extraordinary biological diversity and a remarkably high degree of endemism. Over 120 islands lie in the waters of Yemen with distinct climatic and natural characteristics.

These coastal and marine systems are already threatened by development, overfishing, overuse of resources, contamination, oil exploration and transport resulted in oil spills, sewage discharge, agro-chemicals flushed by floods, sedimentation from urban development, over exploitation and deforestation of mangroves for wood and for fuelwood supply, and demolishing of wetlands and sandy beaches land reclamation for development structures. These threats are contributing factors to vulnerability of the sector, and on top of all these, climate change creates further threats to these systems. However, the three primarily key drivers responsible for coastal and marine ecosystem challenges and degradation: climate change, inadequate resources management, and increased pressure due in part to commercialization.

Marine and coastal resources management is inadequate and remains defined by open access management regimes leading to a high degree of degradation. Moreover, Climate change cause further deterioration and is altering productivity, particularly for near shore fisheries where coral reefs, sea grasses, and other critical habitats are under strain.

[6] https://www.ifad.org/en/web/knowledge/publication/asset/41085709

The effects of climate change will impact both at sectoral and national levels and it will probably affect production volumes, species mix, as well as methods of fishing. Models predict that decreasing primary production in the seas and oceans due to climate change are likely to lead to changes in physiology of fish in short term (within few years); the recruitment success, changes in species composition, abundance and fish population distributions in the medium term (few years to decade) and the long-term changes in net primary production of the oceans (multi decade).

Climate change is noticeable in Yemen, and its impacts on the coastal and fishery sector is plausible. The tremendously sensitive livelihoods of poor fishery communities further worsening the vulnerability context under which any unfavorable climate conditions such as increased sea level rise, extreme events, storm surges, high wave activity, increased acidity etc. will certainly lead to deterioration and elimination of wetlands in low-lying areas, deterioration of marine habitats including coral reef failure, coastal mangrove migration, coastal erosion, destruction and damage of coastal infrastructure, seawater-groundwater intrusion affecting groundwater aquifers in coastal areas and flood low-lying areas, and eventually declined biological productivity of fish communities and loss of opportunities and increased poverty (Kadri Ahmed and Gamal Bawazir 2016) . Altogether, it can be presumed that climate changes may affect coastal and marine systems through posing a number of threats including changes in temperature, precipitation, frequent and stronger weather events such as storms leading to deterioration of sensitive habitats influencing fish productivity and stocks. Higher seawater temperature will also modify marine habitats, their biodiversity and fisheries potential.

1.5.4 Public Health

Yemen's population is dispersed over more than 130,000 localities, making it hard for the government to cover the whole population with the needed and essential services. Roughly 85% of the population lives in extreme poverty, particularly households in rural, remote and less accessible areas who lack the resources to access the kinds of nutritious food that can promote healthy and productive lifestyles. People in these areas are at increased risk of ill health because of limited access to all type of services including health services Therefore, generally the public health status of Yemen’s population is poor as evidenced by high rates of infant mortality, maternal morbidity and under-five mortality associated with communicable diseases.

Some key features of the public health situation in the country are attributed to several reasons including weak institutional planning and infrastructure, very limited number of health facilities which are poorly distributed throughout the country, inadequate staff, low public budgets and allocation of financial resources resulting in low capacity, poor operational efficiency, and insufficient supplies of medicines and drugs, low coverage and bad quality of health services, critical shortages of medical personnel and equipment as well as supplies. Climate change is intensifying hazards that threaten public health through the onset of higher temperatures, more frequent and longer heat waves, more severity and frequency of extreme storms and associated floods, increased potential for landslides, rising sea levels with accompanying higher storm surges, and recurrent drought (Abdulsalam Saeed Al-Ake 2020).

Climate may also act directly by influencing growth, survival, persistence, transmission, or virulence of pathogens; indirect influences include climate-related perturbations in local ecosystems or the habitat of species that act as zoonotic reservoirs. An increase in extreme events can affect disease outbreaks by altering biological variables such as vector population size and density, vector survival rates, the relative abundance of disease-carrying animal (zoonotic) reservoir hosts, and pathogen reproduction rates. Collectively, these changes may contribute to an increase in the risk of harmful pathogen being transmitted to humans.

Floods have a direct impact on human health and well-being by increasing event-related deaths and injuries, and indirectly by contributing to elevated disease burden from waterborne diseases, outbreaks of other infectious diseases, and stress-related disorders after a severe rainfall event.

A study on assessment of climate change impacts on health under the TNC indicated that human health is sensitive to shifts in weather patterns, and all populations are vulnerable and are expected to suffer from climate changes. However, the impacts are expected to be more severe on children, poor people, women (particularly pregnant women), elderly people, people with chronic medical conditions and disabilities, and internally displaced people.

Also, people living in rural and remote areas, which are characterized by rugged topography, lack of essential social services and with no social safety net, are at increased risk of ill health. Moreover, populations living in humid and temperate regions, as well as high lands less than 1500 metres above sea level, are highly vulnerable to vector-borne diseases as a result of rising temperatures and altered rainfall patterns, particularly when disease control systems are weak.

Furthermore, the study highlighted that Yemen is an endemic country for malaria and dengue fever diseases, and people working outdoors in fields without effective protection may experience a higher incidence of these diseases when climatic conditions favour mosquito breeding and biting (Noaman Abdullah 2016).

With climate change, more cases of heat-related illnesses such as heat stroke and heat exhaustion and fatigue among laborers is expected due to these physically demanding occupations. Heat stress and fatigue can also result in reduced vigilance, safety lapses, reduced work capacity, and increased risk of injury.

1.5.5 Eco-Tourism

Due to its geographical position at the conjunction of the Asian, and African ecological zones, Yemen enjoys the richest biodiversity of any country on the Arabian Peninsula, with a wide range of terrestrial, coastal, and marine natural habitats, species and genetic diversity, including many endemic species of flora and fauna. It is characterized by many landscape and cultural features that make it a destination for tourists from all over the world. Although this richness, ecotourism is at minimum levels due to many reasons including poverty, ongoing conflict, unstable security situation, lack of adequate management of ecotourism industry, resource degradation, and declining access to water and other essential resources. While the development of ecotourism has been adversely affected by the recent political conflict, there is widespread recognition throughout the public and private sectors that Yemen, given its rich biodiversity and unique civilization, could someday be an attractive venue for international and local ecotourism For millennia, the people of Yemen have been known for their sophisticated systems of agricultural terracing, rational use of arid rangelands, sustainable fishing practices along the country's extensive coastline and their unique architecture and town planning (Anon n.d.-c). Highly developed ancient cultures existed as far back as the 7th Century. UNESCO has declared three ancient Yemeni cities (Sana'a, Zabid and Shibam) as World Cultural Heritage Sites. The National Environment Action Plan (NEAP) emphasized the importance of ecotourism, especially in the Socotra Archipelago and along the thousands of kilometres of coastal areas, which extend along the Red Sea, Gulf of Aden, and the Arab Sea.

Figure 1:5 Dragon blood tree and Socotra Desert (Source: Yemen TNC)

The country's unique biodiversity in many parts of Yemen, particularly on Socotra, provide quite high potential and attractions for eco-tourism. This diversity occurs in a spectrum of habitats ranging from coastal mangroves and coral reefs to the highlands and deserts of the interior, providing habitat harbour for great number of unique species of wildlife and domesticated animals and plants. Two sites are mentioned here as examples of the many unique eco-tourism locations in the country (Socotra and Jabal Bura'a) which are threatened by climate impacts and increased climate-related extremes. Socotra is an archipelago of four islands that lies in the north-western corner of the Western Indian Ocean, at the junction between the Gulf of Aden and the Arabian Sea. Surveys have revealed that more than a third of the 800 or so plant species of Socotra are found nowhere else. Botanists rank the flora of Socotra among the ten most endangered island flora in the world. All of the terrestrial molluscs, 90 % of the reptiles (over 30 vertebrates) and 33% of the plants (307 species) are endemic making it one of the most important centres for biodiversity that are entirely arid and characterized by concentrations of high endemism. Bird Life International recognizes 22 important bird areas within the archipelago, and it forms one of the world's 221 globally important Endemic Bird Areas. The Worldwide Fund for Nature (WWF) lists it as one of their 200 Eco-regions and it is also included in the regional network of important Marine Protected Areas. It was designated by UNESCO Man and Biosphere Reserve Framework as Biosphere Reserve in 2003 and was also listed by UNESCO in the World Heritage Site in 2008(Attorre et al. 2007). The unique landscape, botanical, marine, bird biodiversity features of the Island offer tremendously attractive destinations for eco-tourism. It is a major attraction for birdwatchers, having six endemic species as well as dozens of permanent and migrant birds. A variety of beautiful wild shrubs such as the bottle and dragon blood trees (Figure 1.5) are ubiquitous against mountainous landscapes that are suitable for trekking and white sandy beaches that are been excellent for swimming and snorkelling. In addition, there are numerous sizable cave systems within the limestone plateau that stretches over much of the island, averaging between 300 -700 metres in elevation. A total of about 22 km of caves suitable for exploration has been mapped for the first time in recent years(Wiebelt et al. 2011a) .

Figure 1:6 Jabal Bura'a protected area (Source: Yemen TNC)

Jabal Bura'a Protected Area is a forested mountainous region spread over 4,000 hectares located 60 km southwest of the capital of Sana'a. The locally well-known Bura'a forest is the last surviving forested area on the Tihama escarpment and is the largest remaining area on the Arabian Peninsula. The forest area spans about 1,500 hectares and is the major habitat for 12 regionally threatened tree species in Arabian Peninsula. Given the large difference in elevation from Wadi Rijaf bottom to the highest point in the catchment area, there are marked differences in climate across and a dramatic shift from humid tropical conditions at lower levels to temperate conditions at the highest elevations. This large difference in elevation created a diverse plant species (Figure 1.6). About 315 plant species are found, including 8 native, 63 rare and 35 facing extinction risk, which altogether account for about 10% of Yemen plants. It also has 93 species of birds and is one of 57 locations that are of maximum importance to birds, according to the International Organization for Bird Protection. There are also 13 species of reptiles, 5 amphibians and 60 butterflies. Its forest is home to various wild animals. In 2011, UNESCO added the Jabal Bura'a Protected Area to its list of World Network of Biosphere Reserves as the second Yemeni protectorate to be included in the World Heritage registration after Socotra.

Historically, Yemen was a good example of economical and sustainable use of the available natural resources, where conservation of soil, crops and rangelands were part of the traditional systems, and agricultural terraces were mainly built for conserving water and preventing soil erosion. However, the degradation of watersheds, from mountain ranges to coastal and marine zones, in response to population pressure and development, has led to rapid declines in the quality of the environment. Deforestation of upper watersheds, overgrazing, terrace degradation and changes in land use are increasingly threatening downstream areas with floods, erosion, reduced dry-season river flows and sedimentation of irrigation systems dependent and surface water. The continued loss of water resources, forests, agroforestry land use systems and desertification reduce biological diversity and ecosystem integrity. All these types of degradation and deterioration resulting from the pressure on natural systems are further exacerbated by climate change impacts making ecotourism as one of the negatively affected and vulnerable sectors.

Ecotourism vulnerability to climate changes has not been intensively explored in the country as the focus was on other sectors including water, agriculture, coastal zones etc. However, climate change impacts on ecotourism could have the same magnitude as it is for other sectors. This is attributed to the fact that ecotourism depends mainly on the natural resources that are directly linked to those vulnerable sectors.

Although, the unique landscape and diversity of the above mentioned two sites and many others offers an attractive destination for ecotourism, their natural systems are quite sensitive to changes in climatic factors such as higher temperatures and less precipitation which may adversely affect ecotourism activities by damaging biodiversity in natural areas and increasing the risks of altering the sensitive equilibriums associated with plant-wildlife-insect populations and their distribution. It is predicted that a more arid climate would be likely to result in further desertification, with increases in semi-desert and desert areas, along with significant declines in wetland areas. Such changes are likely to have important consequences for plants and animals with specific or restricted distributions, and such species may face increased risks of extinction.

Information on the vulnerability of landscapes, watersheds and terraces to climate change is still lacking and climate change is only now emerging as a national development priority for Yemen. There is growing government endeavour to integrate climate change issues into national development planning through the development of the National Adaptation Programme of Action (NAPA) that facilitated participation of NGOs, the private sector, community organizations and government agencies whose role is expected to minimize the costs and enhance the efficiency of climate change adaptation.

1.6 Sector Selection

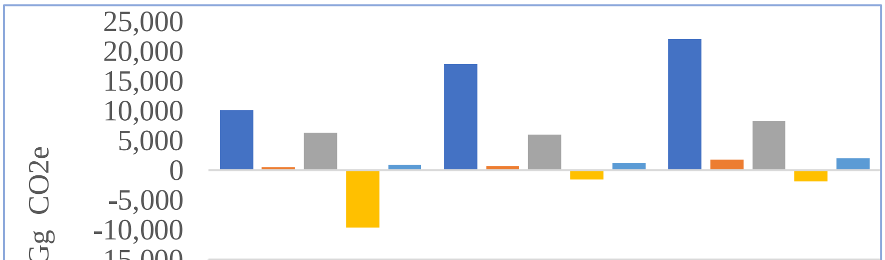
1.6.1 Overview of Mitigation Sectors and GHG Emission

Yemen's second, Third National Communication and INDC to the UNFCCC have served as the baseline for selecting the priority for mitigation and adaptation sectors. The reports, which were submitted in 2013, 2018 and 2015 respectively to the UNFCCC secretariat, present the country's GHG inventory for the years 2000 and 2010 with trend analysis for the period 1995-2010 and sectoral mitigation measures to reduce the national emission. The reports also present the climate risks to Yemen, based on modelled climatic projections, identify the most vulnerable sectors, and propose adaptation measures. The preparation of the NCs was based on a participatory approach where relevant stakeholders were involved in data collection and validation of methodology, baseline, and emission scenarios, and proposed measures and action plans (Environment Protection Authority 2010).

1.6.2 Total GHG inventory

As seen in figure (1.7), the trend of GHG emission had increased about 91%, from 17,866 Gg CO_2-eq 1995 to nearly 34,136 Gg CO_2eq in 2010, or roughly 4%/year.

In 2010 which is the TNA baseline, Yemen's total GHG emission recorded 32,249 of CO_2 equivalent (CO_2-eq). Approximately 65% of all GHG emissions are associated with the combustion of fossil fuels for energy generation for electricity production and transport. Emissions from agriculture accounted for 24% of all GHG emissions, followed by the waste and industrial sectors which accounted for about 6% and 5% of total emissions, respectively, as shown in table 1. 6 and figure 1.7 and 18.



	1995	2000	2010
Energy	10,132	17797	22038
Industry	547	734	1,798
Agriculture	6,294	5,948	8,247
LULUCF	-9,655	-1,501	-1,887
Waste	893	1,214	2,053

Figure 1:7: Total GHG emission trends in Yemen, 1995-2010

Table 1:6 Total GHG emissions in Yemen, 2010 (Gg)

GHG sources	CO_2**--eq**	CO_2	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
1. Energy	22,038	20,543	66.75	0.30	102	514	102	4
2. Industrial Processes	1,798	1,798	0.00	0.00	0	0	183	1
3. Solvent & Other Product Use	0	0	0.00	0.00	0	0	0	0
4. Agriculture	8,247	0	184.00	14.14	1	18	0	0
5. Land-Use Change & Forestry	-1,887	-1,887	0.00	0.00	0	0	0	0
6. Waste	2, 053	0	83.00	1.00	0	0	0	0
Total National Emissions	34,136	22,341	333.75	15.44	103	532	285	5
Net National Emissions	32,249	20,454	333.75	15.44	103	532	285	5

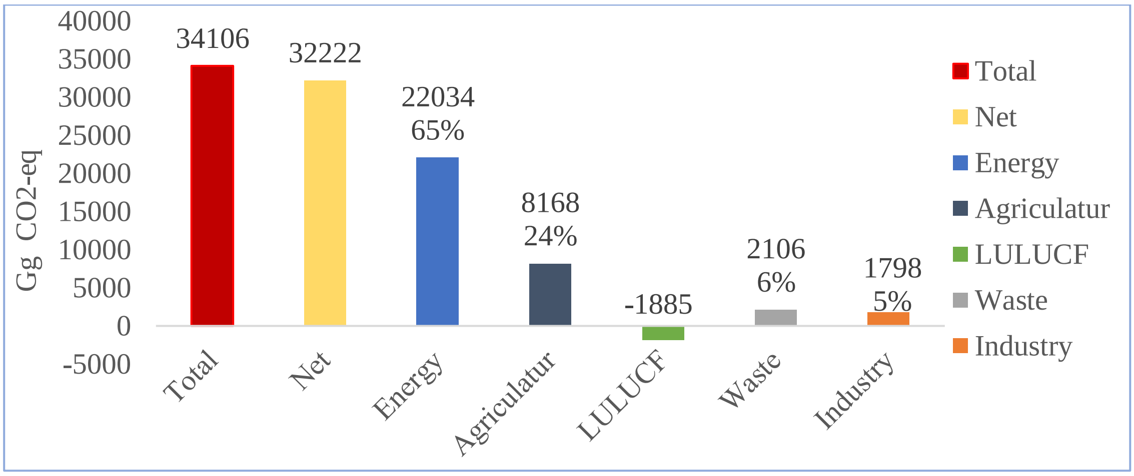


Figure 1:8 Total GHG Emissions by Sector (Gg) of $CO_{2\text{-eq}}$, 2010

1.6.3 GHG Emission by Sector

On a sectoral basis, figure 1.9 shows Energy-related emissions were the most dominant, contributing 65% (22,034 Gg CO_2-eq) to the national total. The non-energy sectors, namely Agriculture, Waste and Industry sectors, constituted 24%, 6%, and 5% of total CO_2-eq emissions. Yemen's per capita CO_2 emissions excluding land use, Land-use Change, and Forestry (LULUCF) were 0.97 tonne CO_2/ capita in 2010, noting that the country's population was 23.2 million in 2010. Yemen's aggregate emissions above exclude LULUCF. However, when emissions & removals are considered, emissions total are sequestered by the amount of 1885 Gg CO_2-eq, resulting in a net emission of about 32,222 Gg CO_2-eq.

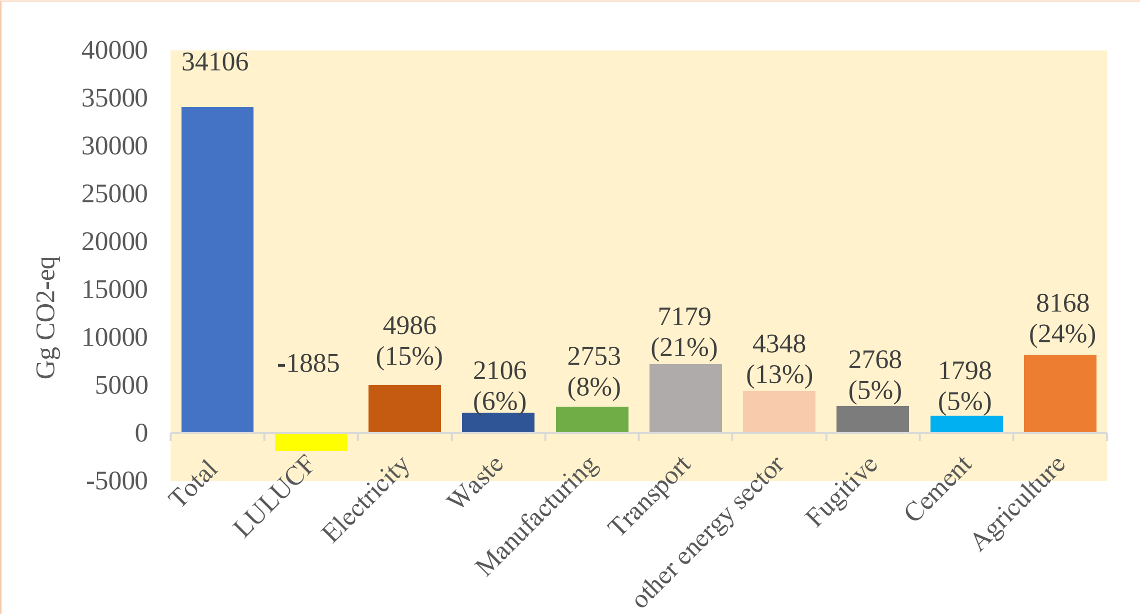


Figure 1:9 GHG emissions by sector, 2010 (Gg of CO_2-eq) & share (%) as compared with national emissions.

1.6.3.1 Emissions from Energy Subsectors

The energy sector emitted 22,034 Gg of CO_2-eq due to fossil fuel combustion in electricity generation, manufacturing, transport, and other energy sectors. The latter comprises emissions from commercial, residential and agriculture, and fisheries. The energy sector also accounts for fugitive mining and oil and natural gas extraction emissions. The distribution of the emissions across the source categories in the energy sector is shown in Figure 1.10.

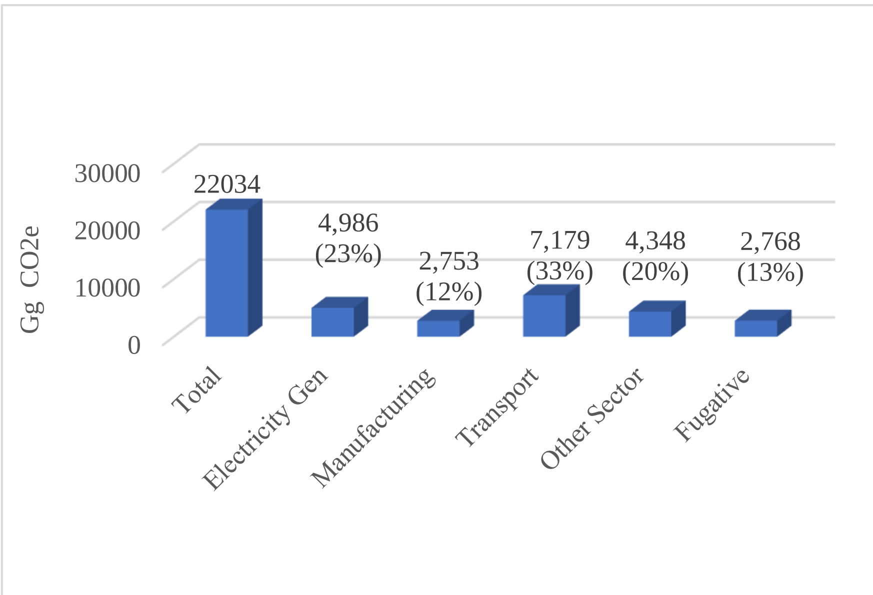


Figure 1:10 GHG emission under energy sector

a) Emissions from Electricity Generation

The total greenhouse gas emissions from electricity generation in 2010 was 4986 Gg of CO_2-eq, being 15% of national GHG emissions (figure 1.10) or 23% of GHG emissions of the energy sector (Figure 1.10). This includes emissions associated with the utilization of 65,784 TJ of Residual Fuel Oil and diesel for operating both national grids and privately-owned networks.

b) Emissions from Transport

The transport sector emissions are reported from road transport, aviation, and navigation. In total, the transport sector emitted 7179 Gg of CO_2 eq, being 21% of National GHG or 33% of GHG emissions of the energy sector, see figure 1.10. About 60% of GHG emissions of the transportation sub-sector came from gasoline combustion by road transportation, and the rest was attributable to the use of diesel & LPG at percentages of 35% and 5%, respectively. The bunker emissions from aviation and navigation have also been estimated but are not counted in the national totals.

c) Emissions from Manufacturing Industry & Construction

In 2010, GHG emissions from the manufacturing industry & construction were 2753 Gg of CO_2-eq representing 12% of the energy-sector emissions or 8% of national GHG emissions, as shown in figure 4 and 5. The manufacturing industry sector emissions were reported to be from the combustion of 39,026 TJ of residual fuel oil, diesel oil, and hard coal by various industrial activities.

d) Emissions from Other Energy Sub-sectors

The emissions of Other Sectors sub-sector included emissions from the Residential, Commercial, and Agriculture, including fisheries category. The Other Sectors sub-sector in 2010 emitted 4,348 Gg of CO_2-eq, being 20 % the energy sector emission or 13% of the country total GHGs, figures 10. The residential sector in Yemen consumed about 46,464 TJ of gasoline, kerosene, diesel, and LPG to meet overall rural and urban households of need for Energy. In 2010, the Residential sector alone generated about 3074 Gg of CO_2-eq or 71% of GHG emissions emitted by the other sector. The remaining GHG emissions of the other sectors were from fuel combusted by the agriculture and commercial sectors at shares of 11% and 18%, respectively.

e) Fugitive Emissions

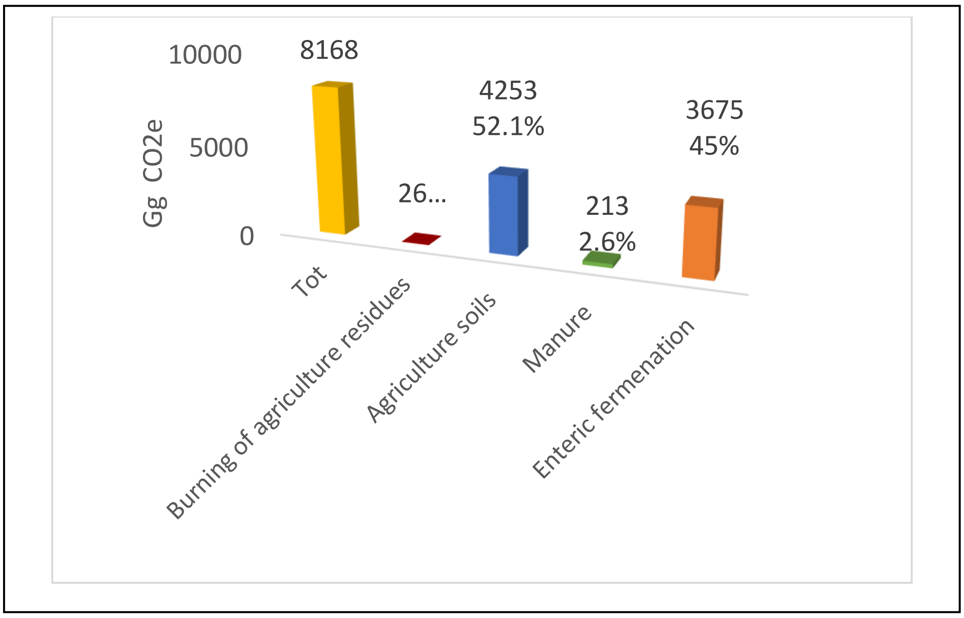
GHGs escape into the atmosphere due to venting, flaring, transport, and storage of oil and natural gas. The total emissions from this source category in 2010 were 2768 Gg CO_2-eq or 8% of national GHGs or 13 % of GHG emissions of the energy sector, figures 10.

f) Emissions from Agriculture

The agriculture sector emitted 8168 Gg CO_2-eq in 2010, which represents 24% of National GHG emissions. GHG emissions from the agriculture sector arise from enteric fermentation in livestock, manure management, agricultural soils, and on-field Burning of crop residue. . Enteric fermentation in livestock released 3,675 Gg CO_2-eq in the form of CH_4. This constituted 45% of the total GHG emissions (CO_2-eq) from the agriculture sector in Yemen. The estimates cover all livestock, namely cattle, sheep, goats, poultry, donkeys, camels, horses, etc. Manure management emitted 213 Gg CO_2-eq, being 2.6% of agriculture sector emissions. Agricultural soils in 2010 emitted 52.1% of (4,253 Gg CO_2-eq) the sector emission, which was in the form of

N_2O, associated with the application of nitrogenous fertilizers in the soils. Emission from Burning of crop residues in 2010 was insignificant (0.3 % of the sector emissions and were released in the form of CH_4 and N_2O.

Figure 1:11 GHG emission from Agriculture and its sub-sectors



1.6.3.2 Emissions from Industrial Process

In 2010, Industrial activities together emitted 1,798 Gg CO_2-eq, being 5% of National GHGs, see figure 1.12. The vast majority of this source emission 99.8% (1,798 Gg CO_2-eq) emitted from the cement industry, and only 0.02% from Limestone production, figure 1.12 GHG emission from cement production came from then Production of 3,600 k tonnes of cement.

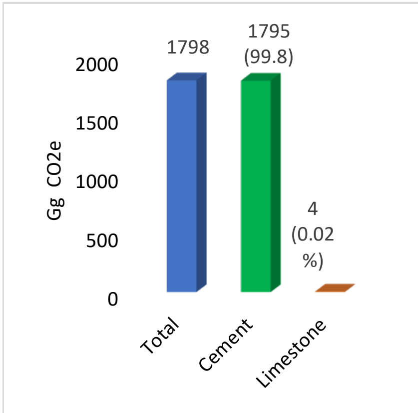


Figure 1:12 2010 GHG Emissions from Industrial Processes – Gg CO_2-eq

1.6.3.3 Emissions from Land Use Land Use Change and Forestry

The estimates from LULUCF sector include emission by sources and or removal by sinks from changes in forest land, crop land and grassland. The LULUCF Sector demonstrated net CO_2 removals amounting for -1,885 Gg CO_2-eq.

1.6.3.4 Emissions from Waste

In 2010, the waste sector emitted 2,106 Gg CO_2-eq, being 6% of total National GHG emissions. These emissions were generated from municipal solid waste management (58.2%), industrial waste (41.4%) and domestic wastewater management (0.4%), Figure 1.13. GHG emissions form Municipal Solid Waste emitted in the form of CH_4 generated due to aerobic conditions accumulated over the years. It is estimated that the MSW generation and disposal resulted in the emissions of 1226 Gg CO_2-eq in

2010. As for wastewater emissions generated were 880 Gg CO_2- eq, of which 99% (872 Gg CO_2-eq) generated from industrial wastewater and the rest from domestic sources

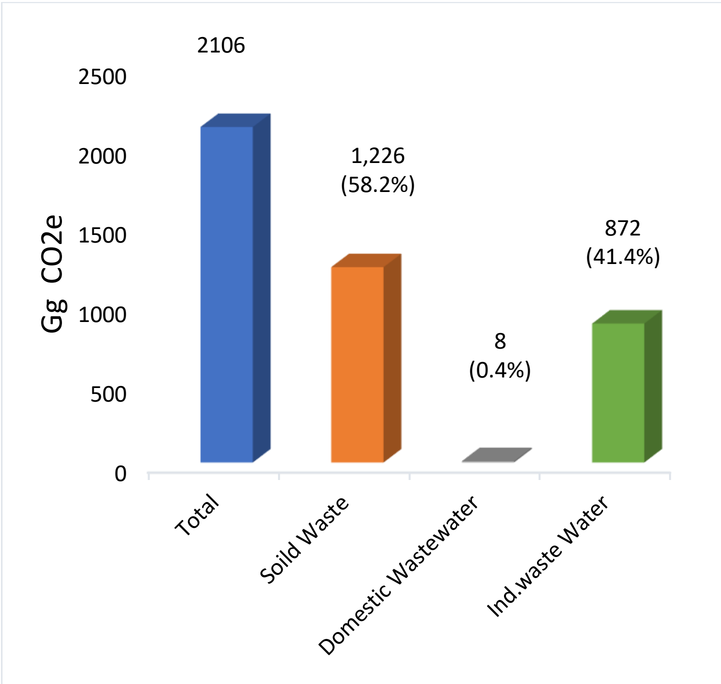


Figure 1:13 2010 GHG Emission from Waste, its sub-sectors Gg CO_2-eq, & their percentage share compared with total Sector emissions

1.7 Overview of Vulnerable Sectors to Climate Change

1.7.1 Water Sector

As mentioned in section 1.3.1 above, the adverse impacts of climate change on water sector are often projected to be most severe in a resource-poor country like Yemen. The study of 2010 to assess the impacts of climate change and variability on the water and agriculture sectors, prepared three simplified climate change scenarios (Described in section 1.2.1.3 above) to illustrate the range of possibilities of runoff and recharge up to 2080, came up with future projects of climatic scenarios 2010-2080 as summarized in table 1.7 (Ali Thabet and Al-Jibly Abdulmalek 2015).

Table 1:7 Annual Changes in Runoff and Recharge for Different Climate Scenarios

Scenario	Year	Runoff	Groundwater Recharge	ET	What to expect
Baseline	1990s	0%	0%	0%	
Mid	2030s	4%	4%	2%	Large increase by the 2050s, then decline below current levels. A modest increase in groundwater recharge until about 2050, followed by a decline reaching about 12% by 2080. Little change in ET.
	2050s	30%	2%	2%	
	2080s	-22%	-12%	0%	
Hot & Dry	2030s	-55%	-31%	-6%	A large drop in runoff, of one half or more. Groundwater recharge rates decline by more than a half by 2080. ET declines steadily as aridity increases.
	2050s	-32%	-32%	-6%	
	2080s	-78%	-55%	-11%	
Warm & Wet	2030s	147%	54%	13%	A doubling in runoff through most of the century, reducing somewhat in the second half. Groundwater recharges up by 50% by 2030, tapering off by 2080. ET well up, although dropping back a little after 2050.
	2050s	137%	41%	10%	
	2080s	66%	27%	9%	

Without going into more details, the following snapshots provide some indicative examples that highlight water situation in the country: In both Sana'a and Taiz as the most populated cities, water problems are not unique as ground water level is dropping in a rate of 5 -7 metres a year. Continuously falling groundwater levels – the result of ineffective regulation – are driving up the costs of municipal water supplies in all areas of the country. In coastal areas, coastal aquifers are also being mined, particularly along the Aden coast and in Tihama, leading to quality deterioration and saltwater intrusion. Wadi Surdud that drains from the western highlands into the Tihamah, the prediction is that flows will vary little in frequency from the present, but the volume of flows may change – ranging from a decrease of 20% ('hot and dry') to an increase of 30% ('warm and wet'). Over-abstraction of the coastal aquifer will continue even in the wettest scenarios (Al-Aizari et al. 2018).

In the Wadi Hadramout basin that drains to the Arabian Sea variability in the timing, frequency and intensity of rainfall is likely to be a significant risk, and spate and flood flows may increase in volume and frequency under both the 'mid' and 'warm and wet' scenarios. Under the 'hot and dry' scenario, flood flows would be smaller and rarer. Despite the smaller risk shown by the 'hot and dry scenario', there is a possibility of a repeat of the 2008 floods or of even more severe events. In Wadi Hadramout, as the case in other parts in the country, climate change is likely to have significant impacts on the hydrology and there is clearly a need to adopt climate adaptation strategies. Water levels in many wadis near Ta'iz have declined substantially due to groundwater pumping as well as the less runoff and recharge levels. In some cases, the lower portions have dried out completely. Lower Al Hima wadi – below the Ta'iz municipal well field, until the 1980s, was a vibrant agricultural community where local inhabitants grew a wide variety of irrigated crops. Now the area is almost dry. Dead trees surround the deserted agricultural extension office. Most agriculture now depends on rain. Drought resistant millet, which produces only a small crop of grain and fodder, has replaced the high value fruit and vegetable crops that provided the economic base for local villages. Children, women and men travel long distances by donkey or camel to collect water at the few taps stands that still run. An assessment study in 2017 under the TNC on assessment of climate change impacts on water resources in Wadi Zabid found that the aquifer will steadily deplete in the coming decades. The rate of groundwater depletion exceeds 350 million cubic metres per year across all climatic scenarios. In the worst case (i.e., future dry climate), the aquifer in the the Wadi Zabid region will be depleted within the next 41 years. Even under an optimistic future climate scenario in which average rainfall increases over the Arabian Peninsula, the aquifer is projected to be depleted within the next 51 years. Table: 1.8(Haidera et al. 2011; Noman Abdullah 2016).

Table 1:8 Groundwater storage and depletion rate

Climate Scenario	Fossil groundwater storage (BCM)		Rate of groundwater depletion (MCM/year)	Full depletion (years)
	2008	2033		
Future baseline climate	27	17.9	364	49
Future wet climate	27	18.1	356	51
Future dry climate	27	16.7	412	41

In all cases, the most vulnerable group to the impacts of climate change on water sector in rural areas is the women as the responsibility for water collection in rural areas remains with women and girls who are responsible for fetching water. Yemen's water crisis and climate change impacts have affected women adversely in different ways. Groundwater irrigation for cash cropping has resulted in aquifer depletion in different agro-ecological regions. Traditional sources of water-harvesting structures are no longer maintained. Thus, women and young girls travel longer distances for water in rural areas, affecting their health, safety, and literacy levels. As more men migrate to cities and other Gulf countries, women's role in irrigated agriculture has increased. In the case of urban areas, richer households purchase water from tanks, whereas poorer women have to line up either to buy water from richer neighbours, to obtain lower quality water from wells, or periodically to fetch water from municipality water projects.

Therefore, it is necessary to have access to a diverse array of adaptation technologies and practices that are appropriate and affordable in various contexts. The scale of these adaptation technologies/practices should range from the individual household level (e.g., household water treatment, or rainwater harvesting from rooftops), to the community scale (e.g. rainwater collection in small reservoirs such as ponds and small dams), to large facilities that can benefit a city or region (e.g. a desalination plant).

Proposed adaptation and mitigation measures to climate change that help to conserve water and reduced the pressure on water resources can be through implementing of a variety of strategies including rainwater harvesting through various techniques including traditional methods, water conservation through reuse of treated waste water and grey water from mosques, and irrigation saving techniques. In rain-fed areas, rehabilitation and maintenance of mountainous terraces and promotion of research on drought resistant and heat- and salinity-tolerant crops, rehabilitation of irrigation systems with reinforcement of flow structures and appropriate diversion structures for drainage of flood waters, prevention of development within the wadi bed and ensuring that vulnerable buildings are raised above flood levels or protected, and the development of appropriate flood forecasting and early warning systems with robust communication strategy in order to prevent loss of life and property before/during flood events.

1.7.2 Agriculture

Changes in temperature caused by climate change will affect cropping patterns, times of planting and harvesting and important ecosystems that, for example, facilitate pollination. Increased temperatures will also increase evapotranspiration. Temperature variability creates hazards to which agricultural ecosystems are not well adapted. High temperatures exacerbate the effects of drought, damage crops and their establishment due to heat stress, and reduce yields. Global food production is expected to increase overall with increases in average (local) temperatures of 1–3°C but it is expected to decrease if temperature rises exceed 3°C. Temperature has significant impacts on crop quality, quantity, and where it can be grown as temperature has impact son all stages of crop development. Because of the nature of this fundamental biological and ecological relationship, any changes in temperature caused by climate change will have a significant impact on crop (commodity) production. Within certain temperature boundaries (e.g., between 10°C and 30°C for wheat), development generally accelerates in a linear fashion, but at extreme temperatures, the relationship becomes non-linear and increasingly difficult to predict.

Moreover, agriculture is one of the sectors most vulnerable to changes in the precipitation regime where intense and short-lived rainstorms imply floods that cause erosion of fertile soil and deterioration of land cover. Prolonged periods of drought that follow these short intense rainstorms, cause spread of sand dunes and expansion of desertification, degradation of agricultural lands, and deterioration of plants and crops (Sadek and Al-Nabhani 2016b; Wilby and Yu 2013a).

Climatic disasters have wide-ranging impacts, with agriculture taking the significant share of damages in recent Yemeni experience. In the 2008 Hadramout-Al-Mahra flood disaster, for example, agriculture was the most sector exposed to damage and losses, in terms of destruction of physical assets, agriculture was the most affected (63% of total damages), and in terms of losses in the economy, agriculture was again the most affected (64% of the total losses). Altogether, these impacts have negative effects on sources of incomes for local communities and lead to food insecurity at national level. Because there is no consensus on the nature of the climate scenario that Yemen will face, it is difficult to predict what the precise impact will be on agriculture. However, there is agreement that crop production will worsen over time, on average. Even in the most optimistic scenario *("warm and wet")*, production increases initially but time will see that increase worn away during the middle and later parts of the century, because all scenarios predict a decline in rainfall after 2050. Temperature effects on crop production are

Table 1:9 Sea level rise trends in Al-Mukalla, 1992-2012 (source: Yemen's TNC, 2018)

Latitude	Longitude	SLR (mm/yr)
13.75	48.75	2.23
13.75	49.00	1.93
13.75	49.25	1.76
13.75	49.50	1.73
14.00	48.75	2.03
14.00	49.00	1.74
14.00	49.25	1.59
14.00	49.50	1.59
14.25	48.75	1.94
14.25	49.00	1.70
14.25	49.25	1.57
14.25	49.50	1.59
14.50	48.75	1.91
14.50	49.00	1.72
14.50	49.25	1.61
14.50	49.50	1.65
Average		1.77

complex and affect crops differently based on altitude: lowland crops are negatively affected by temperature increase, but highland crops may be improved. Table1.9 below shows the marginal impact of climate change on crop production in Yemen, for three different climate scenarios (‘mid’, ‘hot and dry’, and ‘warm and wet’), based on downscaled model results (World Bank, 2010) (Kadri AbdulBaki Ahmed and Gamal Bawazir 2016).

Table 1:10 Marginal impact of climate change scenarios on crop production

	Mid			Hot and Dry			Warm and Wet		
	2030	2050	2080	2030	2050	2080	2030	2050	2080
Temperature ° C	+1.6	+2	+3.1	+2	+2.6	+4.5	+1	+1.2	+1.6
Rainfall change	+3%	+3%	-3%	-13%	-13%	-24%	+25%	+20%	+13%
Crop production	+1%	+1.1%	-6.3%	-10.7%	-11.2%	-27.2%	+14.1%	+11.7%	+6.5%

The focus on climate resilience of agriculture sector needs to be through an integrated watershed management approach and through agricultural diversification. Although climate change is unpredictable, it is expected to bring a generally hotter, drier climate, and increased incidence of drought and floods, which require farmers to consider possible technologies to adapt farming systems and planting materials. Farmers need to be aware of trends and risks, and make constructive and practical contributions to address climate change through the strategic agenda.

1.7.3 Coastal Zones

The long coastline of Yemen makes it one of the most vulnerable countries to climate change and sea level rise. The Intergovernmental Panel on Climate Change ranked the Yemeni port city of Aden sixth among globally twenty-five cities most vulnerable to rising sea levels. Climate change impacts and consequences of seal level rise, extreme events and disasters, and storm surges may include coastal erosion, destruction of coastal infrastructure, increased flooding risks, damage and deterioration of coastal and marine habitats and ecosystems, and saltwater intrusion. Climate change will affect the coastal zone in three ways. First, sea level rise will require adaptation of infrastructure in ports and towns and related support services such as transport, water supply and sewerage networks. Erosion may also adversely affect ecological and cultural assets. Second, populations migrating from the water-short hinterland will require new industrial and commercial infrastructure to generate employment whilst continued high density residence in the highlands may require construction of desalination plants. Fourth, and finally, increased population pressure will increase the demand for natural resources – raw materials for construction and increased utilization of marine resources and fisheries.

Sea level rise will affect a significant portion of the population and productive assets. Main effects will be increased flooding risks, structural damage and contamination by sea water and coastal erosion.

A study under the Initial National Communication in 2000 estimated that 24 % of the Hodeidah population and families are expected to be affected by the sea level rise. In contrast, given its unique physical setting, a study in 2010 under the Second National Communication estimated that about 50% of the populated area of Aden Governorate would be adversely affected. In Hodeidah the potential cost of adapting economic infrastructure to sea level rise was estimated at US$1.3 billion (2000 prices), in Aden adaption costs for a sea level rise two-thirds of that modelled for Hodeidah was estimated at US$2.3 billion (2010 prices.). Sea level rise will also exacerbate sea water intrusion into the Tuban delta aquifer and threaten Aden's main source of water supplies (Red cross and Red Crescent Societies 2018; Yemen Red Crescent Society (YRCS) 2018).

Figure 1:14 Coral bleaching in the Gulf of Aden during the last years (source: Yemen's TNC, 2018)

Impacts of climate change extreme events on coastal areas of Yemen have been increasing in severity and frequency in the last few decades. Examples of experienced recent tropical cyclones include Cyclone Chapala 2015, Mekunu and Luban 2018 and many others which have led to disastrous consequences and damages on several parts along the coastal governorates of Al-Mahra, Socotra, Hadramout, and Aden. Economic losses of infrastructure damages by some of these events was estimated at more than USD1.5 billion, while the non-structural losses such as loss of lives and loss of biodiversity systems and habitats are much higher invaluable losses.

A vulnerability assessment study under the TNC highlighted that climate change is altering physical properties such as salinity, temperature, and pH levels in the marine environment which can lead to adverse impacts on marine biodiversity and commercial fisheries. For example, there is increasing evidence that coral reefs in the northern part of the Gulf of Aden are being damaged by unusual marine conditions, and coral bleaching and mortality events attributed to higher sea water temperatures have been more frequent in the Gulf of Aden (see Figure 1.14).

The study also concluded that sea level rise poses a threat to the built environment in Al-Mukalla coastal area in the form of ocean waters reaching further inland, particularly under high tide conditions. It also increases the potential for adverse shoreline change (i.e., erosion, sediment transport), saltwater intrusion, loss of wetlands for migrating waterfowl, loss of habitats for sea turtles (green, hawksbill, loggerhead), and infrastructure damage, especially when combined with storm surge associated with extreme storm events. Sea levels have been rising in the coastal waters off the Al-Mukalla at a rate of about 1.77 mm per year over the past 20 years.

It could be concluded that strategic documents recommend that adaptation strategies have to include planning to mitigate the risks of exceeding the carrying capacity of the coastal areas given the high reliance on natural resource exploitation for livelihoods and food security, especially of the rural poor. Additionally, they will need to consider other threats to the coastal and marine environment such as uncontrolled use of coastal zones, destruction of marine and coastal habitats and ecosystems, spatial conflicts among various users, unplanned coastal reclamation, the destruction of benthic habitats by bottom trawling and the destruction of endangered species (Kadri AbdulBaki Ahmed and Gamal Bawazir 2016; Noaman Abdullah 2016).

These recommendations would help to design and achieve tangible results such as:

- Reduce the vulnerability of fishermen community to climate change risks, including storm flows and flooding, through the sustainable management of its natural resources.
- Build community capacity to manage coastal resources by assisting village groups to identify appropriate technologies, design and develop alternative income generating initiatives that reduce climate change risks while protecting natural coastal defences such as mangroves, beaches, and coral reefs.
- Reduce erosion from farming practices and improve tidal flushing through the removal of maladaptive coastal infrastructure to improve the resilience of climate-threatened coastal ecosystems by reducing climate-related sedimentation risks.
- Develop and implement awareness raising activities to respond to climate change on coastal zone with all relevant agencies and institutions.
- Assess impacts and identify measures to respond to climate change and sea level rise.
- Mainstream and integrate climate change issues into strategies, programmes, plans.
- Implement other related tasks including research and propose measures in term of employment security; poverty reduction for the most vulnerable areas caused by climate change; research and propose solutions and plans on migration, re-settlement and life security for residents in the most vulnerable areas caused by climate change and sea level rise; issues on gender, population, and livelihood.
- Develop and implement action plan to respond to climate change on coastal zone.
- Develop and implement disaster preparedness and recovery programmes, including forecasting, early warning systems and rapid response strategies to cope with extreme weather events.
- Planting and re-planting of mangroves and palms for adaptation to sea level rise.

More precisely, the NAPA identifies several adaptation options; those of relevance for coastal zone management are presented in Table 1.11

Table 1:11 NAPA Adaptation Options Relevant to the Coastal Zone

• Develop and implement disaster preparedness and recovery programmes, including forecasting, early warning systems and rapid response strategies to cope with extreme weather events
• Encourage and expand desalination for drinking water using renewable energy sources, especially on Yemeni islands and coastal areas, where water is unavailable or vulnerable to seawater intrusion
• Develop and implement an awareness raising programme on adaptation to the potential impacts of climate change on vulnerable sectors.
• Design and implement watershed management and terrace-rehabilitation programmes
• Disseminate flow and flood guidance for stations at main wadis
• Establish a 'National Research Centre' to undertake research on climate change and adaptation issues
• Develop and implement Integrated Coastal Zone Management programmes
• Expand green-belts for coastal area on the main land and is by planting and replanting mangroves and palms; establish and maintain nurseries that provide cultivars and other materials

- Develop and implement sustainable land management strategies to combat desertification and land degradation
- Establish a database for all climate change related issues including adaptation activities
- Design and implement training and education programmes for use of efficient, environment friendly fishing techniques and equipment
- Increase soft protection (e.g., beach nourishment and wetland construction and restoration), and building stone walls to protect from storm surges
- Construct coastal defence and walls for coastal areas vulnerable to erosion
- Improve and activate marine fishing regulatory laws, and engage relevant stakeholders and local communities in monitoring the implementation of valid fishing laws
- Specify fishing seasons for each species of marine resources; issue licenses for definite species

1.7.4 Public Health

In addition to the challenges and problems that the health sector is facing (mentioned in section 1.3.4 above), exposure to climate-related hazards such as higher temperatures, heat waves, and extreme storms associated with floods will severely exacerbate health problems and may lead to vector borne and waterborne diseases which may extend their range into areas that are presently unaffected (Malaria is just an example of such extended diseases). Moreover, chronic diseases such as cardiac, respiratory, and renal diseases may be aggravated by atmospheric conditions (i.e., temperature, humidity) that exceed historical variability(Noaman Abdullah 2016) .

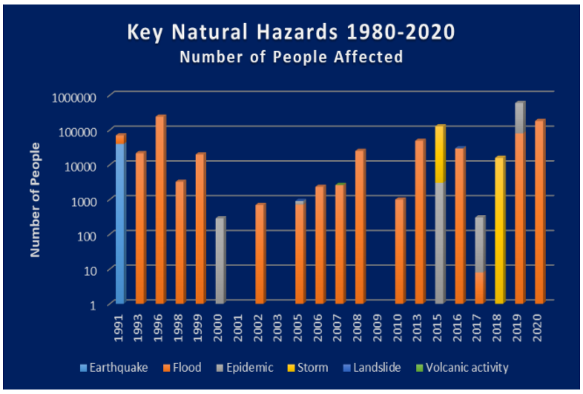


Figure 1:15 Natural disasters incidents 1991-2020. (Source: Modified from World Bank 2021)

Yemen is already a disaster-prone country facing increasing number of natural hazards that take a toll on population morbidity and mortality, it is highly vulnerable to climate extremes and climate variability due to the country's deteriorating economic situation.

Trends of natural hazards in Yemen show an increasing rate of climate-related natural hazards during the last few decades such as extreme floods and heavy storms as well as epidemics (Figure: 1.15) (Anwar and Noaman 2016; Noaman Abdullah 2016).

Yemen's topography renders the different geographical regions susceptible to various climate change induced disasters, and for the last twenty years Yemen had at least one disaster (in average) every year. October 2008: the heavy rains associated with tropical storm Deep Depression brought 90 mm of rainfall over the course of 30 hours, leading to severe flooding in Hadramout and Al-Mahara governorates that caused over 180 deaths, and the displacement of 25,000 people. November 2015: Cyclone Chapala brought strong winds of 120 km/h, and dropped huge amount of rain leading to floods. Hadramout, Al-Mahara, Shabwah and Socotra governorates were hardest hit and witnessed the displacement of over 50,000 people and a subsequent outbreak of dengue fever that left 7 people dead. May and October 2018: Cyclone Mekunu and cyclone Luban dropped heavy rains leading to floods and killed 24 people and 14 people respectively (20 are in Socotra only), and 8,000 people left homeles[7].

In order to respond adequately, quickly and cost-effectively to the increased frequent and intense climate-related hazards, and build health systems resilience, infrastructure, policies, and programmes, a set of adaptation measures are required as follows:

- Establishment and strengthening of an epidemiological surveillance system for:
    - Monitoring changes in vector population abundance in the main targeted high risk and expected transmission areas;
    - Temperature-related mortality and morbidity and adverse health effects of air pollution exposure;
    - Vector borne, waterborne and foodborne diseases
- Development of an effective and responsive preparedness system with full capabilities to deal with unexpectedly disasters.
- Encouragement of research on climate change and its linkage to infectious disease and temperature related mortalities and morbidities.
- Improving access and utilization of health care services for all vulnerable populations taking into accounts equity and gender disparities.
- Improve access to essential medical supplies for effective post-disaster distribution to increase the ability of communities to manage large-scale floods and storms.
- Improving access to clean water and sanitation services for underserved and vulnerable groups.
- Strengthening and expanding routine vaccination programmes, as well as expanding the supply of drugs against malaria and enteric infections for the prompt treatment of people. Capacity building on climate change impacts which include training, surveillance and emergency response, and prevention and control programmes.
- Mainstreaming climate-related health impacts into national health policies, plans and programmes.
- Integration of climate-related adaptation to the broader public health issues such as population growth and demographic change, poverty, public health infrastructure, sanitation, availability and accessibility of health care, nutrition, risky behaviours, misuse of antibiotics, pesticide resistance, and environmental degradation.
- Provide adequate support for health services; emergency response preparedness; training of health workers on how to deal with health impacts of climate change; surveillant vector borne, waterborne, foodborne, and air pollutant-rated diseases; and monitoring of potential health impacts of climate change.

1.7.5 Ecotourism

Climatic impacts and hazards affecting ecotourism include temperature increase, sharp fluctuations in rainfall, recurrent drought, and sea level rise with a potential increase in the frequency of coastal storms and tropical cyclones.

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[7] https://extranet.who.int/countryplanningcycles/sites/default/files/planning_cycle_repository/yeme

Temperature increase and fluctuation of rainfall patterns will lead to increased aridity and consequently large number of eco-tourism sites will be affected, many habitats will be deteriorated, and many species could experience a drastic reduction in the size and extent of their population. Moreover, higher temperatures and less precipitation may adversely affect activities by damaging biodiversity in natural areas and increasing the risks of altering the sensitive equilibriums associated with plant-wildlife-insect populations and their distribution, which are of high potential for ecotourism.

Findings of an illustrative case study undertaken under the TNC in 2017 to assess climate change impacts on ecotourism in Socotra and Jabal Bura'a protected area are summarized and highlighted as following (Environment Protection Authority 2015b; Sadek and Al-Nabhani 2016b):

Climate change will likely lead to a decrease in biodiversity, and increased risks of invasive species, endemic species such as *Dracaena cinnabari* (dragon blood) and Frankincense trees in Socotra, which are highly sensitive to drought and temperature changes, could experience a drastic reduction in their size and extent.

Deterioration of the fragile and sensitive systems of limestone caves of Socotra which are unique ecosystems with an extremely delicate balance of interaction between the physical elements of the inner environment, heat, and humidity. Scarcity of water under the Hot and Dry scenario will affect the amount of moisture, and water infiltration which feeds into the cave lagoons, and hence reduce the natural process of crystal formations. The delicate climate and environment of caves make them highly susceptible to even small changes in temperature and humidity. Thus, caves based eco-tourism in Socotra is extremely vulnerable to the combined effect of temperature increase, and humidity(Environment Protection Authority 2015b).

Any increase in the intensity and/or frequency of climatic events increase the potential for damage to marine biodiversity such as coral reefs and sea grasses and hence undermine marine based ecotourism. Several sites in Socotra (e.g. Dihamri, Homhil, Mahferhin) were identified as extremely sensitive to coastal erosion, and more intense cyclones would increase the risks to the land-based infrastructure needed to support ecotourism activities.

In Jabal Bura'a, the study found that increased aridity is expected to inhibit forest growth and production, likely resulting in a loss of biodiversity, which could have a significant impact on the attractiveness of the region as a touristic destination. Climate change could also exacerbate the existing challenge of invasive species which could push aside native species and transform ecosystems. Aridity would increase the risk of wildlife migration, and also it is possible that certain animal species may be particularly vulnerable to a hotter and drier climate and will seek out new habitats with more preferable climate conditions

To address these threats and help vulnerable stakeholders and systems to cope with and adapt to the adverse impact of climate change. a set of recommended adaptation measures to build resilience in key sectors supporting ecotourism enhance adaptive capacity are identified including:

- Enforcement of enhanced design and planning guidelines for ecotourism establishments in order to increase their resilience to the impacts of climate change;
- Integration of climate change risks into regulatory frameworks for ecotourism development, such as environmental impact assessment and strategic environmental assessments;
- Establishment of protected beaches and marine ecosystems against threats of uncoordinated resort development and urban sprawl.
- Support of protected area management in order to enhance resilience of land-based ecosystems and ecological resources;

- Restoration of forest cover in deforested areas to improve the vegetation cover, reduce erosion, and increase water infiltration;
- Enforcement of laws and traditional knowledge to control cutting of trees and grazing in the forest area and rangelands.
- Creation of financial incentives to encourage investment in sustainable ecotourism activities;
- Build business sector awareness of economic benefits associated with sustainable ecotourism;
- Build public awareness of ecotourism activities; and
- Provision of climatic information to the tourism sector through cooperation with the national meteorological services.

1.8 Process and Results of Sector Selection

The selection of sectors for mitigation was based on the potential of sector contribution to GHG, while the sectors for adaptation were selected based on their vulnerability to climate change. The selected sectors were prioritized according to a specific set of selected criteria.

1.8.1 Selection Criteria for Adaptation:

- Vulnerability to climate change
- Adaptive capacity
- National priority based on development plans
- Socio-economic importance
- Extent to which change can be inflicted
- Technological availability
- Cost of adaptation

To rank the five most vulnerable sectors (agriculture, water, public health, coastal zone, and tourism) they were examined against the selection criteria for adaptation and ranked by Multi-Criteria Analysis (MCA) exercise, using a scoring system of 1 to 5, with 1 being "low important" and 5 being "very high important." The selection criteria were:
According to the MCA results, out of the total maximum scores of 35, the water and agricultural sectors received the highest overall scores (average score of 30.7 for water and 27.8 for agriculture), followed by coastal zones (average score of 24.7) and ecotourism (average score of 17) and health as the last one (average scores of 13.5), as seen in table 1.12.

Table 1:12 Ranking of vulnerable sectors for adaptation through MCA (Score: 1= V. Low and 5= V. High)

Criteria	Sectors				
	Agriculture	Water	Public health	Costal Zones	Ecotourism
Vulnerability to climate change	4.3	4.5	2.5	4.2	2.5
Adaptive capacity	4	4.5	2	4	2.5
National priority	4	4	2	3.8	2.5
Socio-economic importance	4	4.5	2,5	3.7	3
Technological availability	4	4.2	3	3.5	2.5
Cost of Adaptation	4	4.5	2.5	3	2
Extent to which change can be inflicted	3.5	4.5	1.5	2.5	2
Total	27.8	30.7	13.5	24.7	17

1.8.2 Selection Criteria for Mitigation:

- GHG reduction potential
- Fossil fuel dependency
- Availability of technologies
- Potential to attract investment
- Potential of market penetration
- Cost of mitigation

Similarly, the five identified mitigation sectors (Energy, transport, industry, waste, and agriculture) were examined against the selection criteria for mitigation and ranking process through Multi-Criteria Analysis (MCA) exercise (expert judgment as a first step to provide guidance for stakeholder consultations) in which ranking scores range from 1 to 5, with 1 being very low importance and 5 being very high importance. Then, it was followed by stakeholder consultations through which a high agreement and consensus were achieved on selecting energy and transport as the two key sectors.
According to the consensus among stakeholders and the MCA results, out of the total maximum scores of 25, the energy and transport sectors received the highest overall scores (average score of 25.8 for energy and 25.3 for transport), followed by waste (average score of 20.9), then industry (average score of 20.6) and finally agriculture (average scores of 15.7) as seen in table 1.13.

Table 1:13 Ranking of mitigation sectors through MCA (Score: 1= V. Low and 5= V. High)

Criteria	Sectors				
	Energy	Transport	Industry	Waste	Agriculture
GHG reduction potential	4.3	4	4.2	4.5	2.5
Fossil fuel dependency	4.5	5	4	2	2
Availability of technologies	4.4	4.2	3	4	3.2
Potential in attracting investment	4.1	4.3	3.5	3.2	2.5
Potential of market penetration	4.5	4	3	3.4	3
Cost of mitigation	4	3.8	2.9	3.8	2.5
Total	25.8	25.3	20.6	20.9	15.7

Chapter 2: Institutional Arrangement for The TNA and the Stakeholder Engagement

2.1 National TNA Team in Yemen

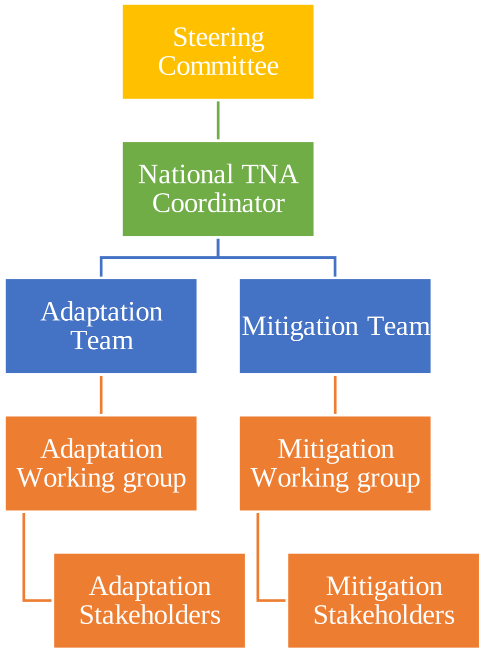

Figure 2:1 National Team and Stakeholders structure

2.1.1 Steering Committee

The steering committee of this project is the members of the Board of Environment Protection Authority and the Minister of Water and Environment, and they are as follows:

1. Minister of Water and Environment
2. Chairman of Environment Protection Authority
3. Deputy Minister of Water and Environment for Water the Sector
4. Deputy Minister of Water and Environment for Environment Sector
5. Vice Chairman of Environment Protection Authority
6. Deputy Minister of Energy and Electricity
7. Deputy Minister of Agriculture, Irrigation, and Fisheries
8. Deputy Minister of Transport
9. Deputy Minister of Planning and International Cooperation
10. Deputy Minister of Industry and Trade
11. TNA Coordinator (Secretary)

All the Steering Committee members were invited to attend the Inception Workshop of the TNA Project. All members had the opportunity to be introduced to the project's concept and objectives as well as provide feedback on its planning and implementation strategy.

2.1.2 The National TNA Coordinator

The Deputy Director of the Climate Change Unit in the Environment Protection Authority, Eng. Abdulwahid Arman is serving as the National TNA coordinator. The TNA Coordinator is in charge of coordinating and facilitating the activities of the TNA in Yemen. He participated in the planning of all activities and consultation workshops and reviewed deliverables and obtained necessary endorsement for actions and deliverables from high-level level entities in the chain of command at EPA.

2.1.3 The consultants' Team

The consultants were selected by EPA to carry out the TNA assignment in Yemen. For the Mitigation sectors, the center of Science and Technology at Aden University was hired to conduct all the needed activities under mitigation. Whereas the Sustainability Foundation of Nature Conservation served as the adaptation consulting entity. Both institutions have a sufficient experience in climate change and environmental issues. Within the national team, each member is responsible for one sector depending on his/her experience and specialization working in close collaboration with sectoral core stakeholders. Series of meetings and working sessions have been regularly held at a working group level, mitigation and adaptation group level, and at the whole TNA project level. Before starting the consultative workshops, the consultants had prepared a fact sheet for each technology in the initial list of options in mitigation and adaptation sectors to be distributed among the stakeholders. These fact sheets were presented by the consultants during the consultative workshops and discussed in detail with the participants. During the first workshop, the participants suggested new options besides the ones prepared by the consultants. The new options were also revised by the consultants, and new fact sheets were prepared before the last consultative workshop, which was for technology prioritization. The fact sheet prepared by the consultants has helped the participants to prioritize the technology options based on the criteria that have been developed by the consultants and the participants in the second workshop. After the last consultative workshop, the consultants discussed the results and outcomes with the national coordinator. They revised the working group activities, which were formed from the most relevant stakeholders and active participants in the consultative workshop. Finally, the workshop findings have been reported by the national coordinator and consultants and reflected in this report.

2.2 Stakeholder Engagement Process Followed in the TNA – Overall Assessment

Indeed, stakeholder engagement was the biggest challenge the TNA team faced because TNA was the first climate change project to be implemented in Yemen since 2014. However, the TNA team has done a great job of reactivating the communication with the relevant stakeholders, as the stakeholder's involvement is the key success of the project. Moreover, the TNA team has succussed to re-establish the national climate change committee after a long stop.

In fact, the TNA project country-driven process where a wide variety of stakeholders must be engaged to identify and prioritize the technology options in each selected sector. The plan of stakeholder involvement was designed to reach the high decision and policymakers as well as technical experts, academicians NGOs to assess the specific needs of each selected sector and verify the project outcomes, and thus filling the gap to develop an integrated strategy to address the climate change issues in the country now in the future. This target was achieved by using several communication tools:

- Expert consultations in the preparatory phase: during the initiation and planning phases of the project, sectoral experts related to climate change issues were consulted through a series of meetings and digital communication in order to identify sectoral needs and gaps and determine their expectations from the TNA project. These expert consultations were used to select the priority sectors, to confirm the choice of the initial list of technologies and to validate the information presented in the factsheets before their dissemination to a wider audience.

- Inception and Consultative workshop: Inception workshop and three workshops from 6 days were held for technology selection and prioritization as follows:
    1) Inception workshop: The main objective of this workshop was to ensure that the participants has built a clear understanding of the project. Therefore, in this workshop, the project objectives and expected outcomes were presented by the TNA coordinator and consultants in detail and the process of technology prioritization was clarified to the participants. Moreover, there was an exercise for technology prioritization conducted by the attendees to understand the MCA process.
    2) The first and second consultative workshops: The first consultative workshop was for mitigation, whereas the second was for adaptation. Each workshop was held on two different days with almost different stakeholders. The objectives of those workshops were to identify a final list of technology options and to suggest the criteria that could be used for the evaluation. Therefore, on the first day, the participants proposed an initial list of 10 to 15 technology in each sector to be assessed through technology prioritization using the MCA process. On the second day, the participants suggested the list of criteria to be used for technology prioritization and evaluation, and furthermore, the participants also gave weight to each criterion.
    3) The last consultative workshops: This workshop was also held for two days, first for mitigation and second for adaptation. The aim of this workshop was to prioritize the technology options using that identified on the first day of the first consultative workshop using the criteria proposed by the participants in on second day of the same workshop.
- Individual meetings: To ensure that the right people are engaged in the prioritization process and to resolve the absence of some key stakeholders in workshops, individual meetings with ministerial advisors, technical public servants, data providers, private companies, and economists were held to collect data or endorse results. These meetings were essential in establishing or maintaining personal contact with stakeholders.
- Official communication: in cases where some institutions' response rates were low, draft reports and documentation were transmitted via official channels for evaluation and validation.

The adoption of these various communication approaches ensured to the extent possible proper stakeholder participation, which resulted in the transfer of new knowledge, particularly local knowledge, as well as insights into specific technology challenges and opportunities that would otherwise have gone unnoticed. Furthermore, throughout the project, special attention was compensated to ensure that the TNA process did not duplicate work and only addressed issues that were currently under-assessed in the country or were of high development interest to decision-makers.

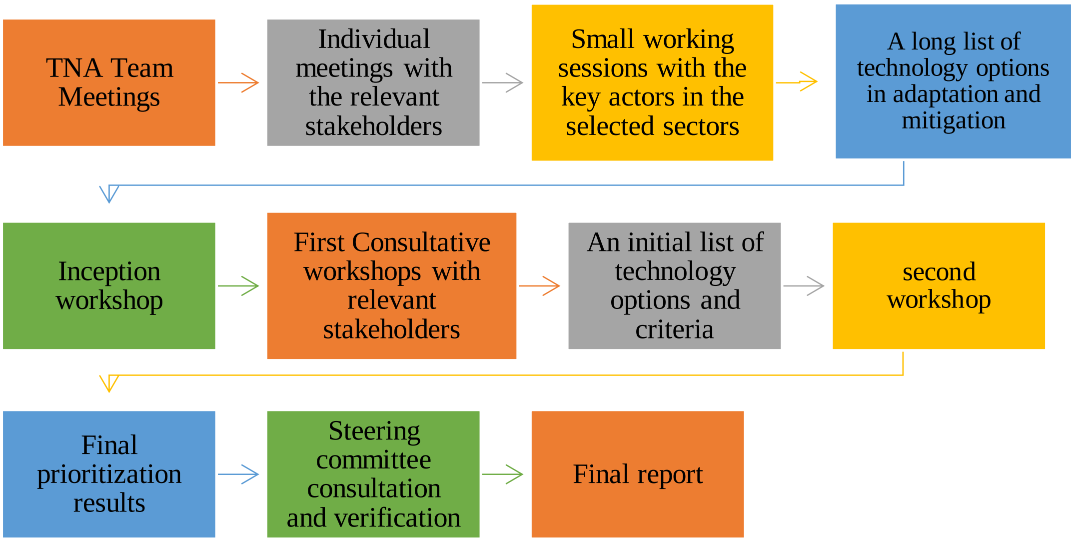

Figure 2:2 The overall TNA process

Stakeholders were identified based on their expertise, decision-making positions, engagement and awareness of the selected sectors, and potential to influence the planned TAP implementation. Most stakeholders have previously participated in the NCs process, which has resulted in the creation of a shared knowledge base and the development of strong inter-institutional and interpersonal relationships. The stakeholder's engagement was categorized as below:

Table 2:1 Stakeholders Categorization

Category	Name of Mitigation Stakeholders	Name of Adaptation Stakeholders
Ministries and governmental institutions	1. Ministry of Energy and Electricity 2. Ministry of Transport 3. Ministry of Public Work and Highways 4. Ministry of Planning and International Cooperation 5. Ministry of Industry and Trade 6. Ministry of Oil and Minerals 7. Public Electricity Company-headquarters and branches 8. Yemen Petroleum company 9. Environment Protection Authority – Headquarter and Branches 10. Aden Refinery Company 11. Yemen Company for Flour Mills and Silos 12. Alhiswa Thermal Power Plant 13. Peromasila Power Plant	1. Ministry of Water and Environment 2. Ministry of Agriculture, Irrigation and Fishery 3. Ministry of Public Work and Highways 4. Ministry of Planning and International Cooperation 5. National Water Resources Authority 6. General Authority for Rural Water Projects 7. National Water and Sanitation Authority 8. Social Fund for Development 9. Environment Protection Authority – Headquarter and branches 10. Agriculture offices in Lahj and Abin
Private sector	14. Alwatinia Cement Industry 15. Alwahida Cement Industry 16. Petromasila Power Plant 17. Alaidrus for renewable energy and Solar systems 18. Car Importer	11. Witex for Water Technology 12. Pure life for water technology 13. Taiba for Agriculture Tools 14. Sustainability Foundation of Nature Conservation

Academic/ research sector	19. Faculty of Engineering – Aden University 20. Centre of Environmental studies 21. Centre of Technology and Science	15. Faculty of Agriculture – Aden University 16. Faculty of Engineering – Aden University 17. Centre of Environmental studies 18. Centre of Technology and Science
NGOs	22. Joood Foundation for Human Security 23. Afaq foundation for Youth 24. Yemen Women for Science, Technology and Development	19. Jood Foundation for Human Work 20. Afaq foundation for Youth 21. Yemen Women for Science, Technology and Development
IGOs		22. UN – Habitat

2.3 Gender Engagement in the TNA project

Gender equality is one of the goals of the TNA project in the mitigation and adaptation sectors. Thus, the effective mainstreaming of gender issues into climate change is crucial in order to achieve a just transition and avoid the adverse impacts of implementing climate change response measures in the future. Moreover, in Yemen, considering gender equity in the climate change policies, strategies and interventions can be a turning point to support and strengthen the capacity of women in Yemen.

The TNA process involved consultation with relevant stakeholders from the public and private. Therefore, it was necessary to ensure that the consultation process considered gender-sensitive in both processes of the project. This means that a) the perspectives of both women and men need to be sought during the consultation process to ensure that both have an opportunity to voice their opinions, and b) gender issues should be treated as part of both sector and technology selection.

As a result, the proposed criteria considered the gender issues under the social and economic benefits, and the gender issues were involved in the prioritization process of the technology options. Accordingly, the women's needs and challenges were taken into account in the final selected technologies, and they will be further analyzed in the next TNA steps, particularly BAEF and TAP.

Furthermore, TNA workshops have ensured gender participation with a percentage of not less than 30%. In mitigation and adaptation workshops, the number of women was almost 31 and 35%, respectively. Accordingly, it can be said that the voice of women was effective in all the project processes until the final prioritization of the technology options.

Energy Sector

Chapter 3: Technology prioritization for Energy Sector

The energy sector is the largest producer of greenhouse gases. Greenhouse gases are mainly produced by the combustion of fossil fuels for power generation. Fuels such as coal, petroleum oil, and natural gas are burnt to drive turbines to generate electricity. However, this sector has the potential to mitigate the effects of climate change using alternative technologies.

This chapter provides an overview of the existing technologies for climate change mitigation in Yemen's Energy Sector. It also outlines stakeholders' identification of applicable technologies for implementation in the country. Stakeholders also participated in the prioritization of the identified technologies using the Multi-Criteria Analysis (MCA). This process was conducted in the technology prioritization workshop held during the consultative workshop from 6 to 14 February 2022, which was attended by participants from relevant ministries, organizations, experts from the University of Aden and the private sector in addition to the TNA team.

3.1 Existing Technologies in Energy Sector

The Ministry of Energy and Electricity (MEE) in Yemen is responsible for formulating energy policy and strategy of power electricity in the country, including the licensing and control of private and industrial auto-generation. As a semi-independent part of the MEE, the Public Electricity Corporation (PEC) is responsible for transmitting, generating, and distributing electrical power via several grids. The PEC generates electricity depend on conventional power plants, which rely on fossil fuels, petroleum, and its derivatives. Oil power plants are the country's largest distributed generation plants with a cumulative generating capacity of 600 MW, followed by steam and gas power plants, generating roughly 495MWand 350MW. Along with several small power plants located in many different regions of the country (as described in Table 3.1), there are four major power plants in Yemen, one gas power plant located in Ma'rib, and three other steam stations located in the Al-hiswah, Mokha and Ras-katheeb regions. The Marib gas power plant is the largest, with a generating capacity ranging from 340 MW to 380 MW. Although Yemen has the fourth largest population in the Middle East region, its generating capacity is one of the lowest and only enough to satisfy 40% of the electricity demand in the country. In general, the total generation of the power plants that follow the national grid is around 1100MW, however; the average load demand for only load-connected national grid reaches 1400 MW (total country demand around 2650 MW28).

The key issue with Yemen's electrical system is the heavy use of diesel power plants, which consume around 79,000 tons of diesel per year to generate a low amount of power as a result, the power sector produces a high amount of CO_2 emission, e.g., in 2012, the power generation emission factor was averaged at 22,038 Gg (Environment Protection Authority 2010). Besides, although the generation capacity is limited, the electricity losses are high due to vandalism against transmission lines and power plants, resulting in blackouts. Furthermore, other issues are related to the lack of maintenance and obsolescence of most outdated stations and transmission lines that have exceeded their service life. To mitigate these issues, there was a tendency by the government to build and operate most of the new power plants with natural gas fuel and therefore move away from burning oil. However, due to political instability in recent years, the construction of a new gas-fired generating power plant called Marib II, with a capacity of 400 MW has been delayed.

Table 3:1 Existing electrical power plants

The station	Location (City)	Service Year	Nominal Capacity	Actual Capacity	Fuel type
Marib	Marib	10	400 MW	340-380 MW	Gas
Al-Hiswah 1	Aden	34	125 MW	75 MW	Mazut
Al-Hiswah 2	Aden	21	60 MW	60 MW	Mazut
Mokha	Taiz	34	160 MW	120-140 MW	Mazut
Ras-katheeb	Hodeidah	38	150 MW	100-120 MW	Mazut
Haziaz 1	Sana'a	16	30 MW	20-25 MW	Diesel
Haziaz 2	Sana'a	15	70 MW	65-70 MW	Mazut
Haziaz 3	Sana'a	12	30 MW	20-25 MW	Diesel
Dhahban 1	Sana'a	39	21 MW	10 MW	Diesel
Dhahban 2	Sana'a	19	30 MW	15-20 MW	Diesel
Sana'a 1	Sana'a	47	5 MW	5 MW	Diesel
Sana'a 2	Sana'a	15	10 MW	10 MW	Diesel
Al-Mansora 1	Aden	37	64 MW	45 MW	Diesel
Al-Mansora 2	Aden	13	70 MW	70 MW	Diesel
Khor Maksar	Aden	16	18 MW	18 MW	Diesel
Osaifirah	Taiz	16	10 MW	10 MW	Diesel
Al-Hali 1	Hodiedah	39	5 MW	5 MW	Diesel
Al-Hali 2	Hodiedah	16	10 MW	10 MW	Diesel
Ja'ar 1	Abyan	38	2 MW	2 MW	Diesel
Ja'ar 2	Abyan	13	4 MW	4 MW	Diesel

Unfortunately, there are no renewable energy technologies implemented in Yemen except for a number of modest projects (PV systems) in different regions that produce a total of just 1.5 megawatt(Al-Shetwi et al. 2021; Environment Protection Authority 2010). In fact, the Yemeni government has planned to establish some renewable energy plants, such as wind and solar energy. In addition, several studies have been carried out, but the establishment of these projects has been suspended due to lack of funding, and the low and inadequate institutional setup promotes green energy and mitigation policies. In this chapter, the TNA team will use the MCA process to select the four most appropriate technologies that achieve the objectives of this report in terms of their ability to mitigate GHG emissions, their applicability in the country, sustainability, cost-effectiveness, and social and economic benefits.

3.2 Potential of Renewable Energy in Yemen29

Yemen is gifted with abundant renewable energy sources, with the majority of these sources untapped despite the great potential of these clean sources. The theoretical and technical prospects for renewable energy potential in Yemen are shown in Table 3.2 (Al-Shetwi et al. 2021; AL-wesabi et al. 2022; Saleh Qasem 2018).

- **Solar Energy**

Yemen is rich in solar energy, as its location in the solar belt between the tropic of cancer and equator. It is endowed with high solar radiation ranging in average from (5.21-7.23) kWh/m2 a day and an annual average daily sunshine ranging from 7.3 to 9.1 hours per day.

- **Geothermal Energy**

Yemen is located close to three of the world's most active tectonic boundaries (Red Sea, Gulf of Aden, and East African Rift). In a triple junction, these three tectonic plates meet and create a significant geothermal gradient, producing geothermal energy of approximately 28.5 Giga Watt (GW). In addition, Yemen has several areas marked by volcanic character and also more than seven areas with natural hot water springs.

- **Landfill Gas**

There are about 36 landfills spread throughout the country. None of them has been utilized, so far, to produce energy.

- **Wind Energy**

Yemen has a long coastal strip of over than 2500 km long and an average width of 45 km along the Red Sea, and the Arabian Sea. These coastal areas have an annual wind speed average of more than 8 m/s. There is a good potential for making wind farms on the coastal strip as well as on the offshore areas, in addition to the vast deserts and mountain ranges.

- **Biogas**

Sewage tanks, waste water treatment plants and sewage channels are available in most of the cities. In addition, industrial, institutional and commercial waste and Livestock waste are also available.

- **Hydropower**

There are many islands in the Red Sea belonging to Yemen, in addition to the Bab al-Mandab Strait, where these advantages can be exploited to establish hydropower stations.

- **Tidal Energy**

Tidal energy is the energy produced by rising seas during the rise and fall of the tides. Yemen has a long coastal strip of over than 2500 km along the Red Sea, and the Arabian Sea.

Table 3:2 Potentials of renewable energy resources in Yemen

Resource	Theoretical Potential (MW)	Technical Potential	
		Gross	Practicable
Wind	308,722	123,429	34,286
Geothermal	304,000	29,000	2,900
Solar Electric	2,446,000	1,426,000	18,600
Biomass-landfills	10	8	6
Hydropower- Major Wadies	12 – 31	11 – 30	-
Solar thermal-Solar Water Heater	3,014	278	278

3.3 Decision Context

Yemen is completely dependent on fossil fuels for its electrical energy production. The Energy sector is the main contributor to GHG emissions in Yemen. It is the largest consumer of petroleum fossil fuels. The cost of fossil fuels and the increasing effects of GHG emissions necessitate a diversified energy and transition to alternative sources of energy. In this regard, the ministry of electricity and energy had planned to implement a number of projects, such as a wind farm of 60 MW and a solar energy power plant of 10 MW[8]. Such a plan will gradually reduce the dependence on fossil fuels to meet the country's energy demands. The aim of this analysis is to select technologies that will help to reduce GHG emissions and to provide energy to meet some of the country's requirements using efficient options and clean and renewable resources. In this report, a long list of technology options with their fact sheets, as well as selection criteria will be identified by the stakeholders. Next, a short list of three to four technologies will be selected based on the multi-criteria analysis approach (MCA).

3.4 An overview of Existing Mitigation Technology Options in the Energy Sector

Some plans were proposed in INDC, NCs, and Renewable energy policies but these policies due to the economic and political situation in the last 8 years, were not reflected to projects. However, there is one gas power plant with a capacity of 350 MW. In the field of renewable energy, the government of Yemen has implemented a number of small projects (PV solar systems) as listed in Table 3.3, in addition to some small (rooftop) systems, whether personal or for schools.

Table 3:3 Governmental solar PV projects (Sadek Al-Nabhani 2016; United Nations Development Programme (UNDP) 2021)

Name of project	Project area	Capacity	Hours.	Year
Osaifrah Alsufla	Sana'a	135 kW	120	2014
Alnashmah	Dhamar	100 kW	70	2014
Alglahib	Sana'a	100 kW	100	2014
WadiJamilah	Dhamar	95 kW	65	2014
Almuhajab II	Sana'a	60 kW	35	2014
Zaheq	Socotra	120 kW	92	2013
Shizan	Socotra	100 kW	74	2013
Haif	Socotra	90 kW	40	2013
Aftlamh	Socotra	80 kW	26	2013
Deshal	Socotra	80 kW	24	2013
Almuhajab I	Sana'a	100 kW	90	2012
Magzar	Marib	100 kW	73	2012
Ara'af	Lahj	120 kW	100	2011
HesnBalid	Abyan	50-100 kW	40	2010
Qawa	Aden	100-200 kW	75	2009

[8]Projects of the Ministry of Electricity and Energy in Yemen

3.5 Mitigation Technology Options for Energy sector and their Main Benefits

GHG emissions of the energy sector can be mitigated if proper technology options are selected. Twelve technologies were assessed in terms of their potential and feasibility of GHG reduction potential. Table 3.4 presents the pre-selected technologies to be analyzed using MCA.

Table 3:4 Pre-selected technologies

#	Technology	Features
1	Combined heat and power gas turbines	- Gas turbines are a mature technology. - They have lower GHG emissions compared to diesel and mazut. - Natural gas is available in Yemen.
2	Off-grid and On-grid photovoltaic systems	- It is a renewable energy. - It is a mature technology. - Yemen is rich in solar energy. - It produces no GHGs.
3	Wind turbines	- It is a renewable energy. - It produces zero GHGs. - There is a good potential for making wind farms in Yemen.
4	Landfill gas	- It is a renewable energy. - Reduces the environmental impact of the landfills. - Considerable amount of methane is utilized instead of polluting the atmosphere.
5	Hydropower	- It is a renewable energy. - It does not contribute to GHG emission. - The Location of the country encourages the application of this technology.
6	Solar water heating	- It is a mature and renewable energy. - Yemen is rich in solar energy. - It has no GHG emissions.
7	Tidal energy	- It is a renewable energy. - It produces no GHG emissions - Yemen is qualified for such a technology.
8	Geothermal power plants	- It is a mature and renewable energy. - They produce no GHGs - Yemen is qualified for such a technology.
9	Hydrogen turbine	- It is one of the best clean renewable energy generation. - It does not produce GHG emissions if hydrogen is produced by renewable energy.
10	Combined cycle power plants	- It is a mature technology. - It produces less GHG emissions as compared with diesel and mazut.. - Natural gas is available in Yemen.
11	Biogas plants	- It is a mature and renewable energy.

		- Produces organic fertilizer as a by-product
12	LED Lighting	- It is a mature technology. - High energy saving potential. - High lifetime. - Low environmental concerns. - It produces no GHGs if it is powered by renewable source. - It reduces GHG emission when powered by fossil fuel

Information on these technologies was organized and tabulated in twelve technology factsheets, which have been finalized based on the mitigation consultant's experience. These factsheets contained information on the technology characteristics, potential of resources, potential of applications, cost, maturity, economic benefits and social benefits (Annex 2).

3.6 Criteria and Process of Technology Prioritization for Energy Sector

The assessment of various technologies for the energy sector is based on their contribution to sustainable development by minimizing GHG emissions from the sector, maximizing development in environmental, social, and economic aspects. In order to determine the criteria and most important technologies within this context, an expert consultation workshop was organized as mentioned above. Experts from all relevant energy stakeholders attended to contribute in opinion, information provision, and experience required to achieving the tasks. Prioritization of technologies was performed using the Multi-Criteria Analysis (MCA) approach .

This was preceded by the identification and analysis of technologies based on the project consultant experience, country reports, country policies and strategies, literature review, field experience and results of the expert workshop meeting held solely for this task.

Table 3.5 shows criteria and weight used to prioritize technologies. Final weights were allocated based on discussions and consultations with stakeholders after extensive discussion of initially proposed criteria and weights by the consultants. Stakeholders were free to discuss each of the criteria and their weights carefully and modify them as appropriate.

Table 3:5 Criteria and weight used to prioritize technologies

#	Criteria			Weight %
1	Cost	Capital Cost Operation Cost Maintenance Cost	90 – 100% very low 75-90 % Low 50-75% Medium 30 – 50% High 0-30 Very High	22
2	Mitigation of GHGs	Reduction of greenhouse gases emission, mainly CO_2 and methane and will not release more emissions to the environment	100 % No emission 75-90% High reduction 50 -75% Medium reduction 25-50% Low reduction 0-25% Very low reduction	25
3	Environmental Impact	No waste, pollution or any other environmental impact	95-100% No impact 85 - 95%Very limited impact 70-85% limited impact 50-70% Medium impact 30-50% High impact 0-30 Very high impact	4
4	Sustainability	Continuity of the energy source, ensuring the availability of spare parts, possibility of maintenance and ability to withstand under all circumstances	90 – 100 % Very High 75 – 90 % High 50 – 75% Medium 30 – 50 % low 0-30% Very low	21
5	Economic Benefits	It saves expenditure of fuel, provides financial return to the country and contributes to economic growth.	85 – 100 % Very High 70 – 85 % High 50 – 100% Medium 30 – 50 % low 0-30% Very low	5
6	Social Benefits	Creating new job opportunities & Community contribution Gender equity	85 – 100 % Very High 70 – 85 % High 50 – 70% Medium 30 – 50 % low 0-30% Very low	5
7	Country readiness and preparedness	National Circumstances Topography Availability of information and data Availability of national experts	90 – 100 % Very High 75 – 90 % High 50 – 75% Medium 30 – 50 % low 0-30% Very low	18

3.7 Results of Technology Prioritization for the Energy Sector

Scoring was determined for each technology by stakeholders, facilitated by the energy consultant and national coordinator, and depicted in an Excel based worksheet designed using the Multi Criteria Analysis (MCA). The MCA was applied to score and rank the technologies. Table 3.6 shows scores of the technologies that were used in the prioritization exercise and the results of evaluation, while Table 3.7 shows final technologies prioritization scores and ranking.

[redacted]

Table 3:6 scores of selected criteria to technologies

#	Technology	Cost		Mitigation of GHG		Environmental Impact		Sustainability		Economic Benefits		Social Benefits		Readiness and preparedness		Total	Ranking
		Scale	Weight	Scale	Weight	Scale	Weight	Scale	Weight	Scale	Weight	Scale	Weight	Scale	Weight		
		100%	22%	100%	25%	100%	4%	100%	21%	100%	5%	100%	5%	100%	18%		
1	Combined heat and power gas turbines	77	17	70	17.50	60	2.40	68	14.28	81	4.05	64	3.200	62	11.16	69.530	10
2	Off-grid and On-grid PV systems	83	18	100	25.00	90	3.60	98	20.58	91	4.55	83	4.150	80	14.4	90.540	2
3	Wind turbines	87	19	100	25.00	85	3.40	98	20.58	90	4.50	72	3.600	71	12.78	89.000	3
4	Landfill gas	73	16	100	25.00	80	3.20	80	16.80	75	3.75	65	3.250	68	12.24	80.300	5
5	Hydropower	64	14	100	25.00	85	3.40	90	18.90	85	4.25	58	2.900	41	7.38	75.910	7
6	Solar water heating	91	20	90	22.50	85	3.40	90	18.90	65	3.25	90	4.500	78	14.04	86.610	4
7	Tidal energy	49	11	100	25.00	80	3.20	90	18.90	78	3.90	63	3.150	40	7.2	72.130	9
8	Geothermal power plants	49	11	75	18.75	70	2.80	80	16.80	77	3.85	50	2.500	43	7.74	63.220	11
9	Hydrogen turbine	68	15	75	18.75	75	3.00	65	13.65	70	3.50	53	2.650	37	6.66	63.170	12
10	Combined cycle power plants	88	19	75	18.75	70	2.80	65	13.65	80	4.00	56	2.800	61	10.98	72.340	8
11	Biogas plants	84	18	85	21.25	80	3.20	80	16.80	80	4.00	70	3.500	62	11.16	78.390	6
12	LED Lighting	90	20	90	22.50	90	3.60	90	18.90	95	4.75	95	4.750	99	17.82	92.120	1

Table 3:7 Results of energy sector technologies prioritization and ranking

#	Technology	Score	Ranking
1	Combined heat and power Gas Turbines	69.530	10
2	Off-grid and On-grid PV systems	90.420	2
3	Wind turbines	89.00	3
4	Landfill gas	77.800	5
5	Hydropower	75.910	7
6	Solar water heating	88.610	4
7	Tidal energy	72.130	9
8	Geothermal power plants	63.220	11
9	Hydrogen turbine	63.170	12
10	Combined cycle power plants	72.340	8
11	Biogas plants	78.390	6
12	LED Lighting	91.400	1

Table 3:8 The selected technologies for the energy sector

Rank	Technology	Score
1	LED Lighting	92.120
2	Off-grid and On-grid PV systems	90.420
3	Wind turbines	89.00
4	Solar water heating	88.610

As seen in tables 3.7 and 3.8, the top four ranked technologies are LED lighting, Off-grid, and On-grid PV systems, Wind Turbines, and Solar Water Heating. All four technologies represent the country's needs in the energy sector. LED lighting and Solar Water heating are considered energy-efficiency technologies. These two options can efficiently mitigate GHG emissions by reducing the consumption of fossil fuels used to generate power plants. As mentioned above, Yemen is potential for renewable energy resources, especially solar and wind. Therefore, it is reasonable to have the Off-grid and On-grid PV systems and Wind turbines within the most prioritized three options, as these technologies are future promising and can effectively contribute to providing an alternative sustainable solution to the problem of electrical power shortage in Yemen and as well as reduce the GHG emissions in the future.

Transport Sector

Chapter 4: Technology Prioritization for Transport Sector

4.1 An overview of the Existing Technologies of the Transport Sector and GHG emissions

Transport alongside energy is the major sector contributing to GHG emissions due to the high fuel consumption. The transport sector is also the second largest sector that consumes fossil fuel to meet the energy demand through the combustion process. The transport sector includes two main categories, namely, the Passenger Category and the Freight Category.

Road transportation involves Cars and Buses. More than 90% of passengers' transportation is road transportation. However, passenger transportation is classified into two types:

1) Private, which involves the use of private cars,
2) Public, which involves the use of Taxis, Buses and Airplanes.

Freight transportation is classified into four types:

3) Small Lorries (Vans, Pick Ups, etc.)
4) Large Lorries
5) Sea Freight Ships
6) Others

The number and type of vehicles used for Road Transportation for the Base Year 2010 are detailed in Table (4.1). Private Cars take the largest share of the total with 46.83% and Buses with the lowest share of 4.35%. However, Passenger Road Transportation accounts for 65.31% of the number of vehicles, while Road Freight Transportation accounts for the remaining 34.69% (Sufian Towfick and Asaad Abdulraqib 2015).

Table 4:1 Number and Vehicle Type used for Road Transportation for Both Passenger and Freight for the Base Year 2010

Vehicle type	Total Number of Vehicles for the Base Year 2010
Private cars	408,643
Small Lorries	160,455
Large Lorries	142,316
Taxies	123,330
Busses	37,958
Total	872,702

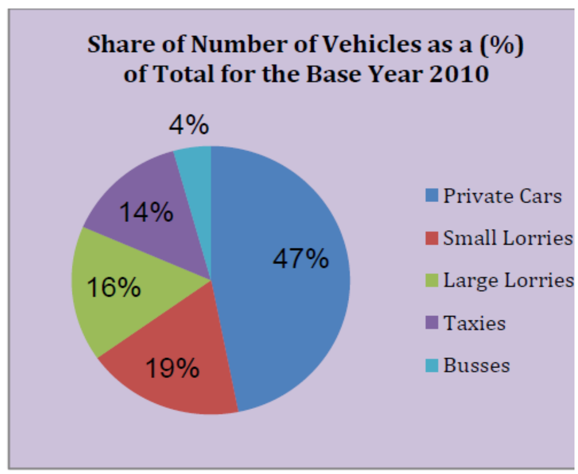

Figure 4:1 Share of Number of Vehicles as a (%) of Total for the Base Year 2010

The energy consumption by the Transport Sector as a whole, including Road, Air, and Sea Freight Passenger and Freight Transportation for the Base Year 2010, is illustrated in Table (4.2). Although different types of fuels are used by the different types of vehicles, energy consumed by all vehicles is calculated here in millions of GJ. The largest amount of energy is consumed by the small Lorries of 63.3443 million GJ (34.86% of the total energy consumption), followed by large Lorries with 55.7613 million GJ (29.8% of the total energy consumption). Airplanes and Sea Freight Ships consume the lowest energy of 5.0899 million GJ and 1.0713 million GJ, respectively (with shares of 2.72% and 0.57% of the total energy consumption, respectively). Furthermore, in the last five years, air traffic in the last seven years was affected in Yemen due to the armed conflict. Therefore, they will not be considered in the prioritization process. The total energy consumed for the Base Year 2010 reaches a little over 187 million GJ (Towfick Sufian 2010).

Table 4:2 Energy Consumed by Passenger and Freight Transportation for the Base Year 2010

Transportation Type	Transport Via	Type of Fuel Used	Energy Consumed (Millions GJ)	Share of Energy Consumption As (%) of Total
Small Lorries	Road	Benzene[9]	63.3443	33.86
Large Lorries	Road	Diesel	55.7613	29.80
Private Cars	Road	Benzene	26.5503	14.19
Buses	Road	Diesel	18.7516	10.02
Taxies	Road	Benzene	15.7943	8.44
Airplanes	Air	Jet Fuel	5.0899	2.72
Sea Freight Ships	Sea	Matzoth	1.0713	0.57
Others	Road	Diesel	0.7387	0.40
Total			187.1017	100.00

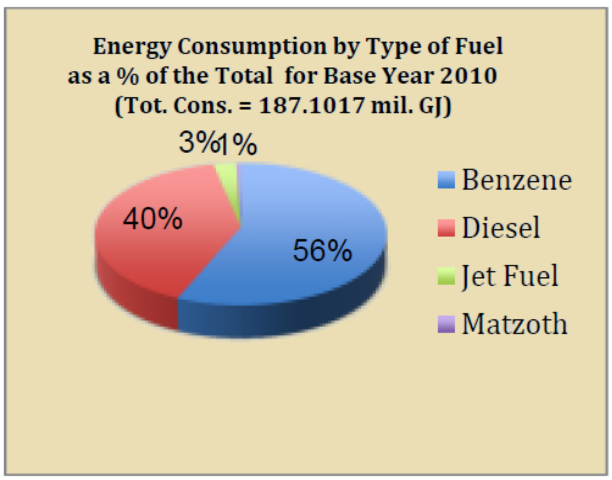

Figure 4.1:2 Energy Consumption by Type of Fuel

In terms of the type of fuel energy consumption, Figure (4.2) illustrates the combined fuel share consumption by type of fuel used in the Transport Sector. Here Benzene takes the largest share of 56% of the total consumption, followed by Diesel with 40%. Matzoth and Jet Fuel contribute a very small share with about 3% and 1% respectively. Accordingly, the overall consumption of the fossil fuel for the base year 2010 led to a GHG emission estimated to be 7,181 Gg CO_2-equiv, (See table 4.3).

Table 4:3 GHG emissions from energy use by transport sector, 2010 (Gg)

GHGs Source	CO_2-**equivlent**	CO_2	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
Transport	7,181	7,134	1.34	0.06	63	501	94	501

[9] Benzene is also known as gasoline (US) or petrol (UK).

4.2 Mitigation Measures for GHG Emissions

In the TNC and INDC, several mitigation measures were proposed and assessed to achieve a long term GHG emission reduction. The proposed measures were identified based on a group of criteria, which are consistent with existing sustainable development objectives, implementation feasibility, and large emission reductions under Yemeni conditions. The identified measures focus on improving the fuel economy of all vehicle classes. It involves the development and implementation of an annual vehicle maintenance, inspection and tuning programme. Such a programme was assumed to become effective for all vehicle classes in 2018 and is projected to increase average fuel economy by 33%, 35%, and 38% for cars, heavy-duty trucks, and motorbikes/buses, respectively, by 2040 relative to the baseline. However, the national circumstances of the country in the last eight years have hindered the government from achieving this target.

The final results of the TNC assessment showed that these GHG mitigation measures will lead to substantial reductions in GHG emissions by 2040, as shown in Figure 4.2. Overall, GHG emissions decline from 48 million tons of CO_2-equivalent in 2040 in the Baseline scenario to 36 million tonnes in the Mitigation scenario. Where the Transport sector constitutes almost 94% of the total, with cumulative savings of 133 million tonnes CO_2-equivalent (Alhakimi et al. 2013; Environment Protection Authority 2017a, 2018; Sufian Towfick and Asaad Abdulraqib 2015; Towfick Sufian 2010).

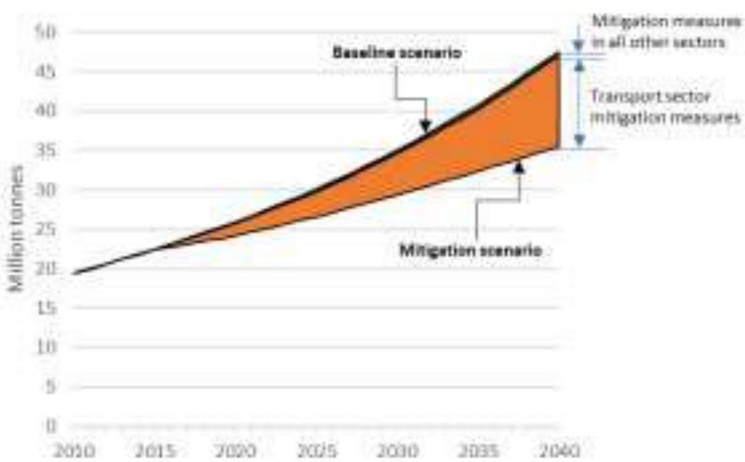

Figure 4.2 :3 GHG emission trajectories, with and without GHG mitigation

In order to achieve the above reductions in the GHG emission, a number of important recommendations were proposed to be considered as follows:

1. Improve Vehicles' efficiencies

To improve vehicle fuel combustion efficiency, a regular maintenance, inspection and tuning are required to be applied yearly. This option was expected to be effective from the year 2018.

2. Fuel Switching Technology
    i. Diesel Buses switching to Compressed Nature Gas (CNG) Buses
    ii. Gasoline Motorcycles switching to fully Electric Motor Cycles (Battery – Powered Motorcycles)

3. Hybrid – Electric Vehicle Scenario

This type of vehicle combines a small internal combustion engine with an electric motor and battery to reduce fuel consumption and produce less pollution than the internal combustion engine. This option is suitable for private cars, government cars, custom cars, diplomatic cars, and Taxis.
Other recommendations were suggested to achieve the above reduction in GHG emissions and to keep them down to a reasonable level for the Republic of Yemen. Organizations or Private Companies. These recommendations can be summarized as follows:

i. Reduce taxation on new Gasoline Vehicles which have emission-reduction equipment fitted into them. The reduction should also apply to any vehicles imported which run on new and renewable technologies,
ii. Introduce a yearly vehicle test that includes emission levels so that inefficient old cars, buses and lorries can gradually be phased out,
iii. Raise taxations on newly imported diesel vehicles to minimize their presence on the road and hence reduce the emissions,
iv. Continue the existing ban on importing vehicles of five years old and above,
v. Introduce Standards and Norms for all imported used vehicles,
vi. Make use of the media and launch awareness programmes to educate vehicle users on the importance of keeping a pollutant-efficient vehicle to our environment.

However, the old proposed measures and recommendations need to be refined and updated to be aligned with the current circumstances of the country. In the last five years, the transportation infrastructure was highly impacted by the war, as well as the policies of importing transportation facilities. Based on experts, thousands of old vehicles were imported to Yemen and utilized by in the country. Therefore, the enhancement of the transport infrastructure and updating the policies must be a priority for the government to achieve the GHG emission reduction goals. Accordingly, the TNA project will support the government to identify the option needed to reduce the dependency on fossil fuels and GHG emission reduction. Moreover, TNA will help the country to mainstream these options into sectoral policies.

4.3 Decision Context

The transport consultants have gathered all the information and data from previous reports on Yemen, such as the National Communications reports on Climate Change. The consultant carried out discussions and consultations with the TNA team in Yemen at the Environment Protection Authority. The purpose is to establish the decision context to prepare the technology options prioritization for the transport sector in Yemen through several objectives.
The first is to identify the technology options that can accommodate with status in Yemen, bearing in mind the country’s susceptibility to accept these technology options. Also, the technology options must contribute to the reduction of GHG emissions and less fossil fuel consumption as well. The second is to identify the criteria for the technology options that can optimize the appropriate technology options needed and can easily be applied in Yemen. The criteria must include reduction of GHG emissions and social, economic, and environmental benefits. The third is to assign weights to the selected criteria; this was done in the workshop meeting together with stakeholders of the Transport sector. Fourth is to optimize the technology options. This was done during the workshop meeting.
The transport experts prepared fact sheets on the selected technology options prior to the workshop, which were shared with stakeholders. Then on the final day of the workshop, an MCA analysis was carried out for the prioritization of technology options for the transport sector.

4.4 An Overview of Possible Mitigation Technology Options in the Transportation Sector and Their Mitigation Potential and their Co-Benefits

Yemen has to consider new technologies for the transport sector and other sectors as well that have less or no emissions of GHGs. Hence, a list of suggested technologies in the transport sector is considered, which would have a major contribution to reducing GHG emissions as a result of fossil fuels consumption in various transport systems in the country. The suggested technologies can be as follows:

1) Bus Rapid Transport
2) Fuel Switching to Gas Fuel
3) Cycling
4) By-Roads Improvements
5) Hybrid Vehicles
6) Electric vehicles
7) Traffic Signal Synchronization
8) Sea Ferries
9) Short Bridges at Cross-Roads
10) Gas Fuel for Fishing Boats
11) Hybrid Electrical Motorbikes
12) Walkable City-Centres
13) Gas Fuel for Commercial Ships

The technology options can be divided into two categories. One for the infrastructure options – such as the construction of roads or building bridges. The second can be for the means of transport and fuel used options, such as by small vehicle (cars, Taxis), buses, sea ferries, boats, etc.

Table 4.4: Technology options for the Transport sector

Infrastructural Options	Transport Means/Fuel Used Options
1. By-Roads Improvements	2. Bus Rapid Transport (BRT)
3. Traffic Signal Synchronization	4. Fuel Switching to Gas Fuel
5. Short Bridges at Cross-Roads	6. Cycling
7. Walkable City-Centres	8. Promoting hybrid Vehicles
	9. Electric vehicles
	10. Sea Ferries
	11. Gas Fuel for Fishing Boats
	12. Hybrid Electrical Motorbikes
	13. Gas Fuel for Commercial Ships

4.5 A brief description of the suggested technologies

1. Bus Rapid Transit (within cities and between cities)

Currently, there are private companies that operate buses between the centers of the governorates and to some destinations abroad, mainly Saudi Arabia, UAE, and Oman. Previously, there was public transport bus run by the Transport Cooperation owned by the government. These buses operated within the city of Aden and between the centers of the various governorates. However, this transport system was abolished in the 1990s.
The introduction of the rapid bus transit system RBT, within cities and between cities, is a method of limiting the use of individual private vehicles by individual people. The use of small private vehicles can lead to heavy traffic and congestion, and the consequent delays on roads. This will lead to large GHG emissions from vehicles during travel. Introducing large buses that can take up to 50 passengers is a method of transporting large numbers of people by one transport system instead of 50 vehicles on the road. Using small private vehicles individually will result in traffic jams and delays, where there will definitely be much larger amounts of GHG emissions compared to a single rapid bus.
There should be an infrastructure for this technology option. Besides the buses, the building of bus stations at or close to the center of cities, bus stops garages for maintenance, establishing routes with timetables of arrivals and departures. The fuel for these buses could be fossil fuel to start with; once the system is functioning, thereafter, a modification of the fuel can be looked at. For instance, using gas fuel which has low GHG emissions, or in the future electrical energy, which has no GHG emissions at all. Another social benefit that will come from this kind of transport, is the cheap fares; as people can travel cheaper, more efficiently, and faster.

2. Fuel Switching to Gas Fuel

By switching the fuel used by various vehicles from petrol/diesel fuel to gas fuel, is definitely a process where the GHG emissions will be reduced significantly. What is required is the technique or method to do this process, it may include changing certain parts in the vehicle engine, so it can operate on gas fuel. In Egypt, this method is used widely for passenger vehicles, particularly on long-distance buses and small inner-city buses.
The method of fuel-switching for vehicles from petrol/diesel fuel to gas fuel has been carried out in Sana'a in the last twenty years. However, the efficiency of the method is not adequate, and new techniques of this method similar to that of Egypt should be considered.
Yemen is one of the lowest income per capita in the world; people can't afford to buy new low-fuel vehicles such as hybrid or electric vehicles. Most vehicle owners keep their cars for more than 25 – 30 years without buying new ones because simply these new technology options are beyond their reach. Introducing the fuel-switching technology to gas fuel for the various transport systems in Yemen could be one of the important steps in reducing GHG emissions. Mechanics need to be trained on this technology, hence, creating jobs as the same time, reducing GHG emissions.

3. Bicycle (Cycling)

Cycling can be considered a method of transport within cities for individual persons who can travel to places such as their jobs, schools, factories, services, etc. Since there aren't any GHG emissions, which definitely will have a huge impact on reducing air pollution. Furthermore, cycling is considered a healthy way of travel, hence, improving the health of society. But there are certain cultural and environmental barriers to such technology. One is the high temperatures and humidity in coastal cities; many people will not consider it as a choice. To make such technology options popular, it has to start with the sports curriculum at schools, universities, and recreation centers. Eventually, the idea will gather up to involve a large number of the society.

However, this technology option has a cultural mishap because gender will hesitate to use such transport in a country still looking at gender with different attitudes and restrictions.

4. By-Roads Improvements

A by-road can be defined as a paved-road smaller than highways (freeways, motorways, expressways), one of such by-roads is the carriageway. The carriageway can have a single carriageway with 2-lanes, 3-lanes, and 4-lanes, or a dual carriageway with two lanes in each direction, as described in the above figure (9). Currently, there are no highways or motorways in Yemen; most of the roads in the country are single and dual carriageways.

The repair and improvements of existing by-roads or carriageways can be considered as a method of reducing GHG emissions. Damaged and old roads are the reasons for the increase in the consumption of fuel due to the delays that occur during travel over these roads. As a result, it will take a longer time to reach destiny when traveling over damaged roads, and consequently, more GHG emissions.

Hence, this technology option (infrastructure option) is considered important for GHG mitigation measures, which must be applied in Yemen. Since most of the roads are old, damaged, and lack the constantly required maintenance. This will definitely have an impact on reducing GHG emissions quite considerably. It is estimated that the cost of constructing a 1 km of road will be around 160,000 $ US Dollars in developing countries, roughly about 160 million Yemeni Riyals.

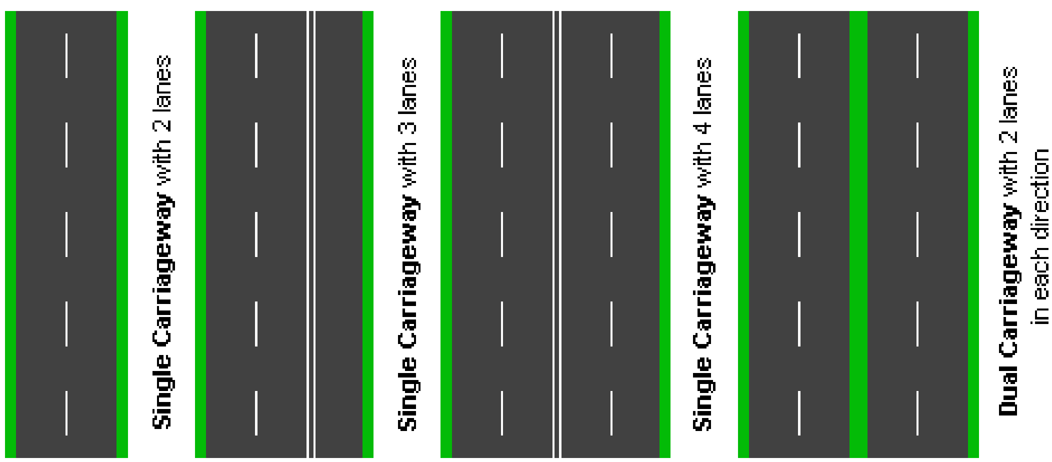

Figure 4.5:4 By roads example

5. Hybrid Vehicles

Hybrid vehicles are new to Yemen, a very few people, particularly in Sana'a city, have acquired these vehicles. This new technology can be considered a good choice because hybrid vehicles consume much less fuel than other existing vehicles. Hybrid vehicles can run on both petrol (fossil energy) fuel and electric energy since it they charge the vehicle battery when the car is run by petrol at higher speeds outside the city. Hybrid cars can run using the stored electrical energy in the battery within cities at lower speeds. One of the benefits of Hybrid vehicles in Yemen is that due to the high prices of petrol/diesel, owners will save money using Hybrid vehicles since they consume little amounts of fuel.

This dual consumption of energy is one of the advantages which suits the car owner and the transport system in general in Yemen. Because there are no electrical charging stations, the electrical power in the country can't meet and satisfy the demand required by various sectors in Yemen. Charging of the battery during the travel by petrol, and using the battery-stored energy in suburbs, can be applied widely in Yemen, in the near future. One disadvantage of this technology option is its high price, which will make people reluctance to buy it.

6. Electric Vehicles

Electric vehicles are one of the alternatives for the reduction of GHG emissions in developed countries. Since there aren't any GHG emissions at all from these vehicles, only electrical energy is needed to run an electric vehicle, particularly if the electricity is generated using renewable energies such as solar energy or wind energy. Another source of energy to generate electricity is nuclear energy; in all three cases, there will be zero GHG emissions.

Moreover, the infrastructure needed for this technology is available in the developed world, such as sufficient electrical power and charging stations, whether at work or home, or along the roads. These conditions don't exist in Yemen and the developing countries because Yemen does not have sufficient electricity to meet the demand needed by the people for everyday life. Hence, for the time being, this technology, "electric vehicles," would face difficulty in being suitable. In addition to the lack of electrical power, the high cost of electric vehicles is another obstacle; most people can't afford them because of the low income of normal people. This technology can be applied once the infrastructures needed have been established. Besides, the income of individual persons increases to a point where they can afford to buy an electric vehicle. One of the benefits of electric vehicles in Yemen is that due to the high prices of petrol/diesel, owners will save money using electric vehicles since they run on electrical energy without using any fossil fuel. Furthermore, the mitigation of GHG emissions will be limited because fossil fuels are only used to generate electricity, not for powering vehicles. In the future, since Yemen is considered to be rich in solar energy and wind energy, solar-powered charging stations can be introduced. This will have a huge impact on both the environment and GHG emissions.

7. Traffic Signal Synchronization

In traffic signal synchronization, a series of traffic lights along the road turns green, allowing a smooth flow of vehicles, reducing the congestion and need to stop in the middle of traffic. In this way, the drivers can avoid travel delays, especially in heavy traffic, and causes lower emissions and air pollution. The synchronization system is usually activated during morning and evening peak hours, and the signals are coordinated based on the congestion level. The existing traffic signals in these areas can be updated for better synchronization. Updated traffic signal control equipment, along with signal timing optimization, can reduce congestion. In Texas, USA, synchronization of traffic signals reduced traffic delays by 23 percent (US Department of Transportation, 2011), while on average, it can reduce travel time by up to 15 percent[10].

8. Sea Ferries

Yemen has about 2,200 km of coastline along the Gulf of Aden, the Arabian Sea, and the Red Sea. Also, Yemen has many islands over 200 islands, Socotra Islands in the Arabian Sea, Kamaran and Hanish Islands, located in the Red Sea, as well as Perim Island in the Bab el-Mandeb Straight. Sea transport is still backward and hasn't developed in the last decades. However, there is a small sea transportation between the mainland and Socotra Islands, particularly from Hadramout and Al-Mahra governorates to Socotra islands.

The idea of establishment of a Sea Ferry transport system within Aden city and along the coastal cities, has been discussed. However, there are other considerations which may arise, one of them is the safety of passengers. Also, the security issue constitutes a major threat in a country which faces many challenges at present and in the foreseeable future. This technology option can be thought of in the future, when an adequate infrastructure for sea transportation is developed. Moreover, this sector needs regulations and capacity building for an efficient operation, in order to reduce the challenges mentioned above.

9. Short Bridges at Cross-Roads

[10] US Department of Energy, 2011

Many of the traffic jams and congestion are due to the lack of good roads, regular maintenance, and inefficient planning. In Sana'a city, many bridges have been built at important cross-roads. These steps have contributed very much in limiting the congestion in the city, which eventually led to less GHG emissions from various types of vehicles in the city.

The traffic jams in Aden can be reduced greatly if short bridges are constructed at roundabouts. At those roundabouts, vehicles would wait up to an hour to pass, because of the huge congestion. The congestion will consequently result in a large amount of GHG emissions from the vehicles stacked at these points.

Building short bridges at cross-roads in major cities will solve the problem of congestion. Hence, will greatly reduce the emissions of GHGs from the vehicles stacked at these cross-roads. There is a debate on the costs of such bridges, but by consultations with the companies that built the bridges in Sana'a city. Perhaps a reasonable cost can be reached for constructing those short bridges much needed in Aden.

10. Gas Fuel for Fishing Boats

Fishing is considered as one of the income of the major income for people residing along the coasts of Yemen, their main transport for fishing in the sea are boats which run by petrol/diesel fuel. In 2012, it was estimated that there were 129 fishing societies, 83,157 fishermen, and 23,582 fishing boats [(10)]. The introduction of boat-engine which run on gas fuel, will be one of the steps of reducing both fuel consumption and reducing GHG emissions.

There are steps that need to be taken; one is to convince the fishermen that substitute their existing engines with the gas-engines. The fishermen will save money using gas-fuel, and that the marine environment will be less polluted using gas fuel, hence, achieving the sustainability of their source of income.

Any future assistance to the fishing communities by the government or UN programmes has to take these steps into account. The boat's engines should run by gas fuel when distributing fishing boats to the fishermen.

11. Hybrid Electrical Motorbikes

Motorbikes are probably the second largest transport means after passenger vehicles. Most of the motorbikes in Yemen are run by diesel/petrol fuel, and some on gas fuel; there are a few electrical motorbikes, but they are not common yet. If hybrid electrical motorbikes are introduced into the transport sector in Yemen, it will have a huge impact on the environment and users as well. This technology option will contribute greatly to the reduction of GHG emissions, particularly when the hybrid motorbike is combined with gas fuel.

The new technology option will have an acceptance among the users since it can run on gas, and charge the battery, and then switch to electric energy when the battery is fully charged. Also, this kind of technology is affordable; people can buy them., particularly in the countryside where motorbikes are used frequently.

12. Walkable City-Centres

Certain places in Yemeni cities can be assigned for pedestrians only, where no vehicles are allowed, and people who want to reach their destination have to walk or cycle. In Sana'a, this option can be applied to the Old City of Sana'a, where people can't use any vehicles that run on fossil fuel in the Old City. Another city that can apply this option is Aden, where people can be prevented from using any vehicles in Crater City. These measures will cut the GHG emissions resulting from vehicles entering a very confined space and stack in the jams that result because of the limited small roads and small spaces. These kinds of options are implemented in some cities in Europe, creating environmentally friendly habitat.

13. Gas-Fuel for Commercial Ships

Commercial ships are mostly run by heavy petroleum products, which can result in large GHG emissions. The Navigation Authority can issue new regulations for commercial ships, forcing them to use gas fuel for their engines, leading to less GHG emissions. But this technology option might cost the owners since they need to change the existing ship's engines to gas-fuel engines. These kinds of step might take some time, since there are other priorities for the Ministry of Transport in Yemen.

4.6 Selection of Mitigation Technology Options and their Mitigation Benefits

The transport mitigation consultant reviewed the technology options list, and after various discussions with the TNA coordinator, got the consensus of the National TNA Committee. In the consultative workshops, a decision was reached on the technology options which are applicable and can be applied in Yemen. The overall conclusion was that the potential mitigation technologies and most appropriate for the transport sector in Yemen had become eight, and they are as follows:

- Bus Rapid Transport (BRT)
- Hybrid Vehicles
- Promoting Bicycle
- Fuel-Switching to Gas
- Electric Vehicles
- Sea Ferries
- Improving By-Roads
- Traffic Signal Synchronization

Each priority technology option the expert started to collect data for each technology option. Then, fact sheets were prepared that included: a brief technology description, the costs of the technology, the application potential in the country, the mitigation, and other social, economic, and environmental benefits. The fact sheet was shared with the transport sector's stakeholders prior to conducting final prioritization. Thus, the sector prioritization process was carried out by taking into consideration constraints and the national context that is illustrated by several criteria.

4.7 Criteria and Process of Transport Sector Technology Prioritization

At the workshop on TNA Technology Prioritization & Criteria Section held on the 7th, 8th, and 13th of February 2022, the suggested technology options were presented. The fact sheets were distributed to the attending stakeholders so that they could put their remarks and find out the appropriate technology options suited for Yemen. Their remarks take into account the present situation in the country.

During the consultation workshop, the initially proposed weights were further discussed with stakeholders and validated, and the ranking was conducted through an open discussion among the experts. Scores were attributed based on consensus.

The criteria were selected based on two main objectives: 1-minimizing the GHGs and pollutant emissions for the transport sector and 2-maximizing the environmental, social, and economic development benefits.

Accordingly, nine main criteria for technologies selection were identified:

- The Cost
- GHG emissions Reduction
- Environment Impact
- Sustainability
- Social Benefits
- Economic Benefits
- Potential Application

- Country Susceptibility
- Maturity (Efficiency)

4.8 A brief description of each as follows:

1. Cost

First, there is the initial cost of the technology, which could be the purchase cost or the assembly/construction cost. Second, the operation cost – the cost needed for operating the technology option. Third, the cost of maintenance of the technology, as some technology options will need less maintenance than others.

2. GHG emissions Reduction

It is whether the technology option will contribute positively or negatively to the reduction of GHG emissions. It is an important criterion that can define the contribution of each technology option. It could also be the contribution from an infrastructure or a governmental measure – such as legislation and regulations, which will lead to a reduction in GHG emissions.

3. Environmental Impact,

The effects of pollutants emitted by a technology option on the environment can cause air, soil, aquatic, or noise pollution. Some technology options will have no impact on the environment for the short term but may have an impact on the soil later on when it is discarded – such as batteries. The type of fuel – such as fossil fuel can have a significant impact on the environment, whereas Green Hydrogen fuel has zero emissions and almost no impact to the environment.

4. Sustainability,

Sustainability refers to what extent the technology option is sustainable and has the ability to withstand at stable efficiency over time under various circumstances. Technologies that rely on renewable energies are considered sustainable.

5. Social Benefits

The benefits that can be gained from operating the technology option, such as improving the health of the community, creating jobs, reducing congestion and supporting the equity between males and females

6. Economic Benefits

The economic gains that can be achieved using this technology option, such as -fuel-saving, high currency savings, creating new jobs, etc.

7. Potential of Application

The infrastructure already available and in existence in the country, such electrical energy, LPG, Green, paved roads, and human resources.

8. Susceptibility: country readiness and preparedness

Good governance in the country, administrative regulations and by-laws, 3- or 5-year development plans, law enforcement, political stability, the capability of public and private sectors, skilled labor force.

9. Maturity (efficiency)

It refers to what extent the option is efficient and can solve the transport problems without adverse impacts.

Each criterion was assigned a weight based on its significance in meeting the national goals of the attending stakeholders. Briefly, the weights are summarized in table 4.5 as follows:

Table 4:5 Assigning weights for the selected criteria for prioritization of Technology Options

Criterion	Sub-Criteria/Description	Scale %	Weight %
Cost	Capital Cost Operation Cost Maintenance Cost	90 -100% very low 75-90 % Low 50-75% Medium 30 – 50% High 0-30 Very High	20
GHG emission mitigation	Contribution to GHG Emissions Reduction	100 % No emission 75-90% High reduction 50 -75% Medium reduction 25-50% Low reduction 0-25% Very low reduction	25
Environmental benefits	No adverse environmental impacts, such as waste and pollution	95-100% No impact 85 – 95% Very limited impact 70-85% limited impact 50-70% Medium impact 30-50% High impact impact 0-30 Very high impact	5
Economic benefits	Positive Impacts of the technology on the national economy	85 – 100 % Very High 70 – 85 % High 50 – 100% Medium 30 – 50 % low 0-30% Very low	8
Social benefits	Social benefits in terms of society and gender equity	85 – 100 % Very High 70 – 85 % High 50 – 70% Medium 30 – 50 % low 0-30% Very low	10
Sustainability	Ability to withstand various conditions	90 – 100 % Very High 75 – 90 % High 50 – 75% Medium 30 – 50 % low 0-30% Very low	12
Susceptibility	- Potential Application - Country Readiness & Preparedness - Maturity (Efficiency)	90 – 100 % Very High 75 – 90 % High 50 – 75% Medium 30 – 50 % low 0-30% Very low	20
Total			100%

4.9 Results of Technology Prioritization for the Transportation Sector

The workshop on 13th February 2022 carried out a Multi-Criteria Analysis (MCA) decision-making exercise. The transport experts and stakeholders assessed the identified mitigation technologies based on their importance in meeting national mitigation goals. The results of MCA analysis are shown in table (4.6)

Table 4:6 Prioritization results of the technology options using the weighted criteria.

SN	Technology Option	Cost		GHGs Reduction		Environmental benefits		Economic Benefits		Social Benefits		sustainability		susceptibility		Total	Ranking
		Scale	Weight	Scale	Weight	Scale	Weight	Scale	Weight	Scale	Weight	Scale	Weight	Scale	Weight		
		100 %	20%	100%	25%	100%	5%	100%	8%	100 %	10%	100 %	12%	100 %	20%	100%	
1	Bus Rapid Transit (BRT)	79	15.8	75	18.75	70	3.5	95	7.6	85	8.5	85	10.2	83.75	16.75	81.1	1
2	Sea Ferries	68	13.6	75	18.75	75	3.75	80	6.8	72.5	7.25	85	10.2	65	13	73.35	6
3	Electric Vehicles	50	10	100	25	90	4.5	45	5.6	65	6.5	70	8.4	65	13	73	5
4	Fuel-Switching to Gas	80	16	75	18.75	90	4.5	75	4	65	6.5	70	8.4	85	17	75.15	4
5	Hybrid Vehicles	75	15	80	20	90	4.5	50	4	65	6.5	70	8.4	90	18	76.4	3
6	Improving By-Roads	76	15.2	70	17.5	46	2.3	70	5.6	95	9.5	100	12	90	18	80.1	2
7	Promoting Bicycle	88	17.6	100	25	95	4.75	37.5	3	30	3	83.33	10	25	5	68.35	7
8	Traffic Signal Synchronization	61	12.2	52.8	13.2	95	4.75	62.5	5	30	3	50	6	25	5	49.15	8

Table 4:7 Prioritization results.

Technology Option	Total	Ranking
Technology Option	Total Percentage %	Ranking
Bus Rapid Transit (BRT)	**81.1**	**1**
Improving By-Roads	**80.1**	**2**
Hybrid Vehicles	**76.4**	**3**
Fuel-Switching to Gas	**75.15**	**4**
Electric Vehicles	73	5
Sea Ferries	73.35	6
Promoting Bicycle	68.35	7
Traffic Signal Synchronization	49.15	8

The results obtained in table 4.7, for the prioritization of the selected technology options, appear to show that Improving BRT has the highest score followed by By-Roads, and the Hybrid vehicles. It should be noted that Fuel Switching to Gas is also important and has high potentiality in Yemen, because of its availability and the ease of its implementation, as most of the small buses and taxies in Yemen are powered by natural gas, therefore the switching technology is familiar in the country to many people. However, the technology used is very old and causes a lot of problems to the engine hardware. At the end, the prioritization results are satisfactory and meet the objectives, which in general, are desired technology options for implementation in Yemen, especially the first two options. The Bus Rapid Transit (BRT) can make significant contribution in GHG emission mitigation and enhance the transport sector capacity in the country, as the public transport in Yemen is facing a lot of problems due to the lack of facilities and policies that arrange the transport sector in the country. By-road improvement is also among the priorities of transport sector infrastructure in the country and at the same time can contribute to reducing the GHG emissions by minimizing the traffic jam that the large cities are encountering in Yemen.

Water Sector

Chapter 5: Adaptation of Water Technologies

5.1 Synopsis of the Water Sector in Yemen

Yemen is one of the most water-stressed countries, with availability of only about 125 m^3 per person annually. The already critical supply situation has been dramatically aggravated by the armed conflict and its escalation following the interventions of regional actors since 2015. In 2018, an estimated 16 million Yemenis needed humanitarian assistance to establish or maintain access to safe water, basic sanitation and hygiene facilities, out of which 11.6 million are in acute need. Water supply and sanitation services in the major urban centers, including the capital Sana'a, are only to a very limited extent maintained. Part of the infrastructure is destroyed, and the electric power supply is failing to a large extent (Wiebelt et al. 2011a).

The pressure on water resources highlights the hydrological, social, economic, and ecological interdependencies in water systems, rivers, aquifer basins,and inland or coastal water bodies. These interdependencies entail more integrated approaches to developing and managing water and land resources. There is a dynamic relationship between basin stakeholders and central governments, who have to work together to ensure the viability of their decisions in meeting sustainable development rudiments.

Water sector in Yemen in a wide aspect,ct is chronically suffering from number of problems and the impact of climate change is non excluded. Climate change is intensifying the global water cycle and exposing large segments of the population to significant water-related hazards, which are expected to increase in severity over time (Abdullah Noman 2016).

Floods and droughts are becoming more frequent and severe. Rainfall patterns are more unpredictable and sea levels are rising. These changes not only threaten the ecosystem and livelihoods of people – particularly the poorest and most vulnerable – they also pose a major impediment to economic and social development. So, it is important to incorporate water security and climate resilience strategies into country development plans (Wiebelt et al. 2011b).

Water sector in Yemen is a key development, environmental, and climate change issue. With reference to all vulnerability assessments and policy documents, the sector has been identified to be the top sector in terms of vulnerability to climate change. Hence, it requires a vital attention and consideration to explore all appropriate and applicable adaptation measures and technologies that address water problems and contribute to reducing vulnerability and improve adaptive capacities.

Water is a resource that is of direct interest to the society as a whole, as well as to most development-related public institutions at central, state and municipal levels, academia, private sector and non-governmental organizations (NGOs). Such widespread interest in water is not a unique situation, it is equally applicable to other important sectors like food, energy, the environment, health, communication or transportation. In an increasingly interrelated and complex world, many issues are of pervasive interest1 for assuring good quality of life of the people.

The current and the foreseeable trends indicate that water problems have already become increasingly complex, and interlinked with other development sectors such as agriculture, energy, industry, transportation and communication, and with social sectors such as education, the environment, health and rural or regional development (Petersen et al. 2022a, 2022b). Therefore, water policies and major water-related issues should be assessed, analyzed, reviewed and resolved within an overall societal and development context.

The objective of this chapter is to assist technical experts and decision-makers in how to select appropriate adaptation technologies together with selection of criteria for prioritizing and assessing such adaptation technologies in the context of broader economic, environmental and social development objectives. It aims to support work on technology needs assessments using Multi-Criteria Analysis (MCA) for prioritizing technologies but can also be applied in other contexts. The criteria are aimed to cover the aspects deemed necessary for performing a robust multi-criteria analysis for the technology needs assessment.

5.2 Existing Technologies in Water Sector

Existing technologies are generally conventional and have been practiced for hundreds of years count; fore, for example method of flood irrigation, is dominant from coast to coast, and that is because of the intermittent flows in a very short period of time during which a maximum agricultural area must be irrigated. In this method, the agricultural land is divided into basins of different sizes with zero-level beds and are covered with flood water to a 40 to 50 cm depth. Other methods are also applied, such as shallow furrows method and the border stripe method, usually when using groundwater with flood water, mutual irrigation (Haidera et al. 2011).

What concern rainwater harvesting for agriculture and domestic supply is traditionally practiced long time ago in limited areas with frequent rainfall and where other water resources are rare.

Well, digging and, lately well drilling also is spread in all the country, and a huge number of wells has been dug throughout the country either for domestic supply or agricultural irrigation. Recently, many wells were dug for industrial and commercial purposes. In many places, these huge number of excavated wells and over-abstraction caused a catastrophic depletion and deterioration of local groundwater reservoirs.

Flood water diversion for flood irrigation by traditional diversion works, levees and spurs are still applied in many plain valley areas in order to divert flood waters to the agricultural land in sufficient quantities for irrigation. In recent decades engineered diversion structures were established in the plain areas of a wadi basins (Noaman 2022).

Wastewater disposal still suffers of lack in infrastructures and proper approaches to maintain sustainable hygiene for urban and rural communities.

Regardless the existence of protecting state laws, wetlands regularly are subjected to violations of different types and harmful consequences to the environment.

5.3 Suggested Technologies for the Water sector by the Consultant

In the early session of the workshop hold for TNA stakeholders (February 7, 2022) the consultant suggested number of adaptable technologies to tackle the problems persistent in water sector in general, the consultant gave brief explanation for each technology. The suggested technologies are as follow,

1. Meteorological station, monitoring of weather parameters and greenhouse gas emissions
2. Hydrometric measurements of wadi flows (weirs level gauges)
3. Hydrogeological data; Groundwater investigation, including exploratory drilling, vertical electrical sounding (VES), dye and isotope tracers, and aeration zone
4. Monitoring the quality of drinking water from wells, fixed and mobile laboratories, training of working cadres
5. Water requirements for agricultural activities, irrigation in watersheds, ET lysimeters and soil moisture studies (types of devices)
6. Irrigation methods (types) of saving water, drip and sprinkler of all kinds
7. Building Storage Dams
8. Construction of detention dams and detention barriers
9. Building diversion facilities and delivery channels, conveyors and distributors
10. Protection and measurement of brooks, springs and natural eyes

11. Rainwater Harvesting Techniques and Harvesting Ponds
12. Conservation and exploitation of wetlands to increase the green area
13. Wastewater recycling and reuse in industry, agriculture and wetland development
14. Waste Water Stabilization Ponds (WWSP)
15. Bioreactors
16. The odorless wastewater treatment technologies
17. Exploration of new wells for drinking water and the introduction of new well-drilling techniques
18. Reverse osmosis (RO) seawater desalination
19. Thermal Distillation
20. DI Deionization
21. Protection of groundwater from landfills
22. Development of water supply systems and networks, collection, sterilization and distribution
23. Development of sewage systems and networks, collection and treatment
24. Social Techniques to Enforce Laws of Sustainable Water Uses and Well Drilling
25. Technologies of Water Bodies and Coasts
26. Techniques for protecting and developing valley estuaries

5.4 Selected Technologies for the Water Sector by the Stakeholders

In the second session of the consultation workshop (February 9, 2022) the two group discussions of the stakeholders selected 12 technologies according to their background, everyday job experience and personal interests of the stakeholders- investors.

To facilitate the stakeholders consultation and to provide them with sufficient information in order to guide their discussion and help them to compare the different technology options using multi-criteria analysis, water consultants prepared technology factsheet for each of the long list proposed technologies. Fact sheets for technologies are provided in Annex (4).

The technologies are as follow,

1) Weather Stations

Meteorological stations, monitoring of weather parameters and greenhouse gas emissions to overcome the absence of enough data records needed for further analysis and prediction of extreme events of heavy rainfall and severe storms.

2) Hydrogeological Data

Groundwater investigation, including exploratory drilling, vertical electrical sounding (VES), dye and isotope tracers, and aeration zone.

3) Monitoring the Quality of Drinking Water

Monitoring the quality of drinking water from wells, fixed and mobile laboratories, training of working cadres and technicians.

4) Ways to Rationalize Water Consumption of all Kinds

Rationalizing water consumption by introducing water saving methods of irrigation, detecting leakage from water supply networks and reducing losses. Minimizing infiltration losses from irrigation canals.

5) Diversion Facilities and Channels

Construction of diversion works and channels to divert and convey flood water to the agricultural lands in order to increase food production and secure food safety.

6) Rainwater Harvesting Technique

This technique is practiced since thousands of years in many places of the country for drinking water supply and for irrigation of small assets.

7) Protection of Brooks and Natural Eyes

Protection and measurement of natural springs and brooks and fencing the surrounding area and boxing the spring and eye of the source.

8) Wastewater Recycling and Reuse

Wastewater recycling and reuse in industry, agriculture and wetland development. Recently this issue has become environmentally of prime importance, resource saving and sanitation development.

9) Explore New Well Fields

Exploration of new wells for drinking water and introduction of new well drilling techniques to meet the growing demands of population.

10) Desalination of Saline Water

Desalination technologies become more and more popular everywhere particularly where the lack of fresh water is overwhelming. RO desalination and thermal distillation has proved to be reliable alternative source to offer fresh drinking water from available saline sources.

11) Development of Sewage Systems and Networks

It is well known that the sanitation status of the community depends to far extent upon the sewerage system and network unbreaking performance which required continuous inspection and maintenance to held the system perfect.

12) Wetland Maintenance

Wetland conservation helps to keep local ecosystems sustainable in terms of biodiversity, withstanding seawater intrusion and green cover extension.

5.5 Decision Contexts

It is obvious that both water and agriculture sectors are - to a high degree - interlinked to each other. Therefore, some proposed technologies for either sector seems to be the same as it serves both sectors. Similarly, the criteria selected for evaluating the usefulness of each technology option for each sector found to be applicable for both sectors as well. No doubt, all the chosen criteria are important for evaluating the selected technologies for adaptation of agriculture sector, but in some cases one criteria seems to be more important than another in terms of its effect in the evaluation process. Although the selected criteria may not be equally important to the decision, the weights given to each criterion should reflect their relative importance in the choice of technology options.

For example, sometimes environmental impact is more important than cost when choos¬ing a new technology for the water sector, or vulnerability reduc¬tion seen as an essential criterion for adaptation measures in the agricultural sector more than any other criteria. So, for this purpose quantitative values are assigned to differentiate the rela¬tive importance of the different criteria.

There are different ways to assign weights, both participatory and statistical. However, in the context of the TNA process, it is essential that the weights reflect the views and priorities of stakeholders, meaning that weights are best determined by participatory methods.

To ensure that selected technologies are in line with national and sectoral policies and strategies, national reports of policy documents, these documents were consulted to take stock of the already identified vulnerabilities, adaptation measures, priorities, and efforts related to the focus areas. Examples of such documents include climate change National Communications (NCs), agriculture and water sectors strategies, National Adaptation Programme of Action (NAPA) etc.

The selection of adaptation technologies option by stakeholders reflects the differences between their backgrounds, experience and interests of individual or group of the participant stakeholders. Usually, the more influential individual or groups tilt the weight towards their choice. Knowledgeable participants give more weight to technologies, which have more adaptive effect on many aspects in the sector. For example, diversion works usually constructed to divert part of flood water by off-take channels to distribute it over agricultural lands. These structures should always be ready to function properly during the flood season in order to make use of the flood water, which is rich with natural fertilizers. Beside the other advantages of the diversion works is the alleviation of the destructive behaviors of high flood flows. Therefore, the adaptation technology in this case should be focused on the operation facilities of the diversion structure, including weirs, sluice and channel segmental and sheet gates. The opening and closing of heavy gates maybe mechanized and furtherly automized.

5.6 Adaptation Criteria, Scale and Weight

A set of criteria was made to evaluate the adaptability of each technology and ranking the priority to select just three of them. For more competency sub-criteria was added to the table of evaluation criteria as given in the description of criteria, and also given scale and weight, as shown in table 5.1 and 5.2.

Scale values assigned to each criterion by scaling its sub-criteria from 0 to 100%. This scale values should be assigned by the stakeholder in order to determine the important of the criterion by itself according to agreed consideration towards the selected technology.

The criteria selected for evaluating the usefulness of each technology option may not be equally important to the decision, nor to the achievement of the overall goal. There¬fore, the weights given to each criterion from 0-100%, should reflect their relative importance in the choice of technology options.

Apart State investment, cost in many cases, is not considered a determinant factor for most of stakeholders/ investors to decide whether any project feasible or not. Fervent investors usually look for a complete feasibility study. In addition to capital cost, feasibility study usually includes another indicators, such as; net benefit, return period, rentability and income per unit currency expenses. All these indicators are considered of prime importance.

Referring to cost only is an apprehension for most donors or NGOs or some individuals but not the majority of prospective investors to decide.

5.7 Assessment Criteria for Adaptation Technologies

Among several number of adaptation technologies to climate change resilience the stakeholders selected 12 according to the agreed about by stakeholders in advance criteria for the assessment, and they are as follows:

Table 5:1 Criteria description

S.N.	Criterion	Description
1	Cost	It is technology establishment cost, including installation, operation and maintenance costs
2	Economic and Social Impact	The benefits of the technology for the national economy and its positive impacts on the society, in terms of new jobs creation, and gender equity.
3	Environmental Impact	The applied technology must not deplete natural resource, and don not releases waste or pollution or any other adverse impacts on the environment
4	Improve ability to adapt to climate change	Improvement of the resilience to climate change under current and future climate scenarios.
5	Recovering ecosystems	Increase green cover, Abundant crop production, Favorable climate for living beings, preserving biodiversity, providing agricultural needs.
6	Improve livelihoods	Job opportunities, improving household income Raising the standard of living
7	Sustainability	Achieving continuous plant growth environment, Durable water facilities, Maintenance of terraces & Water barriers, Continuity of irrigation networks' efficiency, Collecting water revenue, Spreading social awareness . Besides, the ability of technology to withstand under various condition with same efficiency
8	Readiness and preparedness	The national circumstances do not prevent or hinder applying the technology and the country ready to integrate this option into government sectoral policies, such as the availability of the of previous studies, Database and Plans.

Table 5:2 Adaptation Criteria, Scale and Weight

S.N.	Criterion	Scale	Weight
1	Cost	85-100% Very Low 65-85% Low 45-65% Medium 25-45% High 0-25% Very High	10%
2	Economic and Social Impact	0-25-% Very low 25-45% Low 45-65% Medium 65-85% High 85-100% Very High	10%
3	Environmental Impact	0-25-% Very low 25-45% Low 45-65% Medium 65-85% High 85-100% Very High	15%
4	Improve ability to adapt to climate change	0-25-% Very low 25-45% Low 45-65% Medium 65-85% High 85-100% Very High	25%
5	Recovering ecosystems	0-25-% Very low 25-45% Low 45-65% Medium 65-85% High 85-100% Very High	7%
6	Improve livelihoods	0-25-% Very low 25-45% Low 45-65% Medium 65-85% High 85-100% Very High	10%
7	Sustainability	0-25-% Very low 25-45% Low 45-65% Medium 65-85% High 85-100% Very High	15%
8	Readiness and preparedness	0-25-% Very low 25-45% Low 45-65% Medium 65-85% High 85-100% Very High	8%

5.8 Results of Technology Prioritization

Consistent assessment of needed technologies necessitates the inclusion of sub-criteria scale and weight in the evaluation forms that specially prepared to be filled by the targeted stakeholders, which intended to participate in the workshop discussion sessions.

The selected technologies by the stakeholders, according to the agreed-upon criteria and sub-criteria, have been arranged in tabular form in MS excel spread sheet. The scale limits in percentage for each criterion were decided previously also by the participants. These scales in percentage were elaborated to obtain weightage in score point in order to rank the technology in the option and prioritize them accordingly as shown in the brief table (Table 5.2, 5.3).

Thus, as per the TNA guidance four technologies were selected as top priorities of the 12 technologies, and they are Saline water desalination, Diversion Facilities and Channels, Rainwater Harvesting Techniques and Wastewater Recycling and Reuse, as shown in Table 5.4.

Due to the fact that the share of water uses for agriculture irrigation is about 90% in the country. Some of the workshop participants were not able to address water issues from these dimensions. The reason is that they came from low lying and coastal areas, in which the effective rainfall is very rare, brooks and natural springs are almost absent, agriculture activities are very limited and the need of water for agriculture irrigation is quite low, and water uses is limited to almost domestic and industrial purposes.

Therefore, it was found that participants require some orientation on selecting the appropriate technologies, and it was advised to have further discussion with technical experts to validate the obtained results, in order to ensure that they are in line with sectoral strategies, address national priorities, and contribute to tackle water sector problems and challenges. Based on this process, a refined list of ranked technologies was obtained as presented in (Table 5.4).

Essentially, the prioritized technologies reflect the viewpoints of the stakeholders of different backgrounds and indicate the crucial needs to one or another technology that meets their local requirement. For example, saline water desalination appropriate mostly for coastal zones and the adjacent lowland areas, while rainwater harvesting applicable for mid-land and high-land of the country where rainfall is more frequent. Diversion facilities and channels apt for most areas of the country where they are required to divert perennial streams and flood waters to where they are needed. The same thing maybe said about reuse of treated wastewater, it is opportune where possible.

Table 5:3 Water Technologies Prioritization

TECHNOLOGY	Cost %		Economic and Social impact %		Environmental Impact %		Improve ability to adapt to climate change %		Recovering ecosystems %		Improve livelihoods %		Sustainability %		Readiness and preparedness %		Total Weight	Ranking
	Scale	Weight	Scale	Weight	Scale	Weight	Scale	Weight	Scale	Weight	Scale	Weight	Scale	Weight	Scale	Weight		
	100	10	100	10	100	15	100	25	100	7	100	10	100	15	100	8		
Saline Water Desalination	37	3.7	90	9	90	13.5	95	23.75	75	5.25	87	8.7	97	14.55	90	7.2	85.65	1
Rainwater Harvesting Techniques	75	7.5	85	8.5	72.5	10.875	90	22.5	68	4.76	85	8.5	88	13.2	85	6.8	82.635	2
Diversion Facilities and Channels	38	3.8	65	6.5	80	12	85	21.25	56	3.92	80.5	8.05	88	13.2	97	7.76	76.48	3
Wastewater Recycling and Reuse	85	8.5	70	7	70	10.5	76	19	75	5.25	70	7	70	10.5	75	6	73.75	4
Development of Sewage System and Network	41	4.1	63	6.3	55	8.25	80	20	75	5.25	80	8	91	13.65	90	7.2	72.75	5
Hydrogeological Data	63	6.3	58	5.8	50	7.5	85	21.25	64	4.48	50	5	80	12	94	7.52	69.85	6
Water-Saving Methods of Irrigation	30	3	45	4.5	45	6.75	90	22.5	64	4.48	64	6.4	93	13.95	97	7.76	69.34	7
Weather Stations	45	4.5	36	3.6	85	12.75	80	20	72	5.04	60	6	66	9.9	85	6.8	68.59	8
Monitoring The Quality of Drinking Water	77.5	7.75	60	6	70	10.5	50	12.5	48	3.36	69	6.9	85	12.75	98.5	7.88	67.64	9
Explore New Well Fields	48	4.8	74	7.4	47.5	7.125	70	17.5	64	4.48	70	7	65	9.75	80	6.4	64.455	10
Wetland Conservation	51	5.1	48	4.8	55	8.25	90	22.5	16	1.12	48	4.8	58	8.7	48	3.84	59.11	11
Protecting Brooks and Natural	66	6.6	31	3.1	40	6	70	17.5	20	1.4	58	5.8	48	7.2	50	4	51.6	12

Table 5:4 Ranked technologies for water sector

Technology	Total Score	Rank
Saline Water Desalination	**85.65**	**1**
Rainwater Harvesting Techniques	**82.635**	**2**
Diversion Facilities and Channels	**76.48**	**3**
Wastewater Recycling and Reuse	73.75	4
Development of Sewage System and Network	72.75	5
Hydrogeological Data	69.85	6
Water-Saving Methods of Irrigation	69.34	7
Weather Stations	68.59	8
Monitoring The Quality of Drinking Water	67.64	9
Explore New Well Fields	64.455	10
Wetland Conservation	59.11	11
Protecting Brooks and Natural	51.6	12

The four ranked technologies for water sector that were identified, selected, prioritized, and ranked through a consultation process with relevant stakeholders namely 1) Saline Water Desalination, 2) Rainwater Harvesting Techniques, 3) Diversion Facilities and Channels, and 4) Wastewater Recycling and Reuse are considered the most appropriate technologies for the water sector.

Although the cost of saline water desalination technology is high compared to other identified technologies for water adaptation, it provides a sustainable additional source for water to help conservation of ground water from depletion and improve adaptive capacity to climate changes which make the technology a favorable option at the long run.

Rainwater Harvesting Techniques have several advantages for the water sector to adapt to climate change, these include contribution to conservation of ground water through providing additional source of water for irrigation, improvement of crop production, reduced the hardship on women and girls for fetching for water, and improve adaptive capacity of local communities to the impacts of climate change on water resources.

The Diversion Facilities and Channels technique importance is in terms of its contribution to reduce the damage of services and properties resulted from floods, and subsequently conservation of lands and soils from erosion. At the same time it helps to channel and direct irrigation water to the right place and reduce losses due to evaporation.

Also, wastewater recycling and reuse techniques provide additional sources of water that could be used to increase green cover through reforestation and planting of street trees and creating wastelands. However, this technique is more applicable and suitable for urban rather than rural areas since the amount of treated wastewater is more in urban areas.

Agriculture Sector

Chapter 6: Technology Prioritization for Agriculture Sector

6.1 Synopsis of the Agriculture Sector in Yemen

This chapter provides an overview of existing technologies for climate change adaptation in the Agriculture Sector and how technologies are selected. It explains the process for identification, selection, and prioritization of applicable technologies for the sector.

This process was conducted through the technology prioritization meetings held during the consultative workshops from 6 to 14 February 2022. Participants in these workshops represented different relevant stakeholders, including ministries, organizations, NGOs, experts from the University of Aden, and the private sector, in addition to the TNA national team.

The agricultural sector is considered as one of the most important productive sectors in the Yemeni national economy. This importance arises from the fact that it is one of the basic components of local production income.

Yemen has been famous for agriculture since the dawn of history, as it occupies a unique location that includes six climatic regions distributed at heights that start close to the surface of the sea and end with high altitudes of more than 3000 metres above sea level. This unique diversity enabled Yemeni farmers to produce vegetables throughout the year, where agricultural soil is distributed to the Valley, plains, valleys, and agricultural terraces on the slopes of the mountains.

During 2014-2020, the agricultural sector was of particular importance to the Yemeni economy, contributing about 15.9% to the real GDP. Contribution by the sector to real GDP jumped from 12.4% in 2014 to 16.5% in 2020. It is also a key driver of economic development in the country for multiple reasons, inter alia, job creation in rural areas, promoting the economies of agrarian communities, and enhancing food security. The agricultural sector contributes most to real GDP at the national level, especially in light of the declining share of oil and gas to the real GDP, which fell from 22.7% in 2014 to 9.4% in 020 [11]. The total area under cultivation is about 1.4 million hectares, of which 93% are devoted to annual crops and 7% to permanent crops (Anon n.d.-b).

Therefore, Yemen's economy largely depends on sectors such as agriculture, fishers, and water resources that are particularly vulnerable to environmental changes. Among such changes, climate change emerges as one of the most challenging threats that has repercussions on national development efforts and its economic base.

Climate change is expected to result in increased frequency and severity of droughts, extreme weather events and others adding to stress on water resources, food security, health, infrastructure, and in overall development of the country. Thus, adapting to the changing climate has become fundamental to safeguard the climate vulnerable communities and ecosystems in the country which is basically fragile.

Effects of climate change are observed and noticed in different key economic sectors including agriculture. The magnitude and intensity of disaster events increased over the last few decades and taking a toll of lives and damaging huge swaths of properties across the country.

Yemeni people are famous for their indigenous knowledge of their ancestors in the field of agricultural practices and techniques, and for management of natural resources while preserving them. They grows crops in valleys, coastal areas, and terraces built on steep slopes of the mountains. They built dams, and extensive hydraulic works to harvest water. This experience and knowledge have been developed over centuries to suit different production systems and ecosystems. Such special agricultural activities resulted in a good production of different crops, including grains, coffee, fruit, and livestock. Terraces systems -spreads in most

[11] CSO and, National Accounts Bulletin Update based on 2012 data, April 2021.

areas of the country except for the desert and coastal areas - were built by the Yemeni farmer as an excellent practice to protect the soil from erosion and to act as a rainwater harvesting technique .

Similar to other sectors, the agriculture sector is facing several problems and challenges. Several factors and root causes contribute to the existence of agriculture problems and to the continuation of degradation and resource depletion. These are of societal, managerial, institutional, financial, regulatory, and cultural. In addition, national conflicts, economic situations, social problems, and the impact of severe climate changes impacts all together constitute a real threat to the sustainability and success of the efforts of adaptation measures. The following are examples of such multidimensional challenges:

- Rapid urbanization and expansion of infrastructure and building in agricultural lands.
- Improper application and use of pesticides.
- Insufficient and unreliable information and networking on agriculture.
- Sand dune movement and desertification.
- Terraces degradation and soil erosion..
- Rangeland degradation.
- Increased water depletion for Qat production.
- In-appropriate irrigation practices associated with a lack of water conservation systems.
- Declining agricultural production caused by drought and degradation of agro-systems.
- Abandonment of productive traditional agricultural practices.
- Improper use of agro-chemicals (pesticides, fertilizers, fruit ripening agents, etc.).
- Limited capacity and funding for agricultural research.
- wind erosion and sand dune encroachment
- Overgrazing of rangelands including loss of sustainable practices of sound rangeland management by local people.
- Deterioration of native genetic resources as a result of the introduction of alien and invasive species.
- Declining agricultural production caused by drought and degradation of agro-systems.
- The lack of adequate information on the new farming techniques.
- Prolonged drought.
- Cutting trees for firewood.
- The ongoing war and armed conflict in the country.

It is therefore crucial to explore and assess all existing and applicable technologies that help to improve productivity, conserve natural resources including soil and water, and overcome challenges facing the sector. The crop production system in Yemen is generally reflected by the availability of water supply as being the most important factor, and therefore the cultivated area may vary from one year to another depending on the amount and distribution of rainfall (Breisinger et al. 2011a; Wilby and Yu 2013b).

6.2 Key Climate Change Vulnerabilities:

The expected impacts of climate change, particularly reduced agricultural productivity and water availability, threaten livelihoods and keeps vulnerable people insecure. Local communities in rural areas, poor families, and households are the most vulnerable group to the potential impacts of climate change and deserve the priority in the design of appropriate adaptation measures.

The major climate exposure risks associated with agriculture in Yemen were identified as:

Temperature variability creates hazards for which agricultural ecosystems are unprepared. Drought is exacerbated by high temperatures, which damage crops and their establishment and reduce yields.

Temperature Increase: temperature has a large influence on crop quality, quantity, and where it can be grown. Because of the nature of this fundamental biological and ecological relationship, any temperature changes brought about by climate change will have a significant impact on crop (commodity) production. Temperature influences crop development at all stages. Within certain temperature ranges development generally accelerates linearly, but at extreme temperatures, the relationship becomes non-linear and increasingly difficult to predict. Higher temperatures frequently cause heat stress.

Disasters Including Floods: leading to contamination of water bodies, loss of harvest or livestock, increased susceptibility to disease, and destruction of irrigation systems and other agricultural infrastructure.

Changes on Rainfall Patterns: Decrease in average rainfall and changes in rainfall patterns, generally affecting the drier seasons, with declines particularly noted in the Highlands

Droughts: Droughts in agriculture can occur for a variety of reasons, including a lack of precipitation, the timing of water availability, a lack of access to water supplies, or increased water demands from the sector(Anon n.d.-a; Breisinger et al. 2011b; Wiebelt et al. 2011a).

6.3 Overview of Technology Options

Given the fact that the majority of Yemeni people living in rural areas as farmers relying on land resources, there is a wide range of existing technologies in the country which have been developed and practiced by farmers for centuries as traditional methods to improve crop production, conserve land resources, make use of the scarce and limited water resources in efficient manner, and control pests. During the inception workshop (February 7, 2022) the agriculture consultant proposed a series of existing technologies and provided explanation of each technology as sort of orientation for participants. The extensive list of existing technologies and sub-technologies include:

1. New crop varieties
2. Agricultural soil conservation methods:
    a. Terraces
    b. Tillage methods
    c. Contour Farming
    d. Strip Cropping
    e. Windbreaks
    f. Crop Rotation
    g. Use of leaving fields fallow
    h. Cover Crops
    i. Buffer Strips
    j. Mulching
3. Traditional Plant protection
4. Timing of planting (planting and harvesting)
5. location and type of soil,
6. Crop care practices
7. Reuse of treated wastewater and grey water
8. Irrigation saving techniques.
    a. Traditional irrigation systems
    b. Modern Irrigation Systems (Drip Irrigation Systems, Sprinkler Irrigation, Centre Pivot Irrigation, Furrow Irrigation Systems, Terraced Irrigation).
9. Rainwater harvesting and storage technique:

a. Surface runoff harvesting
b. Groundwater recharge
c. Spate water diversion structures (Flood water harvesting)
10. Greenhouse
11. Natural fertilizers (Manure)
12. Mulching and soil cover
13. utilization of mechanization
14. Chemical pesticides and related applications
15. Beekeeping and honey production
16. Livestock management
17. Cultivation in traditional drilling to produce coffee through moisture spray or fog
18. Research and Data management
19. Policy review, adjustment of new policies
20. Extension programmes

The above list of the twenty options were eliminated by the stakeholders and out of which the following 12 were selected. A brief description of eachof the selected 12 technology proposed for the agriculture sector is presented in the following paragraphs.

1. Traditional Plant protection (Biological control)
2. Livestock Management (Traditional Grazing)
3. New Crop Varieties (Genetic Origins and Gene bank)
4. Agriculture Soil Management and Conservation
5. Timing of Farming Practices (Planting and Harvesting)
6. Beekeeping and Honey Production
7. Reuse of Treated Wastewater and Grey-Water
8. Irrigation Saving Techniques
9. Water Harvesting and Storage Technique for Agriculture Purposes
10. Greenhouses
11. Natural Fertilizers (Manure)
12. Integrated Pest Management (IPM)

1. Traditional Plant protection (Biological control)

Traditional agriculture in Yemen is oriented toward sustainable production and eliminate pest infestation and diseases, and the old Yemeni farmers were among the first to use biological methods to control agricultural pests. They excelled in the use of phytophagous insects, mites have been used extensively for weed biological control, and plant pathogens have also been used. Study shows that Yemen host some 2400 plant species useful in plant protection worldwide (Grainge and Ahmed, 1988). Predatory insects or non-biological control, such as spraying with dirt, dousing with water, use of smoke or heat, use of protective devices and manual removal of infected parts are among different methods they used. While the overall context of agriculture has changed dramatically in recent years, it is important to assess the effectiveness of past crop protection measures in Yemen.

Farmers traditionally in Tihama, Taiz, and Hadramout for example used to collect predatory ants from mountains to control date palm pests that attack the fruit. Weed biological control agents can target seeds, leaves, stems, or roots of the weed, and combinations of agents attacking different parts of the plant are often employed. Biological control is usually defined as the use of natural enemies to suppress populations of pests such as insects and weeds. pests often arrive without the suite of natural enemies which would normally keep them in check in their natural range. Consequently, they sometimes undergo periods of the outbreak before existing predators, parasitoids or diseases adapt to them and before pest management strategies, including biological control can be developed.

Farmers used to burn harvest debris and leftovers to eliminate diseases and pests hidden in these materials. Cumin was burnt to deter mosquitoes in houses. Some Yemeni farmers burn the wheat and barley chaff, others dung and manure, to keep pests away (some farmers adding that this measure would also kill the flying insect pests attracted to the fire). Two types of ants were controlled by putting ash, salt and water on their nests, forcing them to leave

In traditional agriculture, farmers also used various mechanical methods of pest control. All members of the farmer’s family used to collect and destroy pests by hands. When locusts attacked the crop, farmers used to make loud noises, using drums and singing group songs. They also guarded their crops at harvest time. The guards make loud noises, or used instruments to hurl stones at birds or to make frightening loud noises.

Farmers in Hadramout and Tihama traditionally used oil for the control of pests and diseases on date palm fruits. Also sesame oil was applied to the flowering branches at the time of pollination in order to protect the pollinated flowers from diseases. Use of repellant plants such as onion bulbs buried in the soil near grape vines for the control of termites.

For protection from storage pets Yemeni farmers traditionally used oil, ash and sand to control pests and diseases. In the al-Hadā and Bani Matar areas, good grain is selected and stored mixed with plants called nacadh to protect the grain against smuts. Farmers in the Taiz and Ibb areas used to mix ash with sorghum or wheat and store the mixture in small tanks closed with mud. In Hadramout old farmers they still follow the traditional methods of keeping dates in clay containers locally called qihalah and azyār, which are closed with soft dates and a layer of ash. Grains and legumes are often stored in underground granaries called Medfan. In Taiz, Ibb, Hajja and Mukayrās areas, farmers also used barrels closed with layers of ash as storage containers. Some farmers used muraymarah (Azadirachta indica) leaves to protect stored grains from pests.

2. Livestock Management (Traditional Grazing)

Livestock is an important source for livelihood especially in dry land. Interventions in livestock sector represented by improving access to veterinary services, vaccination campaign, improve animal nutrition and enhancing animal husbandry. The sector has high potential for improvement and will have great impact on livelihood because many households in Yemen have at least one animal.

Climate change has direct effects on livestock productivity as well as indirectly through changes on the availability of fodder and pastures. Climate determines the type of livestock most adapted to different agro-ecological zones and therefore the animals that are able to sustain rural communities.

Yemen has an arid/semi-arid climate, but large differences in precipitation and between topography and precipitation. There are traditional historical rangeland governance practices that have allowed sustainable rangeland management in the dry areas for centuries. It’s called “Al-Hemah”. In Yemen dialect, Al-Hemah or Mahger refers to the most ancient rangeland management practice through rangeland resting, which is a kind of deferment grazing. This traditional rangeland practice continues today in some parts of the country in the western mountains of Yemen .

Mahger and Al-Hemah are a technique that prohibits domestic herds’ exploitation of collectively identified rangeland areas. It requires the communities’ agreement and sanctions at the same time. Rangeland resting has the ability to reverse grassland degradation and restore the land to its optimum productivity and biodiversity level. It spreads significantly in the western highlands such as Taiz, Ibb, Tihama, Hajjah, Al-

Mahwit, and some interior areas in Sana'a , Amran, Dhmar and Al-Baydah and extends to the South east areas in Wadi Hadramout.

Rangelands are not extensively mapped and their economic potential remains unknown. The highlands are a mosaic of agriculture land, volcanoes, rangeland, rock outcrops, wadis, and areas with a desert pavement. Livestock practices in the highlands are mostly sedentary—herds leave and return to the homesteads on a daily basis.

Herding in general is done mostly by old men and children, and herds of different households are sometimes combined for practical reasons. In those cases, the herders are compensated for watching someone else's herd. Women are mostly responsible for feeding cows and camels, while men are responsible for growing crops or salaried jobs in the major towns.

Livestock ownership is an integral component of rural and peri-urban livelihoods in Yemen, where households mainly keep sheep, goats, cattle, camels and poultry, and rely on the consumption and sale of their products. Livestock constitutes an important component of the national economy and is a repository of wealth for at least one in every three livestock-owning households. Sale of animals accounts for a significant portion of household income and serves as a crucial fallback strategy when these households are faced with shocks. The total number of livestock in the country is estimated at 19 million, dominated by sheep (8.9 million) and goats (8.7 million), and followed by cattle (1.5 million) and camels (360 000) .

Livestock production systems vary from traditional pastoralism to agro-pastoral systems and small-scale intensive animal production units. Pasture-fed livestock has traditionally been practiced and is a prominent feature of the rural economy and agricultural activities in many parts of the country . However, Yemen does not produce sufficient livestock products and imports a huge number of live animals, in addition to meat and dairy products. For example, 95 percent of the milk consumed in Yemen is imported. The productive capacity of the livestock subsector is held back by low levels of investment; limited access to livestock production and veterinary inputs and services; inadequate availability of and access to quality animal feed; epidemics and infectious diseases; inefficient management of resources; and the numerous effects of the current conflict.

3. New Crop Varieties (Genetic Origins and Gene bank)

Yemen is famous for its position on the old trade road between the east and west; several crops have been entered Yemen; for example, the tomato has been entered during the 19th century and other crops entered late, like Potatoes that entered Yemen in 1939 (Keen, 1964), although there aren't enough researches explore the development of crops in Yemen. New crop varieties have been introduced to Yemen through development strategies in the past three decades; however, some of these are more vulnerable to diseases or pests. Research on drought-resistant, heat and salinity-tolerant agriculture crops is needed. Diversification of crops is another important technique to deal with any expected climate change event because it will reduce general loss by different levels of response from different crops.

Improved seed technology uses different types of seeds as suited to evolving conditions is a key mechanism through which agriculture can adapt to climate change.

Different types of improved seed varieties exist in Yemen locally and are imported, aiming to maintain or improve yield (and ideally quality). New varieties produced by international and local research centers and commercial companies are replacing traditional local varieties. The companies that produce new varieties compete in the global market by introducing genetically altered strains with enhanced productivity. Farmers, in their turn, adopt the new strains for their higher yields and enhanced income potential without considering such potential longer-term risks as the failure of new strains to thrive under local conditions. As a result, seed stocks need to be replaced from time to time. Moreover, new seed stocks sometimes introduce blights that may seriously affect other crops. As a result, some improved and imported crops, fruit trees, forest trees and new breeds of animals may replace, completely or partially, local varieties and breeds adapted to local environments over thousands of years.

In the past twenty years, many fruit and forest trees, varieties of wheat, barley and other cereals, and different kinds of vegetables have been introduced to Yemen. These new forms have displaced local forms, causing a decline in genetic diversity. This loss is continuing today, as the responsible authorities are generally ignorant of the scientific and practical complexities of this issue.

The producers of modern varieties seek a profitable product suitable to as wide a range of environments as possible. Such products require annual replacement of seed stocks, heavy manuring or fertilizing of fields, frequent watering, and aggressive measures against crop pests and diseases. So their unintended consequences include environmental pollution, exhaustion of water resources, and deterioration of soils.

New varieties may also introduce new pests that prove extremely difficult to eliminate (e.g. the red palm worm introduced from Pakistan that is destroying at a rapid rate date palms in Gulf countries as well as in Yemen). In sum, increased productivity and profitability over the short term is exchanged for long-term degradation of the productive process as a whole.

The production of improved seed varieties is highly research-intensive. It is essential that improved varieties are bred according to to be appropriate to local conditions. Yemen has long researched improved varieties of seeds through the Agriculture Research and Extension Authority (AREA) and Al-Kod Agricultural Research Center. AREA in collaboration with international donors, had several research programmes on drought-tolerant and early-maturity maize, wheat, and sorghum varieties which are being promoted for adaptation in drought-prone areas.

Drought-tolerant varieties are better suited to changing rainfall conditions, particularly where a drying trend has been observed. Early maturing varieties are also important, especially given the widespread tendency for delayed onset of the rainy season and mid-season dry spells.

GM seeds are particularly not popular in Yemen, although they are controversial and banned in the country. The good practices and technologies making up the improved seeds in Yemen which were found to be effective adaptations are use of improved varieties ex. Onion (Ba-Fatim) which is spread widely in most of the coastal Yemeni governorates Hodiedah ,Taiz , Shabwah , Abyan and Wadi Hadramout .

4. Agriculture Soil Management and Conservation:

Maintaining soil quality is essential to ensure optimal production. Soil quality can decline as a result of farming practices and technologies and types that deplete nutrients and have adverse effects on soil structure. However, soil quality is also affected by natural processes, such as geochemical cycling and wind and water erosion. Changes in the climate can affect the nature and rate of these natural processes. As a result, the need to ensure soil management is even greater under climate change, moreover, pesticides and fertilizers are the mean challenges and problems for agriculture in Yemen which are widely used without control.

Soil management is a good practice to conserve soil and to protect it from deterioration as a result of manmade as well as natural impacts including and climate change induced impacts. Soil management practices and methods aims to maintained and/or improved yields, support ecosystem integrity, and functioning of ecosystem services. Such methods need to characterized by availability of e low-cost options , existence of various techniques of erosion prevention and soil quality protection and enhancement, and facilitate women farmers to have equitable access to resources.

Yemeni farmers protect the soil quality an conserve agricultural soil through different farming practices. These include (as sub-technologies for soil conservation - a) Terraces, b) Tillage methods, c) Contour Farming, d) Strip Cropping, e) Windbreaks, f) Crop Rotation, g) use of leaving fields fallow, h) Cover Crops, i) Mulching. etc.

Fertilizers use will not directly enable farmers to adapt to climate change, but the increase in yields could help them to better cope with threats from climate change. Chemical fertilizers have been widely spread and used in most regions of the country , however, have typically been unaffordable for many small-scale farmers. They can also have potentially adverse environmental consequences – such as leaching, eutrophication, and pollution of water courses – unless effectively managed.

The farmers prefer to use municipal fertilizer in traditional and inherited practices (bio-fertilizer options), such as manure, composting, and the use of complementary plants. This increase the accessibility of soil enhancement as a mechanism of soil and water management. In particular, manure and composting are suitable adaptations to drying conditions. Making compost from animal or vegetable waste through traditional methods is a nationally widespread and practiced by both maize and sorghum farmers.

5. Timing of Farming Practices (Planting and Harvesting)

Indigenous or traditional knowledge is usually specific to a site or community. A good example of this is the relevance of an agricultural calendar. In the past farmers in Yemen timed their plantings not by almanacs or written schedules but by local observations of star risings and settings, the position of the sun's shadow and observable changes in the seasonal round (e.g., bird migration, appearance of certain insects or plants, etc.). Observation and recording change in the local weather can be a useful technology for preventing loss or changing agriculture practices related to site specific for better production.

During the last decades, there have been clear and tangible changes in the distribution of rain in terms of the amount and times of rainfall. In addition to severe stormy rains in a short time, which leads to flooding and soil erosion, forcing farmers to change planting dates, which also entails potential risks, especially in areas that depend mainly on rain.

Farmers, particularly small-scale ones, traditionally waited until the onset of the rains before planting their crops. However, since the timing of onset has become so variable, and is often accompanied by irregular subsequent rainfall, many farmers are now sowing their seeds when it is still dry. Timing farming practice for agricultural adaptation is therefore a good practice shown through:

- Early/dry planting, staggered planting, and altered feeding times make use of the shift in availability of natural resources occurring due to climate change.
- Changing the timing of farming practice is typically optimized when used in conjunction with other practices, e.g. different seed types and cultivars, and production-enhancing inputs such as fertilizers.
- Information on likely weather conditions throughout the season is required in order for early/dry planting, staggered planting and changing feeding times to be successful.
- Access to inputs, including seeds/feed, labor and machinery determine the likelihood of/extent of success from changing the timing of farming practice.
- Changing the timing of farming practices and technologies is likely to have positive environmental benefits because it is done with the intention of linking the crop production cycle with the availability and quality of environmental resources to support the growth cycle.
- If women farmers have access to land, labor and technical know-how, changing the timing of farming practices and technologies can be accessible to them.

6. Beekeeping and Honey Production

Traditional Yemeni beekeepers characteristically move their hives in search of suitable and desirable pastures for their bees. The diversity of climate and topography plays a vital role in the plant cover diversity. Flowering plant species have different flowering times in different locations, so beekeepers change their honeybee locations according to the environmental rhythms of their bees' food. Some beekeepers stay in one location suitable for their bees throughout the year, sometimes close to their home. Adding supplement liquid during the drought season is a practice done by most beekeepers.

The modern introduced Langstroth beehives Production is done in a very traditional manner and lacks the necessary tools and equipment.

In 2015, according to data from the Ministry of Agriculture, the number of bee colonies amounted to more than 1.3 million, and Yemen's honey production was approximately 2,600 tons annually. Some types of Yemeni honey are well known of its high quality, and most of it is exported mainly to neighbouring countries in the gulf. Although, the Sector faces several challenges including the ongoing war and conflicts along with floods and torrents that have destroyed and washed away thousands of Yemeni beehives, and Yemeni beekeepers incurred heavy losses. The battles hindered the beekeeper's ability to move from area to another, especially the battles that took place near the bee pasture, the restrictions on the movement of trade between governorates, and the difficulties of exporting products outside the country that took part in the decline of the Yemeni honey trade.

7. Reuse of Treated Wastewater and Greywater

Quite large amount of water utilized for domestic use and mosques, projects focused on reusing the water from the mosques because it is less polluted with organic materials, quite big amount concentrated in one location and easier to be separated. Generally, the waste and grey water still have high potential with new technologies for water treatments exist in the international market.

8. Irrigation Saving Techniques

According to Yemen TNC (2018), high-efficiency drip irrigation is the most strategy that able to reduce the rate of groundwater depletion from 412 to 280 million cubic metres per year, or about a 32% in the future dry climate scenario.

9. Water Harvesting and Storage Technique for Agriculture Purposes

Water harvesting and storage can be done through different techniques and several capacities. Yemen was and still famous with dams, for example there are approximately 800 dams for rainfall water harvesting in the highlands (Al-Asbahi et al, 2005). People also construct tanks "Cisterns" (building above the ground or digging and building), locally called "Karif", some of them also covered by roof, these tanks collect water from small water catchment area or from the roof of houses. People also harvest the water from the roof to small plastic tanks. The collected water used for irrigation but also very important for domestic use. There still high opportunities for water harvesting by building small dams and city water harvesting, from the street water or directly from the roof of houses. Sometime pre-treatment of harvested water especially isolation of solid waste is necessary. Internationally several other techniques for water harvesting exist.

10. Greenhouses

Greenhouses are considered among the most recent and important agriculture development initiatives in Yemen, representing a genuine pillar of the Yemeni agriculture sector. As they are unaffected by climatic conditions and offer an environment suitable for year-round cultivation and crop diversification, greenhouses represent a source of constant material returns and constitute a safe method of increasing income and ensuring livelihoods for farmers. This technology allow farmers to earn income in innovative ways that support the environment by conserving precious water resources and using solar energy. Excessive heat and scarce of water in many parts of Yemen make it very difficult to grow vegetables without modern agronomic. The greenhouse establishment cost is high, but their benefit also high. It is estimated that 75% of water loss from evaporation can be reduced by using greenhouse supported by solar panel that powers a humidity-regulating fan, water pump and a highly efficient drip irrigation system. The technology is appropriate to demonstrate further sustainable water solutions in places where they are most needed. In some cases in Yemen, a greenhouse can produce up to 10 times more vegetables than a traditional field while using 92 percent fewer pesticides.

11. Natural Fertilizers (Manure)

Many farmers still use manure applications and cover the land with stems, leaves and roots from harvests, women have an important role in this practices especially in rural areas especially in collecting, transferring and applying the manure in the fields. Animals are kept for meat and milk but also for their useful manure. At national level, 75% of the farmers access their fertilizer needs through purchase from the markets followed by 20% using own farm manure and 4.8% from free distribution by humanitarian agencies (Yemen EFSNA, 2017).

12. Integrated Pest Management (IPM)

Yemeni farmers traditionally practiced several methods of pest control that are suitable for different locations and crops. These different biological, mechanical, cultural methods were both protective and preventive in nature. These methods are known recently as Integrated Pest Management (IPM)

Integrated Pest Management (EPM) is an effective and environmentally sensitive approach to agricultural pest management that uses a range of practices to manage population and maintain at level below at which it can cause economic injury and affect agricultural production while providing protection against hazards to humans, animals, plants, and the environment.

IPM makes full use of natural, physical and cultural processes and methods, including host resistance and biological control as opposed to synthetic chemicals. IPM emphasis the growth of a healthy crop with the least possible disruption of agro-ecosystems, thereby encouraging natural pest control mechanisms. Chemical pesticides are used only where and when these natural methods fail to keep pests below damaging levels"

6.4 Decision Context

The impact of climate change on the agricultural sector is unavoidable. Efforts must be made to ensure that the sector can adapt to the changing climate. Yemen's agricultural sector is a large sector consisting of various subsectors. This report, however, will focus only on selected subsectors rather than the entire agricultural sector to ensure that adaptation technologies of interest can be translated and implemented in the most effective manner. Thus, first of all, the target subsectors were identified by considering their vulnerability to climate change and contributions to the country's economic development and food security. To ensure that selected technologies are in line with national and sectoral policies and strategies, national reports of policy documents were consulted to take stock of the already identified vulnerabilities, adaptation measures, priorities, and efforts related to the focus areas. Examples of such consulted documents include climate change National Communications (NCs), agriculture and water sectors strategies, National Adaptation Programme of Action (NAPA) etc.

Simply, the identification process consists of two steps. First, climate change vulnerability analysis for the sector through which both the direct and indirect impacts of climate change, and adaptation priorities were considered. Second, engagement and consultation with relevant stakeholders to explore their perspectives, identify good and bad practices and experiences, and lessons learned. This approach was used to ensure that the proposed technologies are in line with national and sectoral strategies and to effectively response to the real needs.

It is obvious that both water and agriculture sectors are - to a high degree - interlinked to each other. Therefore, some proposed technologies for either sector seems to be the same as it serves both sectors. Similarly, the criteria selected for evaluating the usefulness of each technology option for each sector found to be applicable for both sectors as well. No doubt, all the chosen criteria are important for evaluating the selected technologies for adaptation of agriculture sector, but in some cases one criteria seems to be more important than another in terms of its effect in the evaluation process. Although the selected criteria may not be equally important to the decision, the weights given to each criterion should reflect their relative importance in the choice of technology options.

6.5 Criteria Selection and Process of Technology Prioritization

A set of initial criteria for prioritization and evaluation was proposed and presented by the consultants team to the stakeholders on the second day of consultation workshop (February 10, 2022), and participants discussed the suggested list of criteria to be used for technology prioritization and evaluation. Together, experts and stakeholders agreed on the proposed criteria, and weights were assigned and validated through an open discussion and based on the significance of each criterion as shown in table (6.1).

The national experts and advisory team had an active contribution - with engagement of relevant stakeholders - to the selection of criteria and weights, and played an active role in the whole process including criteria selection, analyzing weights, and carrying out prioritization, scoring, rating, and ranking of technologies.

Table 6:1 Description of selection criteria for Agriculture technologies

No.	Criteria	Brief description
1.	Cost	Technology establishment cost which include installation, operation and maintenance costs.
2.	Economic impact	The economic benefits of the technology for the national as well as communities economy.
3.	The need for technology	The technology respond to and address the needs and priorities of national as well as local communities and natural systems.
4.	Improve ability to Adapt	Enhancement of adaptation and improvement of the resilience to climate change impacts under current and future climate scenarios.
5.	Recovering ecosystems	Increase green cover, creating favorable climate conditions for living organisms, preserving biodiversity, and providing agricultural needs and improving agriculture and crop production.
6.	Improve livelihoods	Creating job opportunities, diversify and improve household income, and raising standard of living.
7.	Sustainability	The positive impacts of technology and economic, social, and environmental benefits gained on the long run leading to sustainable use of natural resources, and continuity of technology application and ability of withstand under various conditions.
8.	Social Benefits and Gender equity	Providing positive social impacts including creation of new jobs and work opportunities, encourage gender engagement and equity, and facilitate equitable access for natural resources.

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Table 6:2 Criteria and weight used for technologies prioritization

No.	Criteria	Scale %	Criteria weight %
1.	Cost	(0 – 25) Very high (25 – 45) High (45 – 65 Medium) (65 – 85) Low (85 –100) Very low	10
2.	Economic impact	(85 – 100) Very high (65 – 85) High (45 – 65) Medium (25 – 45) Low (0 – 25) Very low	10
3.	The need for technology	(85 – 100) Very high (65 – 85) High (45 – 65) Medium (25 – 45) Low (0 – 25) Very low	15
4.	Adaptive capacity Enhancement	(85 – 100) Very high (65 – 85) High (45 – 65) Medium (25 – 45) Low (0 – 25) Very low	25
5.	Recovering ecosystems	(85 – 100) Very high (65 – 85) High (45 – 65) Medium (25 – 45) Low (0 – 25) Very low	10
6.	Improve livelihoods	(85 – 100) Very high (65 – 85) High (45 – 65) Medium (25 – 45) Low (0 – 25) Very low	10
7.	Sustainability	(85 – 100) Very high (65 – 85) High (45 – 65) Medium (25 – 45) Low (0 – 25) Very low	10
8.	Social Benifts and Gender equity	(85 – 100) Very high (65 – 85) High (45 – 65) Medium (25 – 45) Low (0 – 25) Very low	10
	TOTAL		100

6.6 Results of Technology Prioritization

Based on the agreed-upon criteria in section 6.5 above, selected technologies in section 6.4 above have been arranged in tabular form in MS excel spread sheet. The scale limits in percentage for each criterion, that were decided in previous step, were elaborated to obtain weights in score point in order to rank the technologies and prioritize them accordingly. On 14th February 2022, Participants went through a prioritization and ranking process for technology options and come up with a top list of ranked technologies. Summary of prioritization and ranking process using the MCA is presented in table 6.2.

[redacted]

Table 6:3 Agriculture Technologies Prioritization

TECHNOLOGY	Cost		Economic impact		The need for technology		Adaptive capacity Enhancement		Recovering ecosystems		Improve livelihoods		Sustainability		Social Benefits and Gender equity		Total Wight	Ranking
	Scale	Weight	Scale	Weight	Scale	Weight	Scale	Weight	Scale	Weight	Scale	Weight	Scale	Weight	Scale	Weight		
	100	10	100	10	100	15	100	25	100	10	100	10	100	10	100	10		
Irrigation saving tech.	100	10	90	9	88	13.2	90	22.5	80	8	85	8.5	75	7.5	85	8.5	87.2	1
Water harvesting and storage technology for agricultural purposes	75	7.5	90	9	85	12.75	85	21.25	80	8	89	8.9	90	9	80	8	84.4	2
Agriculture soil management and conservation	80	8	90	9	83	12.45	75	18.75	90	9	77	7.7	88	8.8	85	8.5	82.2	3
Reuse of treated wastewater and greywater	85	8.5	70	7	83	12.45	75	18.75	76	7.6	70	7	80	8	76	7.6	76.9	4
Agricultural dates (timing)	80	8	85	8.5	70	10.5	80	20	40	4	50	5	50	5	20	2	63	5
Greenhouses	80	8	65	6.5	40	6	70	17.5	50	5	40	4	60	6	30	3	56	6
IPM	70	7	55	5.5	50	7.5	45	11.25	65	6.5	55	5.5	60	6	50	5	54.25	7
Biological control	40	4	90	9	60	9	40	10	40	4	60	6	60	6	30	3	51	8
Management of natural and animal pastures	70	7	60	6	40	6	50	12.5	50	5	30	3	60	6	10	1	46.5	9
Protection and development of bees and honey production	80	8	90	9	50	7.5	30	7.5	10	1	55	5.5	40	4	10	1	43.5	10
Local germplasm development and gene bank	80	8	50	5	55	8.25	30	7.5	20	2	20	2	40	4	20	2	38.75	11
Natural fertilizer (manure)	70	7	40	4	50	7.5	20	5	20	2	50	5	60	6	10	1	37.5	12

As a result of this process and discussion, the top three prioritized and appropriate technologies for the agricultural sector are presented in table (6.3).

Table 6:4 Ranked technologies for the agriculture sector

Technology	Total Score	Ranking
Irrigation saving techniques.	**87.2**	**1**
Water harvesting and storage technology for agricultural purposes	**84.4**	**2**
Agriculture soil management and conservation	**82.2**	**3**
Reuse of treated wastewater and greywater	**76.9**	**4**
Agricultural dates (timing)	63	5
Greenhouses	56	6
Integrated pest management	54.25	7
Biological control	51	8
Management of natural and animal pastures	46.5	9
Protection and development of bees and honey production	43.5	10
Local germplasm development and gene bank	38.75	11
Natural fertilizer (manure)	37.5	12

Similarly, to the water sector, the top four ranked technologies for agriculture sector namely 1) irrigation saving techniques, and 2) water harvesting and storage technology for agricultural purposes, 3) Agriculture soil management and conservation, and 4) Reuse of treated wastewater and greywater that were selected, prioritized, and ranked through a consultation process with relevant stakeholders are considered to be the most appropriate technologies for the sector.

The irrigation-saving techniques application is simple and suitable for different types and sizes of farms, it has a low investment cost, has proven its successfulness to efficiently reduce the amount of water for irrigation and hence conserve water resources, provides point sources of irrigation water which improve crop production, and eventually help farmers to adapt to climate change and negative impacts on agriculture.

Rainwater Harvesting Techniques are important for the agriculture sector to adapt to climate change, examples of its advantages include providing additional source of water for irrigation, storage of rainwater to be used during the dry seasons, improvement of crop production, and subsequently improve adaptive capacity of local communities to the impacts of climate change on agriculture resources.

The agriculture soil management and conservation technology has more advantages for the environment and agriculture sector including improvement ecosystem conservation, conservation of agricultural soil, reduced land degradation, improve livelihoods of farmers families, and enhancement of adaptive capacity of farmers community to climate changes as ecosystem based adaptation.

Reuse of treated wastewater and greywater techniques provide additional source for water that could be used to increase green cover through reforestation and planting of street trees, and creating wastelands. Its cost is relatively low compared to other techniques; However, this technique is more applicable and suitable for urban rather than rural areas since the amount of treated wastewater is more in urban areas.

Chapter 7: Conclusions and Summary

This chapter presents the conclusions of the TNA activities conducted during the first phase of the TNA project aimed at sector and technology selection and prioritization under mitigation and adaptation. The TNA project is crucial for Yemen due to the lack of dedicated and best industry-based studies to assess climate change technology needs for the sectors contributing to GHG emissions and those most vulnerable to the impacts of climate change. There is a vast need for conducting a systematic assessment of the country's needs for efficient and environment-friendly technologies to backstop Yemen's capacities in identifying and deploying the appropriate mitigation and adaptation technologies. Thus, the TNA Project of Yemen, funded by GEF and implemented by UNEP/UNOPS Partnership, and executed by EPA in Yemen, comes at the right time to fill the gap of technology needs identification and complement the integrated approach that Yemen is following to address the impacts of climate change. This is mainly because the Government of Yemen is currently attempting to overcome the repercussions of the civil war to achieve economic recovery that meets the country's development needs.

Relevant national stakeholders from different entities were involved in the consultation process to select priority sectors and to identify and prioritize technology options for mitigation and adaptation. . In the inception workshop held on 6 February 2022, in Aden, all participants for all relevant sectors were gathered in one place to learn the process of technology and criteria identification and prioritization using MCA. While the consultative workshops held from 7 to 14 February 2022, focused on identifying criteria and identifying as well as prioritization of the most appropriate technologies for adaptation and mitigation.

Through this process, sector selection was based on two main criteria, namely the level of GHG emission under mitigation, and the vulnerability assessment for adaptation. The sector selection exercises clearly indicated that the two top mitigation priority sectors are Energy and Transport, and the top two sectors for adaptation are Water and Agriculture.

The technologies were selected based on screening of initial lists prepared by consultants and reviewed and improved by the stakeholders. Moreover, under the guidance of the TNA team, participants selected criteria and provided scale and weight for each. It is also important to note that participants discussed the advantages and disadvantages of each technology option before and after prioritization using sheets developed by the TNA team.

In order to cover the different climatic zones in the country to the extent possible, the TNA team tried to select up to four technology options for each sector. The final list of prioritized technologies is presented in table 7.1.

Table 7:1 The top four ranked technologies for Yemen's mitigation and adaptation TNA

Rank/ TNA sector	Mitigation		Adaptation	
	Energy	Transport	Water	Agriculture
Rank 1	LED Lighting	Bus Rapid Transit (BRT)	Saline water desalination	Irrigation saving techniques.
Rank 2	Off-grid and On-grid PV systems	Improving By-Roads	Rainwater Harvesting Techniques	Water harvesting and storage technology for agricultural purposes
Rank 3	Wind Turbines	Hybrid Vehicles	Diversion facilities and channels	Agriculture soil management and conservation
Rank 4	Solar Water Heating	Fuel-Switching to Gas	Wastewater recycling and reuse	Reuse of treated wastewater and greywater-

For the energy sector, technologies were divided into energy efficiency options and renewable energy resources. Given the current situation of shortage of electric power, LED lighting and solar thermal can reduce energy consumption and increase the number of electricity beneficiaries. While the PV and Wind turbines will be a clean and. renewable comprehensive solution to the electricity scarcity in Yemen.

The selected options for the transport sector vary between infrastructure and new facilities. On the one hand, improvement of the by-roads can reduce the traffic jam on the main streets in Yemeni cities, and, the BRT can reduce the number of vehicles as this option can cover most of the places in each city. The promotion of hybrid vehicles can lead to a reduction in fossil fuel consumption and consequently reduce GHG emissions.

For adaptation, it is clear that water harvesting and the reuse of treated wastewater were joint priority adaptation technologies for both the water and agriculture sectors. This reveals the critical importance of these technologies and indicates, at the same time, the robustness of perceiving a holistic approach for rainwater harvesting at the watershed level (in high land) and the farm level and water recycling for irrigation and agriculture processes. In the lowland areas, saline water desalination is necessary for the people living in coastal areas to reduce their dependency on underground water. The option of preserving agricultural soils is needed as an ecosystem-based adaptation option to enhance the adaptive capacity against the climate change implications on the farming grounds.

Finally, the TNA team believes that the national stakeholders will maintain the same level of effective involvement and enthusiasm bestowed for the coming phase of the project to carry on barrier analysis and enabling framework (BA&EF) to assess obstacles and limitations to maximize and enhance deploying such technologies effectively and systematically to deal with climate change.

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Annexes

Annex 1 The Participants of the Workshop

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32	Zaki Mahood Abdulrazak	Aden Refinery and Oil Company
33	Othman Sad AL-Hoshbi	General Authority for Environmental Protection/Nature Conservation
34	Mohammed Abdulla Hameed	Farmer
35	Wadee Mohammed Abdulrakeeb	Unity Cement Company
36	Adel Saleh Atef	Unity Cement Company

37	Ismali Yaeen	Pure life treatment of Water Problem Company
38	Hani Ali	Pure life treatment of Water Problem Company
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Annex 2 Prioritized Energy Sector Mitigation Technologies Fact Sheets

(1) Combined Heat and Power Technology (CHP)

Sector	Energy
Technology	Combined Heat and Power Technology (CHP)
Technology characteristics	
Introduction	CHP is a technology that produces electricity and thermal energy at high efficiencies using a range of technologies and fuels. With on-site power production, losses are minimized and heat that would otherwise be wasted is applied to facility loads in the form of process heating. For electricity generation, gas turbines are available in a wide range of capacities and configurations
Technology Characteristics	Large turbines are available for power generation. For CHP applications, gas turbines typically have favorable economics in sizes greater than 5 MW. Gas turbines are well suited for industrial and institutional CHP applications because the high temperature gas turbine exhaust can either be used to generate high pressure steam or used directly for heating or drying. Gas turbines are widely used in CHP applications.
Country Specific Applicability and Potential	Natural gas is available in large quantities in Yemen. This encourages the use of this technology.
Capacity	Capacity of power developed by gas turbines power plant in Yemen is around 300 MW.
Acceptability to local stakeholders	The technology is acceptable to stakeholders.
Scale of Applicability	Can be used for large industrial applications and gas turbine power plants.
Time of Horizon	Long term technology
Status of Technology in Country	This technology is not used widely in Yemen
Availability of technology	This technology is used in the power plant and heaters of cement factories available in Yemen. However, the cement power plants depend on diesel and coal as a fuel.
Climate change mitigation	CHP gas turbines have relatively low GHG emissions. The CO_2generated by burning natural gas is 0.185kg/kWh (DEFRA 2007 Guidelines to Defra's GHG conversion factors for company reporting) while it is 0.245kg/kWh by burning oil fuel(DEFRA 2007 Act on CO_2 Calculator: Public Trial Version Data, Methodology and Assumptions Paper)
Benefits to economic / social and environmental development	Economic benefits: Gas turbines are reliable; provide good economic performance in base load applications where the system operates at, or near, full load. It saves many lost powers by recycling and hence saving expenditure. Social benefits: Creating new job opportunities and Gender equity. Environmental benefits: Getting use of heat lost to the optimum range will contribute to environmental development.
Capital, operating costs	They have relatively low installed costs. The cost ranges from $ 1,250 - $ 3,300/kW. The O & M Cost is around $ 0.0111 /kWh.

(2) Off-grid and On-grid photovoltaic systems

Sector	Energy
Technology	Off-grid and On-grid photovoltaic systems
Technology characteristics	
Introduction	Photovoltaic (PV) cells convert sunlight directly into electricity without causing air or water pollution. Silicon is currently the most common material in PV cells. Cadmium telluride and copper indium (gallium) di-selenide Cells are also available. Each material has its own characteristics that determine the cell performance, manufacturing method and cost. In general PV cells can be classified as: Crystalline Silicon (c-Si): Modules are made from cells of either mono-crystalline or multi-crystalline silicon. Mono-crystalline silicon cells are generally more efficient, but are also more costly than multi-crystalline. Thin Film-Modules are made

	with a thin film deposition of a semiconductor onto a substrate. This class includes semiconductors made from: Amorphous silicon (a-Si), Cadmium telluride (CdTe), Copper indium selenide (CIS), Copper indium (gallium) di-selenide (CIGS).
Technology Characteristics	PV System is a technology that directly converts solar energy (sun light) into electricity. The output of a PV system mainly depends on the sunlight impinging the PV modules or panels. Consequently, modules have to be kept clean and unshaded. Another important factor is the PV module temperature. The higher the temperature the lower the output. Off-grid PV systems are usually used in areas without interconnection to the public grid. Consequently, they either use some kind of storage technology or an additional backup source to provide electricity when needed or they supply loads/consumers that don't require a permanent output like a water pump with a reservoir. Grid-connected PV systems use an inverter to convert electricity from direct current to alternating current and the generated electricity is then supplied through the distribution network to consumers. This kind of system does not require energy storage since the grid is used as a buffer.
Country Specific Applicability and Potential	Yemen is rich in solar energy. This richness is because of its location in the solar belt between the Tropic of Cancer and Equator. It is endowed with high solar radiation ranging in average from (5.21-7.23) kWh/m2 a day and an annual average daily sunshine ranging from 7.3 to 9.1 hours per day.
Capacity	Capacity depends on the number of panels. In some neighboring countries, several hundred MWs are already exists.
Acceptability to local stakeholders	The technology is accepted and easily acceptable to stakeholders and users.
Scale of Applicability	PV is a modular technology that can be installed from as low as few hundred watts to GWs. So it can serve small houses and large buildings to commercial power plants.
Time of Horizon	Long term
Status of Technology in Country	The technology is well known and mature in the country. Although there is no large number of solar energy projects, people use it widely both in urban and rural areas.
Availability of technology	This technology is available in all governorates of Yemen.
Climate change mitigation	Solar PV systems have significant direct GHG mitigation potential by displacing fossil fuel-based electricity generation plants and reducing the amount of carbon emissions produced through fuel consumption in the sector.
Benefits to economic / social and environmental development	Economic benefits: It is renewable; it saves expenditure of fuel, provides financial return to the country and contributes to economic growth. Social benefits: Creating new job opportunities in different fields including installation and consultation. Gender equity. Potential improvement in health and livelihood of peoples not served by the national grid. Energy security through diversified energy sources for electricity production. Environmental benefits: Solar PV systems are considered environmentally benign; no noise or vibration from the operation. No GHG emission.
Capital, operating costs	Capital cost ranges from 2000 to 4000 USD/kW. The operating and maintenance costs of PV electricity generation systems were found to be low and in the range of 0.5 and 1.5% annually of the capital investment costs

(3) Wind Turbine

Sector	Energy
Technology	**Wind Turbine**
Technology characteristics	
Introduction	Modern wind turbines extract energy from the wind transforming mechanical energy of rotation into electricity. Wind turbines come in different sizes and configurations. As trend to towards carbon-free renewable technologies pick up pace, integration of power production from large numbers of wind turbines is becoming an attractive option for

	policy-makers and investors. Large numbers of wind turbines operating in an integrated mode are sited in areas commonly referred to as wind farms
Technology characteristics	Under the Yemeni Ministry of Electricity’s Renewable Energy Strategy and Action Plan, renewable energy sources were studied, including wind. In that respect, a wind resource map was developed based on data from the Civil Aviation and Meteorological Service, the Global Upper Air Climatic Atlas and an ongoing wind measurement campaign. Based on the wind resource map, the technical potential for wind power at technically attractive sites in Yemen (i.e., where more than 3000 full load hours (FLH) could be generated or with a more than 35% capacity factor) could generate 14,214MW. And economically attractive sights in Yemen (i.e., where more than 3500 FLH could be generated or with a more than 40% CF) could generate about 2,507 MW, which is about 8,293 GWH of electricity per year. The total wind power potential is estimated to be 34GW47. The technical potential was estimated at 14,200MW providing about 42,300 GWH of electricity per year. (Prof. Dr. Towfick Sufian Energy Charter Secretariat Knowledge Centre 2019)
Country Specific Applicability and Potential	Yemen has a long coastal strip of over than 2000 km long and an average width of 45 km along the Red Sea, and the Arabian Sea. These coastal areas have an annual wind speed average of more than 8 m/s. There is a good potential for making wind farms on the coastal strip as well as on the offshore areas, in addition to the vast deserts and mountain ranges.
Capacity	Recently, 1a 16 MW wind turbine is already manufactured in China. Its diameter is 242 meters long and its height is more than 200 m.
Acceptability to local stakeholders	The technology is acceptable to stakeholders and users specially in remote coastal area
Scale of Applicability	Wind turbines are available in wide range, from few kWs up to 16 MWs
Time of Horizon	Long term. Sustainable energy
Status of Technology in Country	According to the restless situation in Yemen some projects related to this technology are suspended
Availability of technology	The technology is not available in Yemen so far.
Climate change mitigation	It uses no fuel so it produces zero GHG and it is considered as one of the best future energy sources.
Benefits to economic / social and environmental development	Economic benefits: It is a renewable energy. One of lowest priced renewable energy technologies. Social benefits: Creating new job opportunities. Potential improvement in health and livelihood of peoples not served by the national grid. Energy security through diversified energy sources. Environmental benefits: No GHG emission.
Capital, operating costs	It is estimated that the cost is between $ 2000-5000/kW for an onshore turbine (100MW) with corresponding fixed operation and maintenance costs of around $ 40/kW

(4) Landfill Gas

Sector	Energy
Technology	Landfill Gas
Technology characteristics	
Introduction	The utilization of LFG for power generation, or processing to natural gas, or fuel for boilers and furnaces are considered as a renewable energy source which can compensate for the shortage of fossil-fuel-based energy generation. However, the feasibility of LFG utilization technologies depends on the economic viability, site conditions and end-use markets. Power generation from LFG and processing of LFG to pipe-line-quality natural gas as fuel has become more common in recent years. The beneficial use of LFG is highly dependent on the quantity, quality and efficiency of the LFG collection system
Technology Characteristics	Solid waste is buried in landfills and kept for about ten years before extracting methane gas. LFG is 40 - 60% methane (CH_4) with the remainder being primarily carbon dioxide (CO_2), nitrogen, water and a mix of other gases. There are many different technologies being used to

	convert landfill gas to energy. The major technologies in use and currently proposed include boilers, reciprocating engines, gas turbines, and steam turbines. Electricity is already generated on-site using reciprocating engines, steam turbines, or gas turbines. To use LFG in reciprocating engines and gas turbines, condensate and particulate smatter must be removed. To move fuel gas into a gas turbine combustion chamber, the gas must have lost most the visible moisture and then compressed.
Country Specific Applicability and Potential	There are about 36 landfills spread throughout the country. None of them has been utilized to produce energy.
Capacity	It depends upon the quantity of waste and the dimension of the landfill. 50 MW power plants are available in USA.
Acceptability to local stakeholders	There is no investment in this area yet.
Scale of Applicability	The average capacity of the landfill-gas to energy projects in some countries is approximately 4 MW.
Time of Horizon	It is long term technology
Status of Technology in Country	Currently, there is no deployment of landfill gas collection and utilization technology in Yemen.
Availability of technology	So far, this technology is not available. However, it can be available if a political and economic decision is taken.
Climate change mitigation	Considerable amount of methane is utilized instead of polluting the atmosphere. So low GHG emission, taking into consideration the leakage of methane should be in the safe range. So low GHG emission (1kg of methane is equivalent to 25kg of CO_2)
Benefits to economic / social and environmental development	Economic benefits: It is renewable; it saves expenditure of fuel, provides financial return to the country and contributes to economic growth.
Capital, operating costs	Social benefits: Creating new job opportunities and Gender equity.

(5) **Hydropower**

Sector	**Energy**
Technology	Hydropower
	Technology characteristics
Introduction	Worldwide, hydropower is one of the largest source of renewable energy in the electricity generating sector. A hydroelectric power plant uses a renewable source of energy that does not pollute the environment. It converts the kinetic energy contained in the flowing water into electricity. Hydroelectric power accounts for 6% of the worldwide energy supply and 15% of the world's electricity.

Technology Characteristics	Electrical energy from hydropower is derived from turbines being driven by flowing water in rivers, with or without man-made dams forming reservoirs. Presently, hydropower is the world's largest source of renewable electricity. Hydropower represents the largest share of renewable electricity production. It was second only to wind power for new-built capacities between 2005 and 2010. IEA estimates that hydropower could produce up to 6,000 terawatt-hours in 2050, roughly twice as much as today.
Country Specific Applicability and Potential	There are many valleys and waterfalls in Yemen in addition to Mareb dam, the water is running throughout the year in some of these valleys (5 of them consist of considerable amount of water) where these advantages can be exploited to establish hydropower stations.
Capacity	As known, Pelton turbine is used for low flow high head, Francis's turbine (used specially in dams) for medium head and medium flow while Kaplan turbine for high flow and low head. The capacity range is between tens of megawatts to hundreds of megawatts
Acceptability to local stakeholders	It is far from the thinking of stakeholders. (Some stakeholders may accept the use of the technology as they perceive it to be beneficial and can create opportunities.)
Scale of Applicability	During to the recent circumstances, the scale is low nowadays.
Time of Horizon	Sustainable long term technology.
Status of Technology in Country	Some studies for different locations are available but this technology needs economic and political decisions.
Availability of technology	Not available in Yemen
Climate change mitigation	No GHG emission and global warming.
Benefits to economic / social and environmental development	Economic benefits: Hydropower is being typically a price-competitive technology. Social benefits: new job opportunity Environmental benefits include pollution control and reduction of carbon emissions.
Capital, operating costs	This renewable energy source is cost-effective, reliable and matured. The initial cost is high, around USD4000/kW

(6) Solar water heater

Sector	Energy
Technology	Solar water heater
Technology characteristics	
Introduction	Solar water heaters of 100-300 liters' capacity are suited for domestic use. Water is easily heated to a temperature of 60-80oC. Larger systems can be used in commercial buildings, offices, greenhouses, heating for commercial purposes such as dairies, swimming pools, industrial process heating (temperature up to 250°C), solar cooking, desalination, hospitals, etc.
Technology Characteristics	Solar water heating is the conversion of sun radiation into renewable energy for water heating using a solar thermal collector. Solar water heating collectors

	capture the heat from the sun and transfer this heat to the water. Solar water heating systems have two major components: a solar collector and a storage tank. The solar collector, usually a thin, black plate, is mounted on a building's roof. Water runs through small tubes under this plate and gets heated by the sun. The hot water then flows into a well-insulated storage tank.
Country Specific Applicability and Potential	Yemen is rich in solar energy. This richness is because of its location in the solar belt between the Tropic of Cancer and the Equator. It is endowed with high solar radiation ranging in average from (5.21-7.23) kWh/m^2 a day and an annual average daily sunshine ranging from 7.3 to 9.1 hours per day.
Capacity	The use of a solar water heater of 100 liters capacity can save approximately 1 kW.
Acceptability to local stakeholders	The technology is accepted and easily acceptable to stakeholders and users.
Scale of Applicability	Solar water heaters are used for domestic, commercial and industrial projects
Time of Horizon	20 years
Status of Technology in Country	Most hotels and buildings in cold cities (very cold in winter) use this technology
Availability of technology	Solar water heaters are mature and readily available in the country.
Climate change mitigation	Use of solar heaters, do not emit GHGs. A solar water heater of 100 liters capacity can prevent emission of 1.5 tons of carbon dioxide per year produced if diesel engine is used.
Benefits to economic / social and environmental development	Economic benefits: It is a bill savings renewable energy. Low maintenance. Energy efficient than an electric water heater in many ways. Social benefits: Creating new job opportunities in this field. Potential improvement in health and livelihood of peoples not served by the national grid. Energy security through diversified energy sources. Environmental benefits: Solar heater systems are environmentally benign; no noise or vibration from the operation. No GHG emission.
Capital, operating costs	In Yemen the cost is approximately $ 300 to $ 400.

(7) Tidal Stream Generator

Sector	Energy
Technology	Tidal Stream Generator
Technology characteristics	
Introduction	Tidal streams are water currents associated with the periodic piling up and ebb of water masses in oceans, coastal seas and estuaries driven by gravitational interaction between the Earth and the Moon. Tidal streams are thus characterized by continuous changes in speed and direction, and are usually stronger nearer to the coast. Historically, the global oil crisis in the 1970s and global environmental and energy policies in subsequent decades are two of the key driving forces behind invigorated interest in tidal energy resources, whose viability was first demonstrated by the commissioning of the Rance tidal power station in 1966
Technology Characteristics	Tidal current energy converters capture the kinetic energy of the tidal streams by driving a generator that converts the energy into electricity. The Resource Potential Tidal stream energy is as of yet a largely untapped resource with no commercial size application, although some are very close. Essentially, tidal stream power generation is a no barrage approach to power generation that uses axial turbines, oscillating hydrofoils, Archimedes screws, and Venturi devices to extract energy from the mass of moving water. Axial turbines, the most commonly deployed tidal stream generators (TSGs) technology harvest kinetic energy of water mass in much the same way as a wind turbine does from wind streams. Prototype and commercial TSG installations can be found in the UK, Norway and US.
Country Specific Applicability and Potential	There are many islands in the Red Sea belonging to Yemen, in addition to the Bab al-Mandab Strait, where these advantages can be exploited to establish hydropower stations. As with wind power, selection of location is critical for the tidal turbine. Tidal stream systems need to be located in areas with fast currents where natural flows are concentrated between

	obstructions, for example at the entrances to bays and rivers, around rocky points, headlands, or between islands or other land masses.
Capacity	Tidal Power Station in South Korea has electricity generation capacity of 254 megawatts (MW).
Acceptability to local stakeholders	Not so acceptable.
Scale of Applicability	Non-market technology.
Time of Horizon	Long term.
Status of Technology in Country	Not available in Yemen
Availability of technology	Not available.
Climate change mitigation	No GHG emission.
Benefits to economic / social and environmental development	Economic Benefits: can contribute to economic growth. Save fuel expenses Social Benefits: opportunities for new employments Environmental Benefits: Little environmental impact
Capital, operating costs	As with most renewable energy technologies, location-specific energy density of the energy resources has a big impact on unit costs of energy production. In the UK, reputed to have some of the world's most promising tidal stream sites, capital cost of electricity generation from TSG deployment is estimated to lie between GBP1429/kW and GBP1,736/kW. Elsewhere in the US, capital cost is estimated at $5,880/kW, with corresponding fixed operation and maintenance (O&M) cost of $198/kW

(8) Geothermal Power Plants

Sector	Energy
Technology	Geothermal Power Plants
Technology characteristics	
Introduction	Geothermal energy is thermal energy (heat) generated and stored in the earth. Whenever hot matter comes close to the surface less than 4,000 m – it can be used to produce steam, which generates electricity using turbines. In order to produce steam, wells have to be drilled to reach the resource. These drillings are large infrastructure developments that require access roads and water supply to the drilling site. Due to its complexity a geothermal development takes several years to be executed. Once operational, a geothermal power plant is able to deliver base load energy, meaning that it produces electricity on a continuous basis. Yemen is located close to three of the world's most active tectonic boundaries (Red Sea, Gulf of Aden, and East African Rift). In a triple junction, these three tectonic plates meet and create a significant geothermal gradient, producing geothermal energy of approximately 28.5 GW.
Technology Characteristics	As Yemen is located near three tectonic boundaries which generate high geothermal gradients, the region has geothermal energy potential. The geothermal springs and gas vents are grouped according to their elevation, and geothermal resources are classified according to the degree of enthalpy resources. Studies have identified fields with high geothermal potential that are suited for power generation and exploitation, particularly the area of Dhamar, which is in the proximity of the national transmission network and is estimated to have technical potential of between 125 and 250MW (Prof. Dr. Towfick Sufian Energy Charter Secretariat Knowledge Centre 2019) Small Hydropower Energy Resource
Country Specific Applicability and Potential	Yemen has several areas marked by volcanic character and also more than seven areas with natural hot water springs. In sum, this situation demonstrates the potential of geothermal energy.

Capacity	A typical geothermal power plant has a power output around 30-50 MW
Acceptability to local stakeholders	Not so acceptable (the stakeholders did not choose to invest in this technology in Yemen according to recent events)
Scale of Applicability	High scale.
Time of Horizon	Sustainable long-term technology.
Status of Technology in Country	So far there is no experience with geothermal power production in Yemen.
Availability of technology	It is not available yet.
Climate change mitigation	Significantly reducing the emission of GHG and the environmental damage associated with nonrenewable resource extraction.
Benefits to economic / social and environmental development	Economic benefits: It is renewable; it saves expenditure of fuel, provides financial return to the country and contributes to economic growth. Social benefits: Job opportunities for technically skilled people in the field of operation and maintenance Environmental benefits: geothermal systems eliminate the combustion of fossil fuels on site.
Capital, operating costs	This renewable energy source is cost-effective, reliable and matured. The initial cost is high, around $ 4000/kW

(9) Hydrogen Turbine

Sector	Energy
Technology	Hydrogen Turbine
Technology characteristics	
Introduction	Hydrogen can be generated from a variety of feedstock's and chemical processes. Photosynthesis with algae, natural gas steam methane reforming (SMR), partial oxidation of crude oil, coal gasification, and water electrolysis are only a few examples. The following sections will go over steam methane reforming and electrolysis as possible hydrogen-generation pathways for energy production.
Technology Characteristics	Modern gas turbines are capable of operating on a wide range of hydrogen concentrations. Thus, gas turbines operating on hydrogen could provide the needed grid firming. Hydrogen has the highest calorific value so it can be considered as the best fuel but it is highly inflammable. A significant amount of carbon-free electricity would be needed to support the idea of producing hydrogen with electrolysis using renewable power (also known as the power to hydrogen). The great news is that the global push for carbon-free energy has resulted in an unparalleled increase in renewable energy output
Country Specific Applicability and Potential	No infrastructure for producing Hydrogen.
Capacity	One kg of hydrogen can produce 33.6 kWh. Hydrogen turbine of 41 MW is already available.
Acceptability to local stakeholders	Not so acceptable
Scale of Applicability	Not available
Time of Horizon	Long term
Status of Technology in Country	According to current situation this technology is difficult to be used in Yemen in the nearly future.
Availability of technology	Not available
Climate change mitigation	It produces low amount of GHG emission and global warming as turbine not the Hydrogen Production. But at high temperatures NOx may be produced which contribute in the destruction of Ozone layer.

Benefits to economic / social and environmental development	Economic Benefits: Gas Turbines using hydrogen as a fuel will be able to meet the market's needs in future. Social Benefits: Job opportunities for technically skilled people in the field of operation and maintenance Environmental Benefits: without compromising today's high-performance standards in terms of emissions, response, and productivity.
Capital, operating costs	It costs around $1,320/kW

(10) Combined Cycle Gas Turbines (CCGT)

Sector	Energy
Technology	Combined Cycle Gas Turbines (CCGT)
Technology characteristics	
Introduction	The principle is that the exhaust of one heat engine is used as the heat source for another, thus extracting more useful energy from the heat, increasing the system's overall efficiency.
Technology Characteristics	A well-established technology. Larger units, have peak, steady state efficiencies of 55 - 59%. Operating such plants need experienced and expert people from different engineering fields.
Country Specific Applicability and Potential	In Yemen there is no CCGT so far. Gas is abundant in Yemen.
Capacity	Capacity of power developed by Gas turbines power plant in Yemen is around 300 MW.
Acceptability to local stakeholders	The technology is acceptable to stakeholders.
Scale of Applicability	Large scale
Time of Horizon	Long term technology.
Status of Technology in Country	This technology is not use in Yemen
Availability of technology	Not available
Climate change mitigation	Gas turbines have relatively low GHG emissions compared to Diesel engine power plants using oil fuel (CO2emissions are 0.185 kg/kwh for using natural gas and 0.245kg/kWh when oil fuel is used)
Benefits to economic / social and environmental development	Economic Benefits: Gas turbines are reliable; provide good economic performance in base load applications where the system operates at, or near, full load. It saves many lost MW by recycling and hence saving expenditure. It utilizes natural gas available in the country. Social Benefits: It is worth noting that a CCGT requires between 200 and 250 employs. Environmental Benefits: CCGT has less impacts on climate change as compared with diesel and mazut.
Capital, operating costs	The cost varies between $800 to $1200/ kW. Operation cost is around $8.5/kWh

(11) Biogas

Sector	Energy
Technology	Biogas
Technology characteristics	
Introduction	Biogas is the product of an anaerobic process that breaks down biodegradable matter. Various types of microorganisms are involved in the process that finally produces biogas, a mixture of methane and carbon dioxide.
Technology Characteristics	Methane is the main ingredient of natural gas. The methane when oxidized (burned with air) releases thermal energy that can be used for heating and cooking or when burned in a gas engine can produce electricity or propel vehicles. Biogas can be compressed for storage and transportation and it can be purified to increase the

	methane content to achieve natural gas quality. However, this only makes sense on a large scale as the process is energy intensive.
Country Specific Applicability and Potential	The biomass potential for power generation in Yemen is limited. There is insignificant potential from the residues of crops and forestry. The most potential is identified in animal wastes and municipal solid waste. A study of biogas generated from animal wastes in family and large-scale farms was conducted and it was found that the animal waste from an average family farm would not generate sufficient biogas to power both cooking and lighting. Large-scale farms however, could generate sufficient biogas for electrical power generation. As for biogas from municipal wastewater, it was found that sewage sludge from all wastewater treatment plants in Aden (i.e. one of the main sludge production centers) would be on the low side for power generation but significant for heating and cooking purposes
Capacity	Installed capacity of biogas energy worldwide reached some 21.4 giga watts in 2021. Each cubic meter of biogas contains the equivalent of 6 kWh of heat energy.
Acceptability to local stakeholders	Not so acceptable(the stakeholders did not react to invest in this field although it is promising)
Scale of Applicability	Small scale
Time of Horizon	Sustainable long term technology.
Status of Technology in Country	Today some small-scale systems for personal use are in operation in the rural areas used for cooking purposes.
Availability of technology	It is available in rural areas
Climate change mitigation	Reduction in GHG emission.
Benefits to economic / social and environmental development	Economic Benefits: saving of fuel expenditures. Social Benefits: significant for heating, lighting and cooking purposes. Environmental Benefits: Reduces pollution in waterways because organic waste is better managed by the biogas system and the recommended fertilizer management system.
Capital, operating costs	Around $ 2000/kW

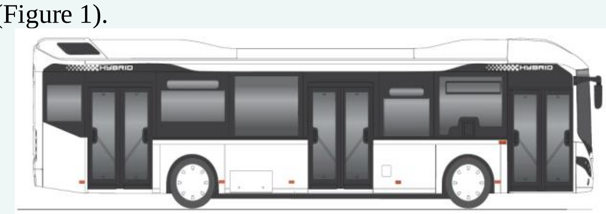
(12) LED lights

Sector	Energy
Technology	LED lights
Technology characteristics	
Introduction	Light Emitting Diodes (LED) are semiconductors that transform electricity to light in a very efficient manner. Invented in 1962, it took LEDs more than forty years to advance from a niche application to a mainstream light source. Due to their superior efficiency, their longevity, their low environmental concerns, their variability in regard to size (accumulation of diodes), color, and intensity, LEDs have become the fastest growing lighting technology. In 2017 approx. 12 % of all lights installed globally and more than 25 % of newly sold lights have been LEDs. This makes LEDs the only technology with increasing sales numbers while sales of all other technologies are either stagnating or decreasing.
Technology Characteristics	In addition to the undisputed efficiency of LEDs, longevity is often an issue. Depending on the quality of the semiconductor material, the assembly, the environmental conditions (temperature and humidity) as well as the quality of electric supply, LEDs can last up to 100,000 hours of operation. In contrast, incandescent light bulbs usually only last 1,000 hours. Even cheap semiconductors should allow for a lifetime of 10,000 to 15,000 hours of operation. Lifetime in this case means that the devices still emit 50 % of their nominal value. Completely failing devices on the other hand are an indication of either deficient assembly or serious issues with the quality of electricity. This said, customers should be informed and look for certifications and manufacturer guarantees.
Country Specific Applicability and Potential	Given the undisputed advantages of LED lighting devices, this technology has the potential to cover 100 % of the market. However, attributing a number of lighting devices

	to those 100 % is difficult without knowledge of existing units of any technology in the country.
Capacity	Depending on the bulb and the manufacturer, LED technology typically produces 75-110 lumens/watt.
Acceptability to local stakeholders	Most of stakeholders accept the use of this technology as they perceive it to be beneficial and can create opportunities.
Scale of Applicability	High scale
Time of Horizon	long term technology.
Status of Technology in Country	LEDs are available and used in Yemen. Exact numbers are not known.
Availability of technology	It is available and wide spreading nowadays.
Climate change mitigation	No GHG emission if it is powered by renewable energy. Low consumption of energy by using LED leads to reduction of GHG in case of power plants supplied by NG or HFO.
Benefits to economic / social and environmental development	Economic benefits: It is energy efficient. Could lead to the establishment of LED factories. High lifetime. Social benefits: May create new job opportunities. Environmental benefits: Low environmental concerns
Cost	Around \$0.5/W.

Annex 3 Prioritized Transport Sector Mitigation Technologies Fact Sheets

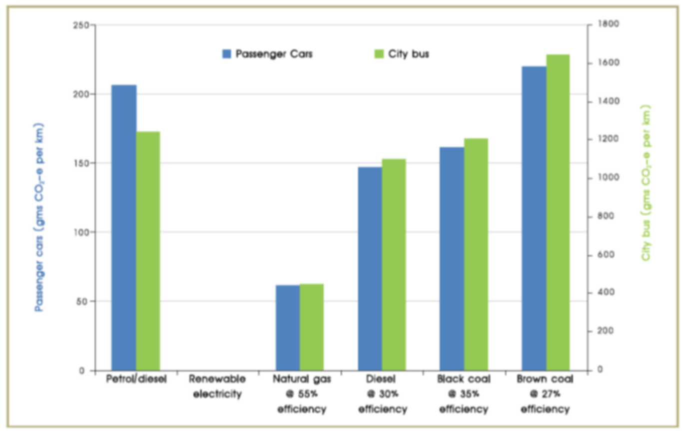
(1) Bus Rapid Transit (BRT)

Sector	Transport
Technology	Bus Rapid Transit (BRT)
Technology characteristics	
Introduction	Though diesel buses are still the most used bus technology worldwide, several bus technologies have made a breakthrough in public transport services, relying on different sort of fuels other than diesel. Among them alternative fuel buses operating on CNG, LNG and LPG, and electric driven buses. In this document, 12-meter buses are assessed, using diesel, gasoline, alternative fuels and electricity (Figure 1).  Bus public transport is a real medium to short-term solution to today's environmental and noise pollution issues, particularly when bus technologies are coupled to a well-designed Transport Demand Management (TDM) system: particularly, the Bus Rapid Transit (BRT) system
Technology characteristic	BRT system is a high-capacity transport system with dedicated lanes for bus transit. It consists of a systematic combination of infrastructure (bus ways, stations, terminals) with organized operations and intelligent technologies to provide a higher quality experience than possible with traditional bus operation. Main services enhancements are increasing the average velocity and ensuring matching the scheduled timetables. BRT systems can make an important contribution to a sustainable urban transport system, particularly if combined to clean bus technologies. It is more energy efficient than passenger cars and conventional buses (per person-kilometer), due to the higher speeds and higher capacity buses. Thereby they contribute in all the aspects of sustainable development
Country specific applicability and Potential	This technology option can be applied widely in various cities in Yemen, because simply it will save money for the travelers, and beside they can reach their destinations much quicker. The private sector can participate in the investment in such technology option which would be welcomed by the public, hence, it has a great potential of covering most of the cities in Yemen.
Capacity	At the present time, the capacity is nil. But, in the future it could increase gradually with time.
Scale of application	On a wide scale, it may cover most of the populated cities in Yemen.
Time horizon- Short / Medium /long term	Public transport bus technologies implementation could start immediately. However, BRT system need an adequate planning and could be implemented on the short to medium-terms
Status of technology in country	Unfortunately, BRT does not exist in Yemen at the present time. There was a public bus transport in the 1970s, owned by the government in Aden, which was later abolished.
Availability of technology	Not available at the moment
Climate change mitigation/ adaptation benefits	BRT system will reduce the congestions in the cities, and thus limiting the GHG emissionsby limiting the number of small vehicles used for transport to various destinations by passengers less than 4 individuals. Hence, the BRT system which carry up to 50 passengers will greatly reduce the GHG emissions, which makes it a climate change mitigation benefit.
Benefits to economic / social and	❖ · Reduction of air pollution ❖ · Reduction of GHG emissions ❖ · Congestion reduction ❖ · Increase in energy supply security, due to reduction of imported oil ❖ ·

environmental development	Social equality and poverty reduction by providing affordable high-quality transport with lower operating costs than passenger cars per passenger-kilometer ❖ · Economic prosperity by reducing travel times and congestion
Financial Requirements and Costs	Cost benefits Bus technologies present clear cost savings per passenger-kilometer comparing to passenger cars, these savings, by comparing to the average fuel cost of the car fleet with 1 and 4 passengers/vehicle. · In average occupancy (15 passengers/vehicle), Diesel and CNG buses present cost savings around 75-80 % independently from the fuel price difference. · These savings could reach 88 % with 30 passengers/vehicle, estimated for rush hours. · As for passenger cars, savings could be considered only when the car is shared by 4 passengers
Capital, operating costs	The cost of a fleet of buses consisting of say 24 buses, 75 k US$/per bus, could cost 1.8 million US$. The operating and maintenance costs can be 15% and 8% of the capital costs respectively.

(2) Electric Vehicle (EV)

Sector	Transport
Technology	Electric Vehicle (EV)
Technology characteristics	
Introduction	An electric vehicle (EV) uses one or more electric motors for propulsion, powered by electricity generated off-board the vehicle. Electric vehicles can include electric bicycles, electric motorcycles and scooters, electric cars, electric trucks, electric buses, electric trams and trains, and even electric boats and airplanes. However, this section focuses predominantly on private electric road vehicles (two, three and four-wheelers). On the other hand, we have a plug in hybrid electric vehicle (PHEV) which is a hybrid electric vehicle with the ability to recharge its energy storage with electricity from an off-board power source such as a grid. (Pesaran et.al, 2009) The PHEV can run either on its Internal Combustion Engine (ICE) or on its battery. Increased concern over the environmental impact of petroleum-based transportation, along with the looming economic impacts of peak oil, has led to a significant boom in the development of electric vehicles
Technology characteristics	▪ they can be recharged with electricity produced from local sources ▪ -they potentially offer very low running costs in terms of energy use and maintenance ▪ -they produce no direct tailpipe emissions during operation, offering significant air quality benefits ▪ they are more easily manufactured locally ▪ -they offer a truly carbon-neutral transport solution when recharged from renewable sources
Capacity	NA
Scale of application	Can have wide scale of application if the followings are met : vehicle affordability, range and recharging infrastructure
Time horizon- Short / Medium /long term	NA
Status of technology in country	There is no existing technology for the manufacturing of any type of vehicles, this including E.V. All types of vehicles are imported, which can empower the ministry of trade to impose its restrictions to the imported diesel/petrol-fueled vehicles, and encourage the imports of gas-fueled, electric and Hybrid vehicles, by giving tax and custom incentives.
Availability of technology	Not available
Climate change mitigation/adaptation benefits	Reduction of vulnerability to climate change/reduced emissions,

	The greenhouse gas reduction potential of electric vehicles depends on the source of electricity for charging, below chart shows the CO2 (e) Produced per km for both cars and buses depending on source of energy used to generate the electricity for charging the EV. **Figure 3.43 Relative greenhouse gas emissions for petroleum vs. electric vehicles**[17] 
Benefits to economic / social and environmental development	Energy Resilience: Electric vehicles differ from petroleum-powered vehicles in that the electricity they consume can be generated from a wide range of sources, including fossil fuels, nuclear power, and renewable sources such as solar, wind or biomass, or any combination of these, and most countries have such a combination Energy efficiency: The electricity for an electric vehicle is typically stored onboard the vehicle using a battery, flywheel, or super capacitor with very high energy efficiency Low operating costs: While the purchase cost of electric vehicles must be addressed if they are to be broadly available across income groups, they are very economical to run. Employment opportunities: The possibility of local production of electric vehicles, as well as local retrofitting, creates opportunities for local employment, and this can have a multiplier effect and create further employment in the communities concerned. Reduced effects of pollution: Electric vehicles generate no local pollution and are very quiet, both of which lead to major benefits for the health and wellbeing of urban populations Less pollution: Electric vehicles emit no direct tailpipe CO2 or other toxic air pollutants (such as carbon monoxide or particulates) during their operation. Pollution may be produced from the electric power generation used to recharge the vehicles, but it is typically easier to build pollution control systems into centralized power stations rather than retrofit enormous numbers of cars. Carbon neutral transport: Electric vehicles can be recharged with renewable electricity, thus enabling their operations to be truly carbon-neutral
Financial Requirements and Costs	As a general rule, electric vehicles cost approximately 2-3 times as much as an equivalent combustion vehicle. For example, the electric Nissan Leaf currently sells in America for US$ 32,780 compared to the equivalent Nissan Sentra SL that costs only US$ 18,850.
Capital, operating costs	Beside the cost of the E.V., there is the cost of charging, and replacing a new battery

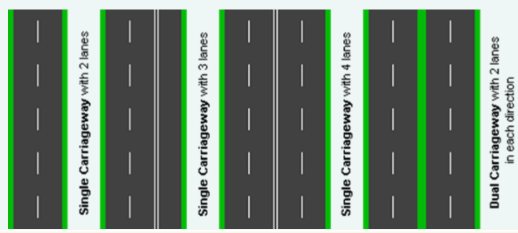
(3) Hybrid Electric Vehicles

Sector	Transport
Technology	Hybrid Electric Vehicles
Technology characteristics	

Introduction	One approach to lowering the CO2 emission from traffic is the hybridization of vehicles. A hybrid vehicle uses two or more distinct power sources, i.e. hybrid electric vehicles (HEVs) combine an internal combustion engine and one or more electric motors. Vehicles employed in urban areas like small passenger cars, local delivery trucks and city busses benefit from hybridization and show substantially lower CO2 emissions, ranging from 23 to 43% depending on the traffic dynamics. For passenger cars there are various levels of hybridization possible all giving rise to various amount of CO2 emission reductions at different costs. Small passenger cars benefit the most from strong downsizing in combination with micro hybridization. Cars running most of their kilometers on motorways do not benefit from hybridization mostly because on motorways vehicles drive at more or less constant speeds. Hybrid vehicles are still more expensive than traditional vehicles using an internal combustion engine. They have the advantage of higher fuel efficiency and reduced CO2 emissions without additional infrastructure requirements. Currently there are four different levels of hybridization available in vehicles (Larsen, 2004):)1(Micro hybrids do not use electric motors to propel the vehicle; (2) Mild hybrids have electric motors which are used to propel the vehicle but cannot drive solely electrically; (3) Full hybrid cars are parallel hybrids which can be propelled fully electric at low speeds and use the internal combustion engine at higher speeds or when the electric energy stored in the car battery is low; (4) Series hybrid cars are full electric vehicles which use the internal combustion engine as a generator to produce electricity.
Technology characteristics	Hybrid electric vehicles (cars, buses, local delivery vans) are most feasible for use in urban traffic, where there is a frequent need for breaking. Regenerative braking and electric motors of a hybrid car moving at a speed of 30-40 km/h lower CO_2 emissions by 33-40% compared to a car using conventional fossil fuels (liquefied petroleum gas, diesel oil, gasoline). Hybrid vehicles do not show significant improvements in fuel consumption when driven on highways. A large advantage of hybrid vehicles compared to other options for reducing GHG emissions in transport is the fact that no additional infrastructure investments are required. It is assumed that by 2030 urban passenger transport will switch from diesel buses to hybrid ones. Research has demonstrated that, depending on the traffic dynamics, the hybrid buses have 23 – 43% lower CO_2 emission and 18-39% lower NOx emissions compared to similar new non hybrid diesel articulated buses.
Country specific applicability and potential	Hybrid vehicles are expensive for the majority of the people in Yemen. There are some Hybrid vehicles, but very limited. The advantage of an individual acquiring a Hybrid vehicle is saving of fuel, since it can run on both electric energy and fossil fuel, particularly when the cost of fossil fuels are quite high. But, it must be emphasized that it is still much preferred vehicle than electric vehicles or fossil-fueled vehicles. It can be applied reasonably well with time, and it will definitely have a potential in Yemen in the near future.
Capacity	At the moment limited capacity.
Scale of application	The scale of application can increase as the country enters political stability
Time horizon- Short / Medium /long term	Medium
Status of technology in country	Exist in very limited numbers, might increase when the political turmoil ends.
Availability of technology	At the present time no manufacturing industry for any kind of vehicles exist in Yemen, which includes Hybrid vehicles.
Climate change mitigation/adaptation benefits	It will definitely contribute to the mitigation of climate change, since it will consume less fossil fuels. Additional advantage is if the batteries of the Hybrid Vehicles are charged using electricity generated by renewable energy

Benefits to economic / social and environmental development	a) Social – (i) employment, (ii)fuel-saving b) Economic –(i) enhance energy security by reducing imports of fossil fuels; (ii)improve balance of payments; c)Environment –(i) improving quality of local air, (iii)contribution to the reduction of GHG emissions
Financial Requirements and Costs	The original cost of hybrid cars could range from US $23000 to $48000 depending on the type and brand of car and the features of the car.
Capital, operating costs	The cost of the fossil fuel used in the combustion engine, also, the cost of battery renewable, and the cost of charging the battery if the Hybrid car in not one of the Series hybrid cars-full electric vehicle which use the internal combustion engine as a generator to produce electricity.

(4) Improvement of By-roads

Sector	Transport
Technology	Improvement of By-roads
Technology characteristics	
Introduction	Proper maintenance of byroads for efficient and smooth flow of traffic with lower CO_2 emissions. Proper maintenance of the road edges/shoulders to prevent erodibility and damage, hence, can contribute positively in the reduction of GHG emissions. 
Technology characteristics	The material used in road construction is also important in relation to CO2 emissions; although construction of asphalt/concrete roads are favoured most of the time, a research study has found that 'metalling and tarring' roads have lower emissions and high durability for roads in rural sector.
Country specific applicability and potential	Applicable throughout the country
Capacity	The roads are usually constructed by the government, because of the current situation in the country, the Asphalt material is not readily available in the market. Most of the roads are built through co-sponsorships between the government and international aid.
Scale of application	Large scale of application, can involve all cities, and all roads throughout the country
Time horizon- Short / Medium /long term	Short – medium term
Status of technology in country	Currently, most of the main roads are occupied by heavy volumes of vehicles, and passengers tend to choose certain byroads, bypassing certain heavily congested main roads. However, most of the time byroads are poorly maintained, causing vehicle damage and slower driving speed. This is mostly obvious in situations when the byroads are used as detours. Proper and timely road maintenance practices should be enforced through the respective local authorities
Availability of technology	It is available to some extent, although due to the country circumstances, the Asphalt material can become difficult to obtain.
Climate change mitigation/adaptation benefits	Improving by-roads can contribute positively in reducing GHG emissions, since un repaired damaged roads can cause lots of congestion which will lead to delays, consequently will result in more GHG emissions by vehicles stuck in the congestion. and can be considered as a way of an adaptation benefit, because improving by-roads can be both a mitigation measure of GHG emissions and an adaption measure in the process of the reduction of GHG emissions.

Benefits to economic / social and environmental development	a. Socioeconomic - It will help avoid unnecessary traffic delays and idler time on roads caused by slow driving under poor road conditions. - Smoother flow of vehicles on proper byroads causes efficient fuel consumption and less damage to vehicles b. Environmental Lowered emissions due to better fuel use efficiency (But this is only a short term benefit, as smoother flow of vehicles with no congestion can draw more vehicles to the road over time).
Financial Requirements and Costs	It is part of the 3 or 5 years' development plan that the government allocate annually. Cost can be provided partly by the government and partly by a loan from World Bank, or by U.N. Aid
Capital, operating costs	Can be applicable within a low-cost budget. It is estimated that 160,000 USD per kilometer of road, maintenance could be set annually by government budget

(5) Switching to Liquid Petroleum Gas (LPG) Fuel

Sector	Transport
Technology	Switching to Liquid Petroleum Gas (LPG) Fuel
Technology characteristics	
Introduction	When LPG is used to fuel internal combustion engines, it is often referred to as auto gas or auto propane. Research carried out in 2013 by Atlantic Consulting compared results for 1,251 models of bi-fuel vehicles and concluded that there was an average 11% CO2 reduction when run on LPG compared to the identical cars running on petrol. The research also indicates that LPG cars produce less Nitrogen Oxides (NOx) than both petrol and diesel cars. In fact, when compared to diesel, five times less NOx is emitted. LPG vehicles are significantly lower on particle emissions as well. Extensive independent tests showed that one diesel vehicle emits 120 times the number of fine particles as the equivalent LPG vehicle. It takes 20 LPG vehicles to emit the same amount of NOx as one diesel vehicle. The above figures are sourced from the European Fuel Quality Directive which put LPG as part of the solution to decarburizing the transport sector in Europe. LPG has a lower energy density than either petrol or diesel, so the equivalent fuel consumption is higher but is one third the cost of regular petrol. This technology transfer intervention seeks to retrofit existing petrol (gasoline) vehicles in Yemen to use LPG.
Technology characteristics	LPG, also known as propane and auto gas, is a by-product of crude oil extraction and the refining process. Many people who consider LPG as an alternative to petrol do so because they believe that the combustion of propane results in lower CO2 emissions. LPG burns cleaner than petrol and therefore emissions of particulates is very low. Moreover, LPG is non-toxic, non-corrosive and free of tetra-ethyl lead and additives. It also has a high-octane rating (The octane rating is a measure of how likely a gasoline or liquid petroleum fuel is to self-ignite. The higher the number, the less likely an engine is to pre-ignite and suffer damage)
Country specific applicability and potential	The main advantages of converting a vehicle to LPG are that they would emit less GHGs, and are cheaper to operate and maintain. The technology's acceptability will be determined during the promotion of the technology. It will also depend on whether the potential savings outweigh the innate fear of using LPG as stated previously. The LPG Vehicle Conversion market has great potential in Yemen because of the high cost of fuel, vehicle parts and the transport sector high carbon emissions. Many people in Yemen would prefer to have a vehicle that run on LPG rather than petroleum gasoline/diesel fuel.
Capacity	There are suppliers and installers of such systems in Sana'a city, where a significant number of vehicles have converted their engine vehicles to gas-fuel. However, there will be a need to encourage investments in the LPG engine conversion market.

Scale of application	Once the technology is developed in Yemen, it would have quite a large scale of application. The reason is people will prefer to use cheaper fuel than the much expensive petrol/diesel fuel.
Time horizon- Short / Medium /long term	Can be applied on medium term. As technologies are developed constantly, another technology option could have a much advantage on this technology.
Status of technology in country	The technology and expertise currently have little existence in the country, but only on a limited scale, mainly in the north such as Sana'a
Availability of technology	Very limited, in the beginning people were keen to switch their cars from petrol/diesel fuel to gas fuel engines. Now people just carry on with existing engines.
Climate change mitigation/adaptation benefits	Fuel switching to gas fuel can contribute positively in the reduction of GHG emissions, but still there is GHG emissions from the gas fuel.
Benefits to economic / social and environmental development	There are no statistics on the number of vehicles in Yemen that have already converted to LPG. However, a proposed initiative to convert 15-25% of existing vehicles to LPG would create jobs for people to install and maintain these LPG systems. Other areas of potential economic benefits would come from the need to build more LPG refueling stations. Lower operating costs would be beneficial to both the private and commercial sectors. LPG is about 50% the cost of petrol. Also, national cost savings arising from reduced imports of higher priced petroleum products would enable Yemen to retain more foreign currency. Vehicles converted to LPG will emit up to 11% less carbon than a similarly sized petrol vehicle.
Financial Requirements and Costs	Currently the approximate cost to supply and install a LPG switching parts is as follows: $ 1,2500 per vehicle This may drop gradually, due to competitions, introducing new cheaper parts from say India or China.
Capital, operating costs	A vehicle running on LPG will return slightly fewer miles per gallon than when running on petrol. However, the cost of running a vehicle on LPG will be about 40% less than the cost of running it on gasoline or diesel. Conversion costs can vary depending on vehicle type and tank arrangement required. LPG Cost Savings Example — Fuel (Gasoline /Diesel). — Fuel (LPG) Annual Mileage — 20,000 — 20,000 mph — 34 mph — 28 mph Fuel Price (Yemeni Riyal). — 1500/liter — 325/liter (prices set on the date 26/3/2022, it must be noted that prices change all the time) (Source: Original cost savings example derived from http://tinley.com.uk/; TOMZA Ltd. LPG Converters, personal comm. Plant Director.)

(6) Promote Cycling

Sector	Transport
Technology	Promote Cycling
Technology characteristics	
Introduction	Cycling offers numerous advantages to its users and to society in general. These include affordability in terms of ownership and maintenance; health benefits; the need for very little space for movement and parking in comparison to motor vehicles; and minimal impact on the environment. Main advantages of the technology that it can make an important contribution, not only to the transport system, but also to the environment, the economy and the social fabric of communities
Technology characteristics	❖ Affordable for most community levels

	❖ Low maintenance need ❖ High accessibility to narrow roads and small areas. ❖ Easy parking ❖ Very low impact on the environment
Country specific applicability and potential	Almost all of the Yemeni cities have leveled streets with no slopes or mountains, so this technology can be implemented in the northern cities because of the cool weather, in Aden and most coastal cities this technology can work during winter, because of the temperature and high humidity
Capacity	NA
Scale of application	A bicycle provides high levels of personal mobility at very low cost, so this technology will be open for the public and anyone could be a beneficiary, but it needs a good health conditions to be used and only for short distance, this could limit the people who can use it.
Time horizon- Short / Medium /long term	Long term process
Status of technology in country	It is very limited, the public in Yemen hardly use bicycles for transport
Availability of technology	There is no available infrastructure or laws that help the use of this technology in Yemen. Also, there is no industry that manufacture bicycles in Yemen
Climate change mitigation/ adaptation benefits	A two kilometer bicycle trip saves 419 grams of CO_2 (e) if it replaces a car trip, although there are some emissions generated in the production and distribution of bicycles. (TNA Guide book) ❖ Emissions: a bicycle emits no greenhouse gases or local air pollution when operated and its GHG emissions is far less than a car when manufactured ❖ Noise and congestion: bicycles are far quieter than motor vehicles and take up less space. Electric bikes have similar advantages. ❖ Sprawl: by requiring less road space and by reducing the average length of trips, cycling contributes to urban consolidation.
Benefits to economic / social and environmental development	❖ Transport efficiency: cycling and walking are the most space efficient transport modes for short trips. Bicycles need less than a third of the space cars need to transport the same number of people. ❖ High benefit to cost ratio from investment in facilities: the cost of building facilities for cyclists is small, compared to those for cars, but the economic benefit can be significant. Benefits include reduced road infrastructure, congestion and pollution; improved road safety for pedestrians and cyclists; and savings in private and public transport running costs. ❖ Reduced reliance on fossil fuel: increased use of bicycles reduces reliance on crude oil, which most countries must import. ❖ Higher worker productivity: it has been demonstrated that cycling to work leads to better attention levels due increase in blood circulation, higher productivity and reduced absenteeism. ❖ Greater economic inclusion: because of its affordability, cycling gives more people access to jobs, education and services. • Good life: the more we flock to high-status cities for (money, opportunity, novelty), the more crowded, expensive, polluted, and congested those places become, surveys show that Londoners are among the least happy people. • Affordability: a bicycle provides high levels of personal mobility at very low cost. • Equity across localities: cycling can provide high levels of personal mobility for negligible cost in dispersed settlements, including rural or pre-urban areas, where population densities make public transport economically less viable.

	• Health: physical inactivity results in increased health problems such as obesity, heart disease, diabetes, stress and high blood pressure. Cycling increases physical activity levels and reduces the economic cost of health problems
Financial Requirements and Costs	The financial requirements will be on developing an infrastructure such as special pavements for cycling. Due to the current circumstances the government priority is in other urgently needed projects. In
Capital, operating costs	<u>Cost of implementing the mitigation technology</u> Bicycling is an inexpensive and efficient form of transport compared with most other modes, particularly car use. As already noted, the cost of constructing cycle paths or lanes is about one-tenth of the cost of constructing roads. If included as part of the design for a new or upgraded roadway the cost will be a small fraction of the total cost of the roadway. Providing cycling lanes on existing roads can be cheaply done when resealing or restriping roads as part of regular maintenance.

(7) Sea Ferries

Sector	Transport
Technology	Sea Ferries
Technology characteristics	
Introduction	Yemen has a long coastline ~ 2300 km, and more than 200 islands. In the future, sea ferries will have a major contribution to sea-transport between cities along the coast and between the mainland and the inhabited islands in the Red Sea and the Arabian Sea. This sub-sector is important for economic and social development, tourism, exchange of goods, between mainland and various islands.
Technology characteristics	A sea-ferry is basically a boat which is designed to carry passengers from certain point to another. It should have all the necessary requirements to meet the standards such as – safety, comfortable seats, cafés, cafeteria, toilets, emergency measures such as- life-jackets, radio-communication, life-boats. All these need well-qualified personal, some sea-ferries also, can carry vehicles, goods etc.
Country specific applicability and potential	This technology option can easily be applied, since Yemen has a long coastline and many islands. Also, it will have a great potential, this off-course need the government to encourage the investment of private companies, which can get high revenues in return. Sea-ferries have an engine which run on gas-fuel for it to have a great potential for implementation on large scale, most important is the reduction of GHG emissions using gas-fuel. Future sea-ferries can use renewable energies such as – solar and wind energies to generate electricity which will be used to operate the engines.
Capacity	At the present time the country capacity is limited. No existing plans to develop this technology option with all its needs of infrastructure and trained human resources.
Scale of application	Once initiated and developed it will involve all the coastal cities and islands in the Red Sea and Arabian Sea. Hence, can have a large scale of application
Time horizon- Short / Medium /long term	Short to medium term, once sea-ferries are introduced, the process of modernization can be carried-out with time.
Status of technology in country	There is a sea transport by boats from Hadramout & Al-Maharah governorates and the islands of Scotera. But, still limited since it is functional only at certain time of the year to avoid the season of strong winds, storms and hurricanes.

Availability of technology	No organized or licensed sea-ferry companies which meet the international standards of sea-ferry operation.
Climate change mitigation/adaptation benefits	Sea-ferries can contribute positively in the reduction of GHG emissions if they operate using gas-fuel, however, if renewable energies are used, in this case can have a huge reduction of GHG emissions.
Benefits to economic / social and environmental development	Sea-ferry transport will have great benefits for economical development, beside employment, trade will increase between coastal cities and the islands, and can become easily accessible, encourage exchange of goods and vegetables and fruits, fish products. Gas-fueled sea-ferries will have less GHG emissions and less environmental pollution.
Financial Requirements and Costs	The need for the initial government investment in infrastructure and training human resources. The cost of a fleet of sea-ferries consisting of 12 ferries, will cost around 6 million US $.
Capital, operating costs	Private companies could put the required capital to establish sea-ferry transport industry, also, this will include the operating costs and maintenance.

(8) Synchronization of Traffic Signals

Sector	Transport
Technology	Synchronization of Traffic Signals
Technology characteristics	
Introduction	In traffic signal synchronization, a series of traffic lights along the road turns green allowing smooth flow of vehicles, reducing the congestion and need to stop in the middle of traffic; this helps avoid travel delays, especially in heavy traffic, and causes lower emissions and air pollution The synchronization system is usually activated during morning and evening peak hours, and the signals are coordinated based on the congestion level.
Technology characteristics	The existing traffic signals in various areas in Yemeni cities can be updated for having better synchronization. Updated traffic signal control equipment along with signal timing optimization can reduce congestion. In Texas, USA, synchronization of traffic signals reduced traffic delays by 23 percent (US Department of Transportation, 2011), while on average it can reduce the travel time by up to 15 percent (US Department of Energy, 2011).
Country specific applicability and potential	This is an important technology, especially in avoiding the heavy traffic entering and moving out of city areas with heavy traffic during peak hours.
Capacity	At the present time it has a limited capacity, in the future it could increase as such technology option are definitely needed
Scale of application	It can be applied in all cities throughout the country
Time horizon- Short / Medium /long term	This is only a short term benefit, as smoother flow of vehicles with no congestion can draw more vehicles to the road over time
Status of technology in country	Currently there are traffic signals in Sana'a city, most of the time is controlled by the traffic officers, while in the city of Aden the traffic signals are neglected, old and not functioning at all. There is a need for establishment of more traffic signals at certain other intersections which are currently being controlled using traffic police officers. Traffic light synchronization will definitely help improve the efficiency of the existing traffic lights, while leading to a smoother flow of vehicles, as a result high fuel use efficiency, and lower pollution.
Availability of technology	No such Technology exist in Yemen, but, traffic authorities can think about introducing such technology. The private sector can have the role of introducing such technology to Yemen.
Climate change mitigation/adaptation benefits	This technology option will have a major contribution of reducing GHG emissions, also, reduce air pollution significantly

Benefits to economic / social and environmental development	a. <u>Socioeconomic</u> ❖ -Reduced congestion and enhanced time use efficiency ❖ -Better transportation system and improved quality of traffic light signaling ❖ -Avoidance of unnecessary traffic delays/stops ❖ -Improved safety, without having to make sudden stops ❖ Higher fuel use efficiency. b. <u>Environmental</u> Lowered air pollution and GHG emissions due to smooth flow of traffic and higher efficiency of fuel use
Financial Requirements and Costs	Cost is around US $ 2500-3100 per signal (US Department of Transportation, 2011)
Capital, operating costs	The cost of say 100 signals will be around $300 k US Dollar, operating cost will be the cost of electricity, if solar-powered then operating cost will be zero, only maintenance cost can be added say 1% of capital cost.

Annex 4 Prioritized Water Sector Adaptation Technologies Fact Sheets

(1) Seawater Desalination

Sector	Water
Technology	Seawater Desalination
Technology characteristics	
Brief technology description:	Desalination is a series of industrial processes conducted to remove all or part of excess salts and minerals from water. This term is used to remove salts and minerals dissolved in water. And sea water can be desalinated so that it can be used in practical life such as agriculture, drinking and industry. The desalination process requires techniques that consume a lot of energy and money, and have harmful effects on the environment. Energy consumption in the desalination process is one of the important problems and difficult obstacles that need to be overcome, and it is one of the goals that are being worked on in scientific centers that focus on finding alternatives with lower energy consumption, more effective and environmentally friendly. The desalination process takes place in three basic stages; primary treatment, salt removal and final treatment. In the desalination process, a semi-permeable membrane known as the reverse osmosis membrane is used, as this membrane allows fresh water to pass in the direction of low pressure and not to pass salt and bacteria through it. There is also distillation process consists in raising the temperature of salt water to the boiling point and the formation of water vapor, which is then condensed into distilled water, so that the distilled water is free of salt. This distilled water has no taste, and then it is treated with additives to be water suitable for drinking or irrigation. There are four types of distillation used in the desalination process; such as, Normal distillation, Multi-stage flash distillation, Multi-stage (Multi-Effect) Distillation, Distillation using solar energy.
The costs	The initial costs of this technology range from 5000US$ to 100M US$ for industrial and commercial large-scale units.
Application potential in the country	There is a prosperous market country-wide of membrane technology RO mainly from household scale to commercial scale.
Technical aspects (geographical applicability range, maturity)	RO chain production of commercial units in some central cities, and also local skills and experts are available.
Potential for reduction of vulnerability	Desalination technology cover a huge deficit of fresh drinking water in country and also for other needs of agriculture and industry. It provides additional source of fresh water to defeat drought. Also, one of the environmental problems is the remnants of the desalination process, which is known as the concentrated brine, which when thrown into the sea increases the concentration of dissolved salts in it and thus negatively affects marine life. It is necessary to choose the place of taking from the water source and, as well as choosing the place to dispose of the concentrated salt water so as not to adversely affect the aquatic organisms.
Social, economic, and environmental benefits.	Availability of additional sources will improve the hygiene and social life of the community, raise the economic level and environmental remedies.

(2) Diversion Facilities and Channels

Sector	Water
Technology	Diversion Facilities and Channels
Technology characteristics	
Brief technology description:	The application of these technologies is widespread in the flood plains of the internal valleys and near the mouths of the valleys in different regions of especially Yemen. Water diversion and diversion dams constitute one of the important facilities for exploiting water resources in seasonal valleys in dry and semi-arid areas for agricultural development and improvement of natural pastures in particular. This facility aims to organize the investment of the waters of rivers and seasonal valleys with high returns in agricultural projects by diverting flood waters and spreading it to irrigate neighboring farms. It also aims to reduce losses and disasters through shortages and reduce the amount of running water in valleys by constructing several dams on riverbeds. Flood Water Diversion is the irrigation technique by diverting the flood requires many, repeated and permanent efforts from the population, as every time and after the flood water passes through the canals, the farmers must carry out the implementation of the canals and reclaim the agricultural lands again in order to prepare to receive a large amount of water in a short time. Implementation methods for diversion dams differ according to the conditions of each site. They may be very simplified in some cases or complex in others, and need maintenance work from time to time to ensure their survival.
The costs	Installation cost per system from 1M$ to 50M$ and more.
The application potential in the country	Benefiting from the water resources of seasonal valleys to improve soil moisture to raise the productivity of rainfed crops and to grow cotton, as a cash crop, in some areas and limited vegetables in some cases.
Technical aspects (geographical applicability range, maturity	This technology is traditionally practiced country-wide and Helps to reduce the effects of sedimentation and erosion problems and the distribution of sedimentary materials over large areas.
Potential for reduction of vulnerability	It helps in some cases to improve the natural recharge of the aquifers, and thus it is considered as a means of rationalizing the uses of surface water resources by storing them in the ground.
Social, economic, and environmental benefits	It helps social stability in the countryside. Its economic return is large in the long run compared to its construction cost. It protects river embankments and agricultural soil against erosion.

(3) Water Harvesting

Sector	Water
Technology	Water Harvesting
Technology characteristics	
Brief technology description:	Water harvesting is defined as a technique used to develop surface water resources that can be used in dry areas to provide water for livestock, domestic uses, agroforestry, and agriculture in small areas as well. Water harvesting systems can be defined as artificial methods through which precipitation water can be collected and stored for later use. Water harvesting provides a sufficient amount of water suitable for use, as the collected water can be an additional source of supply to the already existing amount of water,

	or be the main source in areas where providing water from other sources may be very costly, and water harvesting systems include What follows: • A water collection area prepared in such a way that rain water flows efficiently. • A facility to store the collected water, and it is used in case the water is not concentrated directly in the agricultural soil. • Water distribution scheme, which is required in subsistence farming systems for irrigation in dry periods. Some farmers build their own basins to collect, store, and use rainwater throughout the year instead of relying entirely on groundwater or municipal wells. Rainwater maybe collected from the roofs of houses or rocky surfaces to be stored, then exploited in homes, irrigation and other traditional uses. The method of water harvesting is considered ancient, as its use dates back to more than a thousand years in various dry lands around the world, but the techniques of these systems have undergone great development over time, especially in matters related to irrigation, in addition to the development of water conservation techniques to provide water for humans, animals and Irrigation.
The costs	Installation cost per system from 1,000 to 50,000 US$
The application potential in the country	Rainwater harvesting has been used for thousands of years in many places of the country. In this technique water is collected from rom the rocky plain areas or rooftop of the house to a storage tanks for domestic use or irrigation. The locals call the technique "siqaya" or in some another places "magil".
Technical aspects (geographical applicability range, maturity	This technology is widely applicable in mid-land and high-land areas where the rainfall is frequent and abundant for harvesting.
Potential for reduction of vulnerability	Rainwater harvesting provides water to cover the shortage in water supply and reduces the vulnerability towards dryness in dry periods.
Social, economic, and environmental benefits	Availability of harvested rainwater helps the people to practice their activity in their places without having to move to distance places or water.

(4) Wastewater recycling and reuse

Sector	Water
Technology	Wastewater recycling and reuse
Technology characteristics	
Brief technology description:	Wastewater recycling is one of the most rational and win-win options for enhancing water adequacy, and it can range from simple household methods to sophisticated industrial wastewater purification systems, so reusing different types of wastewaters is a way to improve water use in the home. Wastewater can be used for agricultural purposes such as irrigating gardens and lawns; it can also be used equally for irrigating vegetable and fruit nurseries or flower bushes and fences. To the extent that irrigation increases crop yields it should be used in accordance with WHO (1989) guidelines for the safe use of wastewater in agriculture by monitoring levels of water contamination in wastewater. Redirected wastewater (gray sewer systems): Gray water refers to wastewater from plumbing fixtures other than toilets such as showers, sinks, and faucets

	from domestic use. This is used sparingly and does not come into contact with faeces but can contain some elements of household cleaning products or grease or hair, food, or dirt. This reuse method involves diverting wastewater from drain pans and washing machines and then directing it to the greywater collection system.
The costs	One treatment plant cost from 4M US$ to 6M US$.
The application potential in the country	irrigation of public and private parks, sports facilities, street cleaning and fire protection system. Treated wastewater can be used for restricted agricultural irrigation, pastures, seeds, ornamental flowers, aquaculture, and viticulture. And, many Industrial, Recreational, Environmental uses. Also, ground water recharge and withstand seawater intrusion.
Technical aspects (geographical applicability range, maturity)	To maintain public health, environment preservation and water recovery.
Potential for reduction of vulnerability	Conservation of potable water and expansion of agriculture. Reducing the need for artificial fertilizers due to the presence of necessary elements in that treated water. Reduce over-extraction of groundwater. Reducing nutrient loads into rivers, canals and other surface water resources.
Social, economic, and environmental benefits.	Promote environmental protection by preserving wetlands and ponds. Increase employment and strengthen the local economy.

(5) Water-saving Irrigation Methods

Sector	Water
Technology	Water-saving Irrigation Methods
Technology characteristics	
Brief technology description:	There are several guiding methods for irrigation water, including drip irrigation, bubble irrigation, irrigation with small, medium and large sprinklers, and industrial mist or spray sprinklers, which are used in greenhouses. Drip irrigation is one of the most water-saving methods. Drip irrigation systems deliver water directly to the roots of the plant, which reduces evaporation that occurs in some other irrigation systems. Timers can be used to schedule irrigation at cooler times during the day to reduce water loss, in addition to Properly installed drip irrigation pipes save up to 80% of water compared to traditional irrigation methods, and contribute to increased crop production as well. The principle of work of this method depends on supplying the crops with water in very small and continuous quantities, as a network of tubes is distributed above the surface of the soil and sometimes under the surface of the soil. The discharge from a single emitter of water ranges between 2 to 10 liters per hour. Therefore, this method has several advantages and some disadvantages, which are as follows:
Advantages of Drip Irrigation	Saving a large amount of irrigation water. This method is suitable for all types of soils and for different surfaces and topographic levels. Reduce the need to settle agricultural land. Preventing the growth of weeds around plants. The possibility of adding the necessary fertilizers for the plant in the irrigation water. This method is not affected by weather conditions. The chances of the spread of fungal diseases and insects are reduced. It does not increase the

	humidity of the surrounding atmosphere. Its distinctive results and a good, high-quality yield.
Disadvantages of Drip Irrigation	The high construction cost compared to other methods. Possibility of damage to pipes due to some rodents. The possibility of clogging the dripper head by salt and other dirt.
The costs	Installation cost per hectare around 6,000 to 10,000 US$
The application potential in the country	Applicable for water and soil with low salinity
Technical aspects (geographical applicability range, maturity	There are number of water-testing well equipped laboratories with qualified personnel.
Potential for reduction of vulnerability	Drip irrigation ideal for water consuming plants and crops.
Social, economic, and environmental benefits	Low requirement for man power, low water consumption, less pesticide and no herbicide is required

(6) Hydrogeological data

Sector	Water
Technology	Hydrogeological data
Technology characteristics	
brief technology description-	They are data on the distribution and movement of groundwater in soil and rocks in the Earth's crust. Groundwater does not always follow the topography of the surface; Groundwater follows pressure gradients (flow from high to low pressure), often through fractures and channels in circuit paths. Taking into account the interaction between the various aspects of a multicomponent system often requires knowledge in many diverse areas at both an empirical and theoretical level. The absence of accurate information, based on detailed studies, of the general water situation in many sites in the country is one of the most important difficulties facing future development, researchers, or investors. The hydrogeological and hydro-chemical maps are among the main pillars that describe the general situation of water in the different regions of the country. The hydrogeological and chemical maps include many important information, starting with the quality of groundwater, through precipitation, and ending with surface water basins. The information contained in hydrogeological and hydro-chemical maps is also considered one of the basic building blocks for building and updating the water information bases that the state focuses on and pays great attention to. Providing specialized studies on water sources, their quality, quantity, management and development, proposing the best ways to conserve them, and harnessing scientific techniques for survey and investigation of the surface and groundwater resources and terms of water cycle.
The costs	Total study of hydrogeological budget costs approximately from 2 to 2.5 M$
The application potential in the country	There are a number of river basins need water budget studies for groundwater recharge
Technical aspects (geographical applicability range, maturity)	Hydrologic cycle study and term-wise for major Wadi basins and recent status assessment.

Potential for reduction of vulnerability	Estimation of recoverability and deficit of natural recharge.
Social, economic, and environmental benefits.	Demand-supply studies, non-conventional sources and environmental remedies.

(7) Monitoring the Quality of Drinking Water

Sector	Water
Technology	Monitoring the Quality of Drinking Water
Technology characteristics	
Brief technology description:	Water quality is the physical, chemical and biological properties of water. This term is frequently used to refer to criteria for assessing water. The most common criteria are used to assess the quality of drinking water, the suitability of water for human use and the health of ecosystems. Water quality is the physical, chemical and biological properties of water. This term is frequently used to refer to criteria for assessing water. The most common criteria are used to assess the quality of drinking water, the suitability of water for human use and the health of ecosystems. The United Nations has recognized clean water as a basic human right. However, a large part of the world's population must live with threatened water every day. This can mean that drinking water is unsuitable or that surface water sources are at risk - in other words, polluted rivers, lakes and oceans. This affects not only humans, but all forms of life. Drinking water quality refers to the acceptability of water for human consumption. Water quality depends on the composition of the water that is affected by natural processes and human activities. Water quality is characterized by water parameters (physical, chemical, microbiological), and human health is at risk if the values exceed the acceptable limits. Various agencies such as the World Health Organization (WHO) and the Centers for Disease Control (CDC) have set exposure standards or safe limits for chemical pollutants in drinking water. Although water quality is usually sampled and analyzed in laboratories, since the late 20th century there has been a growing public interest in the quality of drinking water supplied by municipal systems. Many water utilities have developed systems to collect real-time data on source water quality. In the early twenty-first century, a variety of sensors and remote monitoring systems were deployed to measure pH, turbidity, dissolved oxygen, and other parameters. Some remote sensing systems have also been developed to monitor water quality. The specifications of drinking water are compared according to national standards and the standards of the World Health Organization WHO published in its literature, which is constantly renewed.
The costs	Laboratory with advanced testing equipment and skillful personnel 3-5M$. Continuous chemical and biological (microbial) testing costs 100$ per sample.
The application potential in the country	Water testing widely practiced in the country with portable kits and stationary laboratories.

Technical aspects (geographical applicability range, maturity	There are number of water-testing well equipped laboratories with qualified personnel.
Potential for reduction of vulnerability	Testing water for domestic supply reduce vulnerability for water quality avoid water-borne diseases.
Social, economic, and environmental benefits	Drinking water quality testing enhances hygiene, community health and environmental remedies.

(8) Meteorological Stations

Sector	Water
Technology	Meteorological Stations
Technology characteristics	
Brief technology description	A facility used for weather monitoring and forecasting, whether on land, sea or air, with tools and equipment for observing the Earth's atmosphere to provide weather information and study weather and climate. It takes measurements of temperature, atmospheric pressure, humidity, wind speed and direction, and rainfall.
Major digital weather stations	This type of key weather station can measure indoor and outdoor temperature, indoor and outdoor humidity, barometric pressure, also known as atmospheric pressure, wind speed, wind direction, and precipitation, and with this data, forecasts can be calculated along with Combined with dew point, wind chill... etc.
Smart weather stations	Some smart weather stations can understand voice commands and respond with the required information. Two of the new major weather stations now use Alexa for example. This type of weather station, in some cases, is able to use IFTTT technology and trigger remote actions when certain weather criteria are met. .
Professional weather stations	This popular type of weather station is built with reliability, durability and accuracy in mind, and professional weather stations must meet international meteorological standards.
Portable weather stations	Portable weather stations range from portable units that report only wind speed and temperature, all the way to handbag types that include everything you might find in a professional weather station as well as any specialized sensors, for example, nuclear radiation detectors.
Agricultural weather stations	Agricultural type weather stations are professional weather stations with some additional sensors and networks, and they work to measure soil temperature, humidity and sun exposure are important for farmers, as well as measurements of leaf wetness and water temperature, and farmers also need a weather station that can alert them to conditions such as frost or floods.
Marine weather stations	Anything around salt water has a problem with corrosion, marine weather stations must be corrosion resistant and sealed, this applies to stations on the water and on the shore, some weather station manufacturers suggest staying at least 400 meters from shore, tending Marine quality weather stations to be expensive.
The costs	The costs of different type vary from 800 to 30,000 US$ per set.
The application potential in the country	All the above-mentioned types have their application in different parts of the country.

Technical aspects (geographical applicability range, maturity)	Different types for different geographical conditions for the high-land or mid-land or low-land, the coastal areas and islands where harsh weather is dominant.
Potential for reduction of vulnerability	Collecting data helpful for frequency analysis, hydrologic cycle studies and water budget
Social, economic, and environmental benefits	Long-term forecasting, preparedness, ecosystem protection and conservation

(9) Development of sewage systems and networks

Sector	Water
Technology	Development of sewage systems and networks
Technology characteristics	
Brief technology description:	The main objective of the sanitation system is to protect and promote human health by providing a clean environment and breaking the cycle of disease. In order to improve sanitation, it must be acceptable, not only economically, but socially, technically and institutionally. and to protect the environment and natural resources. Densely populated areas and industrial cities rely primarily on centralized wastewater treatment plants (WWTPs) to receive and treat wastewater. Intricate networks of underground sewer pipes bring sewage from homes and buildings to a sewage treatment plant using gravity and pumps. Once wastewater reaches the wastewater treatment plant, it undergoes several stages of treatment before being discharged. Primary, physical treatment begins with sifting: The wastewater is passed through filters to remove large solids. Drain is then brought to sedimentation tanks where gravity helps to precipitate the additional suspended solids. Secondary, or biological treatment, aims to remove organic matter from wastewater prior to disinfection. It uses oxygen and microorganisms to stimulate and enhance biochemical reactions that break down pollutants. This process models natural systems and is made more efficient by aeration or exposure to supplemental oxygen. Oxygen is necessary for decomposition, and aeration helps remove dissolved gases. These interactions eventually encourage the remaining particles to settle. After secondary, or chemotherapy, to promote greater stability and nutrient removal. The added polymers attract pollutants to form clumps while carbon or charcoal filters induce physical adsorption to reduce nutrients. Finally, the effluent is disinfected to neutralize any remaining pathogens. While chlorine is the most common disinfectant, UV or ozone is used to reduce residual chemical concentrations. Primary and secondary treatment is required in some areas and the number of facilities incorporating tertiary treatment is increasing. Reference However, even when treatments are required, failures are common and it should not be assumed that applicable laws indicate appropriate treatment. In addition, restrictions on nutrient concentrations in effluents are implemented at the municipal and facility level to address nutrient loading and its consequences. Treatment criteria are useful, but not sufficient to protect marine ecosystems from pollution.
The costs	Initial costs of sewage system and network improvement is around 8M US$ to 10M US$.
Application potential in the country	It is widely practiced in many central and medium cities and needs improvement and extension to cover the newly built-up areas and to enlarge the capacity of the existing ones.

Technical aspects (geographical applicability range, maturity)	To avoid sewer overflow and lifting stations' failures by regular maintenance of the whole system.
Potential for reduction of vulnerability	Beside the regular maintenance setup of early warning system and readiness reduce the probable failures of the system.
Social, economic, and environmental benefits	Proper design, maintenance and operation of the sewage system and sewerage network serves community hygiene and social and economic stability and preserve environment.

(10) Explore new well fields

sector	water
technology	Explore new well fields
Technology characteristics	
Brief technology description:	Exploration of new fields of drinking water wells in the proposed sites by surveying the area using the required devices as follows: - Studies to evaluate the water situation in the region. - Preparing special maps; geological, hydrogeological and, explaining on them the quality of groundwater, the spread of wells, if any, rainfall, and the boundaries of surface water basins, such as: Hydrogeological maps. Hydro-chemical maps. Contour- groundwater isohyetal maps. Distribution of chemical elements maps. Climatic Data. Determination of the hydrogeological and hydrological characteristics of the various components. Delineation of total catchment area and determination of the hydrological characteristics of the water basins. Collecting samples of groundwater and surface water, using the latest methods and equipment. Interpretation of the results of laboratory analyzes of samples, with regard to chemical elements and analyzes of bacteria, trace elements, radioactive elements and environmental isotopes and reporting the quality of water and its compliance with national and international standards. Well drilling and Pumping tests. Estimating the volume and quantities of available water and the water balance in the water basin, including evaluating hydrological and hydrogeological studies, Evaluating pumping test results and calculating the rate of safe production of wells, Conducting feasibility study for wells.
The costs	Well drilling and pumping test costs 30,000$ as an average. Additional costs of equipment and installations 15,000$ as an average.
The application potential in the country	Drilling groundwater well is widely applied in the country.

Technical aspects (geographical applicability range, maturity	There are number of well drilling companies well equipped and has qualified staffs.
Potential for reduction of vulnerability	Drilling new wells for drinking water will reduce vulnerability for water deficit and cover, to some extent, the shortage in water supply
Social, economic, and environmental benefits	Meeting the community demand for drinking water, enhancing hygiene and environmental remedies

(11) Wetland Conservation

Sector	Water
Technology	Wetland Conservation
Technology characteristics	
Brief technology description:	Wetland protection or wetland conservation aims to protect and conserve areas where water is found at or near the surface of the earth, such as swamps, marshes, and slugs. Wetlands have become a central issue of protection and conservation due to the ecosystem services they provide. Besides food, wetlands provide fabric, fuel, and medicinal plants. They also provide valuable ecosystems for birds and other aquatic creatures, help reduce the harmful impact of floods, control pollution, and regulate the climate. From economic importance, to aesthetic, there have been many reasons for wetland conservation over the past few decades. Wetland may be defined as lakes and rivers, swamps and marshes, wet grasslands and oasis lands, estuaries, deltas and tidal plains, offshore areas, mangroves and coral reefs Man-made sites such as fish ponds, paddy fields, reservoirs, and salt pans. Wetlands are diverse and differ in terms of salinity levels, climatic zones, the forms of plant life they support, surrounding geography, whether they are coastal or inland. Wetlands can store millions of cubic meters of flood water per hectare. By storing and slowing down water, wetlands allow groundwater to be recharged. By adding the ability to purify water from sediments, wetlands play an important role in delaying erosion. Wetlands have the potential to be highly bio-productive due to their high ability to absorb nutrients. Its ability to efficiently produce biomass may become important for the development of alternative energy sources. The habitat of wild animals is not only important for the conservation of the species, but also for providing a number of other recreational opportunities. As a conservation objective, habitats for wild animals are managed so that they are preserved and use resources in a sustainable manner. Some parts of the area are wetlands that are managed to provide habitat for migratory birds.
The costs	Establishment of wetland by using treated wastewater costs 100K US$ to 500K US$
Application potential in the country	Wetlands are swamps and marshes, wet grasslands and oasis lands, estuaries, deltas and tidal plains, offshore areas, mangroves and coral reefs Man-made sites such as fish ponds, paddy fields, reservoirs, and salt pans. The primary functions that wetlands perform are: water purification, water storage, vital productivity, and provision of habitat for wildlife.
Technical aspects (geographical applicability range, maturity)	Wetlands are diverse and differ in terms of salinity levels, climatic zones, the forms of plant life they support, surrounding geography, whether they are coastal or inland. Wetlands help purify water by removing excess nutrients.
Potential for reduction of vulnerability	Wetlands can even purify and absorb harmful bacteria from the water. Their complex food chains host a variety of microbes and bacteria that invertebrates

	feed on. These invertebrates can purify up to 90% of bacteria from water in this way.
Social, economic, and environmental benefits	Man-made sites such as fish ponds, paddy fields, reservoirs, and salt pans. These forms of wetland can be a permanent source of income for local people. Besides, tourism and migratory birds watching for people who view migratory birds as a hobby.

(12) Protecting Brooks and Natural Springs

Sector	Water
Technology	Protecting Brooks and Natural Springs
Technology characteristics	
Brief technology description:	Just as water naturally flows at the intersection of the water level and the surface of the earth, this phenomenon is called eyes. There are also several conditions that lead to the flow of springs from them. When there is an anhydrous layer above the water level, a water level is formed. When water leaks from the surface into the ground, a quantity of it is reserved above the anhydrous layer, resulting in a limited amount called the suspended water level. They are impermeable through cracks and fissures, or decomposition channels within these rocks. If these water courses intersect with the surface of the earth on one of the slopes, a water spring is formed. Water springs can be protected by installing a pumping system, a lined basin to protect the spring water, and an appropriate drainage system. In addition, a lined drainage ditch, (water drainage trench), can be made a lined hole above and around the area around the water springs that prevents the runoff from polluting the water source. If the area around the spring outlet is unstable or prone to erosion, stone chains or dry masonry can be used to stabilize the area. In the area surrounded by a fence or in the internal protection area (within a radius of 10-20 meters), all activities that have a risk of contamination are prohibited (such as: farming, sheep herding, making fires, using pesticides and fertilizers, building latrines, and the use of chemicals, etc.) In addition, another extended protection zone must also be established (within a radius of at least 100 meters). The area of that zone depends on the depth and type of soil covered. The required radius increases if the watershed is close to the surface and also if the soil is highly permeable. If the soil consists mainly of coarse sand and gravel, its permeability is high. The extended protection area should be increased and the radius should be greater than 150 meters. This area should be planted with a mixture of trees and shrubs to prevent erosion and strong runoff. It is not recommended to plant trees that absorb large amounts of water (such as eucalyptus) in the protection area. Examples of useful trees that can be planted: cypress trees and pine trees. But local varieties that do not absorb large amounts of water should be given more priority.
The costs	Brooks and springs protection technology costs from 5,000 to 50,000 US$ per site.
The application potential in the country	A fence that is built around the water source precisely defines the inner protection zone and prevents animals that may defecate or destroy the facilities from entering.
Technical aspects (geographical applicability range, maturity)	It is recommended to put up a barbed wire fence in the indoor protection area and to support the wires with hard bushes around the fence.

Potential for reduction of vulnerability	Fencing is mainly done for springs as they are more susceptible to surface contamination. But brooks may also need protection zones.
Social, economic, and environmental benefits.	This technology enhances stability of the community. Saving water for efficient economic use. It also helps keeping local ecosystem sound.

Annex 5 Prioritized Agriculture Sector Adaptation Technologies Fact Sheets

(1) Irrigation Systems

Sector	Agriculture
Technology	Irrigation Systems
Technology characteristics	
Introduction	The history of Yemeni irrigation is not only a measure of the rich cultural heritage of its people but also a vital source for planning sustainable development of Yemen's agriculture in the face of rapidly diminishing water resources. Irrigation is a technique, not an end. Development of irrigation systems must be accomplished as part of a resource use strategy that balances production needs, water supply needs, and environmental stability. This delicate balance has not remained the same over Yemen's history; nor should we argue, that existing methods should be preserved simply because they have worked in the past. The Yemeni farmer excelled in devising multiple ways to save water using closed irrigation channels and lined channels that do not allow water leakage, in addition to the channels extending under the surface of the soil, which are still working today in some areas such as Hadramout, Shabwah, Sana'a and Taiz. Total area equipped for irrigation in Yemen remained stable at 680 thousand hectares over the last 10 years.
Technology characteristics	Yemen agriculture depends on seasonal rainfed but also, they use several methods for irrigation, some inherited traditional methods, and some new methods. One of the famous traditional irrigation systems is traditional channels that, several modern irrigation systems are currently used in Yemen which will be discussed in the next lines.
A. Runoff irrigation systems	This system is based on controlling surface rainwater movement. This system is the oldest form of irrigation, which has been practised in semi-arid and arid areas for millennia in the ancient world. Ancient civilizations in arid and semi-arid regions developed very effective systems for harvesting rainwater in many parts of the world. Although, it is very difficult to date the historic bench terraces in Yemen. harvesting systems are characterized by collecting runoff water collected from a large catchment area. Many different types of flood irrigation systems have been used to harvest the flash floods in ancient Yemen
B. Traditional irrigation systems	Ma'aayeen system, where channels above and below the ground extend for kilometers from the water source to reclaim expansive areas of agricultural land. These systems are comparable to the qanat systems found in other parts of the world. water harvesting systems in areas of severe drought, especially on the Hadramout, Shabwah and Mahra, these include the karfaan (Traditional Tanks) and dams. The shurooj "plots" of land are directly irrigated by rainwater.
C. Drip Irrigation Systems:	Drip irrigation or trickle irrigation is a type of micro-irrigation system that has the potential to save water and nutrients by allowing water to drip slowly to the roots of plants, either from above the soil surface or buried below the surface. Advantages: • Increase in yield. • Continuous flow allows water to penetrate deep into the soil and down to the roots • Saves water up to 70% compared to flood irrigation. More land can be irrigated with the water thus saved. Uses 30–50% less water than other systems. The crop grows consistently, is healthier, and matures fast. • Early maturity results in higher and faster returns on investment. Fertilizer use efficiency increases by 30%. Prevents soil erosion and nutrient runoff. • The cost of fertilizers, inter-culturing, and labour use get reduced. • Fertilizer and Chemical Treatment can be given through Micro Irrigation System itself. • Controls fungal growth

	• Easy to modify Disadvantages: • The installation process needs time. • Sun heat affects tubes, sometimes they get broken of excessive heat production. • Plastic tubes affect soil fertility. Sun degrades plastic sometimes and that affects soil and fertilizers too. • Tubes get clogged sometimes. Water cannot pass through, and roots get dehydrated. • Loss of water by heat if not installed properly. • Drip irrigation systems develop salinity zones, which can affect plants and soil fertility. Cost: Conventional drip irrigation systems typically start at US $1500 – 2000 per hectare
D. Sprinkler Irrigation	Sprinkler irrigation system allows application of water under high pressure with the help of a pump. It releases water similar to rainfall through a small diameter nozzle placed in the pipes. Water is distributed through a system of pipes, sprayed into air, and irrigates in most of the soil types due to wide range of discharge capacity. Advantages: • Affordable and easy to set up • Easy to cover large areas • Water at your chosen time of day to minimize evaporation. • Suitable in all types of soil except heavy clay. • Water saving up to 30% - 50 %. • Suitable for irrigation where the plant population per unit area is very high. • Helps to increase yield. • Reduces soil compaction. • Mobility of system helps system operation easy. • Suitable for undulating land. • Saves land as no bunds are required. • Soluble fertilizers and chemicals use are possible. • Reduces labor cost. Disadvantages: • High operating cost. • Water will drift when there is a lot of wind. • A stable water supply is needed. • Saline water may cause problems. • Water must be free from sand, debris, and a large amount of salt Cost: The typical cost for an irrigation system ranges from $1,759 to $3,350.
E. Centre Pivot Irrigation	Centre Pivot Irrigation is a method of crop irrigation in which equipment rotates around a pivot and crops are watered with sprinklers. A circular area centered on the pivot is irrigated Advantages: • Water is distributed evenly • Covers large areas in a short period of time • Prevents water runoff • Operates at a lower pressure saving energy • High degree of automation, which can save a lot of labor; • There is no need to level the land, saving a lot of money and reducing environmental damage; • The service life is usually more than 20 years, and the investment per unit area is moderate; • Low operating and maintenance costs.

	Disadvantage: • The sprinkler intensity at the end of the unit is usually greater than 100mm/h, which is easy to produce short-term surface runoff; • Without the ground angle (arm) system, the leakage spray area is large, accounting for about 25%; with the ground angle (arm) system, the investment per unit area is too high; • Dragging the transfer plot is not convenient Cost: Center pivots can range in cost from $60,000 to $140,000, depending on age and options, although some used systems have been available for as low as $30,000.
F. Furrow Irrigation Systems	Furrow irrigation is a method of supplying water to crops through shallow, evenly spaced furrows. Furrows are made with a hipper that forms parallel beds and are usually spaced 30 or 38 inches apart. Water flows from a pump to furrows in lay-flat plastic pipes. Holes are punched in the pipe to obtain the desired flow rate. Advantages: • Low installation cost • Saves time and labor • A quick mass area irrigation is possible. • This is a cost-efficient method as it minimizes water loss of gravity irrigation system. • The unit cost of pumped water is lower which saves money. • Recirculating irrigation runoff water is possible. • It is possible to reduce chemical leaching in furrow irrigation. • Higher crop yields can be ensured through proper furrow irrigation practices. Disadvantages • Hassle maintaining water flow. Experience and soil surface evaluation is required to set the number of gates opened or tubes set. Otherwise, slow water advance or surface runoff can occur. • Not Suitable for sandy soil. • Salts are accumulated in ridges of soil between the furrows. Re-plowing the field for each new crop can redistribute the accumulated salinity. • The movement of farm equipment is difficult in the furrow fields. • Initial filed preparation labor cost is high. • Not suitable for some crops Cost: The estimated annual capital costs of siphon tube irrigation systems range from $13.34 per acre, for a traditional system with 1/2-mile furrows, to $13.82 per acre, for 1/4-mile furrows, and $14.17 per acre, for 1/6-mile furrows

(2) Rainwater Harvesting and Storage for Agriculture

Sector	Agriculture
Technology	Rainwater Harvesting and Storage for Agriculture
Technology characteristics	
Introduction	Rainwater harvesting is a method for bringing, collecting, storing, and conserving local surface runoff for agriculture almost in arid and semi-arid regions like Yemen. Rainwater harvesting practices is the simplest and oldest method by which rainfall is collected and stored for future usage, collected from a roof-like surface and redirected to a tank, cistern, deep pit like well, aquifer, or a reservoir with percolation, so that it seeps down and restores the groundwater. The collected rainwater from surfaces on which rain falls may be filtered,

	stored, and utilized in different ways or directly used for recharge purposes the practice has less storage cost and no maintenance cost involved except for periodical cleaning. Various forms of rainwater harvesting have been used traditionally throughout the centuries. Some of the earliest agriculture, in Yemen was based on techniques such as diversion of "Wadi" flow onto agricultural fields. The desert Arabian Peninsula. The importance of traditional, small scale traditional systems of rainwater harvesting in Yemen has recently been recognized. Rainwater harvesting is a type of harvest in which the rainwater is collected and stored for the future use, instead of allowing them to run off. However, it is used for orchards/gardens, raising livestock, irrigation, domestic use with proper treatment etc. The harvested water can also be used as drinking water, longer-term storage, and for other purposes such as groundwater recharge. This type of practice is widespread in most areas of Yemen, especially in the mountainous slopes, valleys, and high basins in both the northern and southern governorates and is considered a cultural knowledge of the local communities acquired since ancient times.
Technology characteristics	Water can be collected from roofs, dams and ponds can be constructed to hold large quantities of rainwater so that at the time of little or no rainfall occurs, enough is available to irrigate growing crops Water harvesting enables farmers to store water when it is plentiful and make it available when it is scarce. Three categories of small-scale storage can be distinguished: (1) soil moisture storage (2) groundwater storage and, (3) surface storage. Normally water harvesting is practiced in arid and semi-arid regions for agriculture, and it is more effective in areas situated near hillside or where cultivation is difficult due to a large portion of bare soil. To enhance irrigation in arid environments, ridges of soil are constructed to collect and prevent rainwater from running down hills and slopes with investing the collection water on the terrace's practices.
A. Surface runoff harvesting	Simply surface runoff from rainwater is stored for future use. Surface water can be stored by diverting the flow into reservoirs on the surface or underground. Such stored water is used in farming, for cattle and for general domestic use. Rooftop rainwater/storm runoff can be harvested in rural areas through: • Recharge Pit. • ponds • Al-Majiel • waterers • Water barriers • Cisterns • Water tank
B. Groundwater recharge	It is a hydrologic process where water moves downward from surface water to groundwater. Recharge is the primary method through which water enters an aquifer. The aquifer also serves as a distribution system. The surplus rainwater can be used to recharge groundwater aquifers through artificial recharge techniques. The construction cost is discretionary and depends on the location, availability of raw materials, labor, currency, and market rates. However, these are very common in Yemen. There are some ancient rainwaters harvesting methods followed in Yemen including ponds, "Al-Majel" in the north parts of the country and "Al-Maeen" in Hadramout and Shabwah.
C. Spate water diversion structures (Flood water harvesting)	Spate irrigation is an ancient water harvesting system by which floodwater is diverted from its wadies and channelled to basins where it is used to irrigate crops and feed drinking-water ponds, serve forest and grazing land and recharge local aquifers. In Yemen, large traditional

	spate systems consisting of numerous individual intakes and cannels irrigating areas were developed in individual Wadis. The spate irrigation areas in Yemen vary and difficult to measure, depending on the availability of rainfall and flood water. The name of the diversion structures of the traditional spate irrigation system differs from area to area. The terms used to depend on the size, order length, type of building material, shapes, way of built and position in the Wadi.
D. Major categories of Rainwater Harvesting	In crop production systems, rainwater harvesting is composed of a runoff producing area normally called the catchment area and a runoff utilization area normally called cropped basin Therefore rainwater harvesting systems for crop production are divided into different categories basically determined by the distance between the catchment area and cropped basin as follows: In-situ rainwater harvesting The first step in any rainwater harvesting system involves methods to increase the amount of water stored in the soil profile by trapping or holding the rain where it falls. This may involve small movements of rainwater as surface runoff to concentrate the water where it is wanted most. In-situ rainwater harvesting is sometimes called water conservation and is basically a prevention of net runoff from a given cropped area by holding rainwater and prolonging the time for infiltration. This system works better where the soil water holding capacity is large enough and the rainfall is equal or more than the crop water requirement, but moisture amount in the soil is restricted by the amount of infiltration and or deep percolation. The in-situ rainwater harvesting is achieved mainly by the following means: Deep tillage: Tillage normally assists in increasing the soil moisture holding capacity through increased porosity, increasing the infiltration rates and reducing the surface runoff by providing surface micro-relief or roughness which helps in temporary storage of rainwater, thus providing more time for infiltration. The depth of tillage is the most important factor controlling or affecting soil moisture characteristics. Deep tillage helps to increase porosity, reduce surface sealing of the soil and permit root proliferation to exploit soil water and nutrients. Depth of tillage is Significant reducing the surface runoff and increases crop yields. Contour farming and ridging: This is important where cultivation is done on slopes like the western mountains of Yemen. All farm husbandry practices such as tilling and weeding are done along the contours to form cross-slope barrier to the flow of water. Where this is not enough, it is complemented with ridges which are sometimes tied to create a high degree of surface roughness to enhance the infiltration of water into the soil.
Advantages	• Rainwater harvesting systems are cost-effective, provide quality water, lessens dependence on wells and are easy to maintain. • Storing water underground is environment-friendly; groundwater is not directly exposed to evaporation and pollution. No land is wasted for storage purpose and no population displacement occurs. • Reduces soil erosion and flood hazards by collecting rainwater and reducing the flow of storm water to prevent urban flooding. • Harvesting rainwater mitigates the effects of drought. Rainwater is mostly free from harmful chemicals, which makes it suitable for irrigation purposes. • Rainwater Harvesting increases the productivity of aquifers resulting in the rise of groundwater levels and reducing the need for potable water. • Local people can be easily trained to implement such technologies, and construction materials are usually readily available.

	• Use of rainwater harvesting technology promotes self-sufficiency and has a minimal environmental impact. • Rainwater harvesting and its application to achieving higher crop yields can encourage farmers to diversify their enterprises.
Disadvantages	The main disadvantage of rainwater harvesting technology is the - limited supply and uncertainty of rainfall. Rainwater is not a reliable water source in dry periods or in time of prolonged drought. - Low storage capacity will limit rainwater harvesting potential, whereas increasing storage capacity will add to construction and operating costs making the technology less economically viable. - The effectiveness of storage can be limited by the evaporation that occurs between rains. - In water basins with limited surplus supplies, rainwater harvesting in the upstream areas may have a damaging impact downstream and can cause serious community conflict. - When runoff is generated from a large area and concentrated in small storage structures, there is a potential danger of water quality degradation, through the introduction of agro-chemicals and other impurities.

(3) Agricultural Soil Conservation Methods

Sector	Agriculture
Technology	Agricultural Soil Conservation Methods
Technology characteristics	
Introduction	The traces are traditional practice technology in Yemen. The agricultural terraces are taken care of through permanent maintenance and good drainage for excess rain, as well as ploughing operations. The loss of water is compounded by the loss of agricultural land as dryland terrace systems collapse through abandonment. The erosion of these terraces results not only in direct loss of the terrace, but also threatens irrigated land, especially along the upper and middle reaches of major coastal Wadis. Once the terraces are destroyed and the soil washed away, farmers are forced off the land and must seek employment elsewhere. The terraces constructed on even the more isolated mountain slopes in Yemen are striding evidence of centuries of labor and ingenuity. Farmers literally carved unusable steep slopes into productive land where agriculture would not normally occur. The common small, narrow terraces, when properly maintained, enhance water retention in the soil so that there is more crop per drop than would occur on flat dryland plots. In addition, many of the terrace systems utilize slope runoff so that plots receive up to 40 percent more moisture than that from direct rainfall on the soil. The use of slope runoff on terraces represents a resourceful ecological response to fluctuations in rainfall and the relative lack of suitable soil in much of the mountainous area. The ingenuity of terrace construction is still quite visible in the Yemeni highlands. Farmers considered a variety of factors in the local terrain to maximize water collection but not to the point of erosional stress. On steep slopes of more than 30 ° incline terraces are quite narrow, at times no more than a meter in width and supporting as little as one row of crop or trees. In more gentle slopes up to 15° incline the terrace may be up to eight meters wide. Few of these large terraces exceed ten meters in length and most are much shorter. A slope is rarely continuous, so existing rocks and boulders are often incorporated into terrace walls. The rocks for terrace walls are generally available locally, but soil usually has to be brought in. In the past this had to be done by donkey load from alluvial fans far below the system. Most terraces are constructed to take advantage of the local water regime. Where there is a spring or spring line, terraces will be in clusters below so that a gravity-flow sequence can

	irrigate the system through a common channel network. In these Spring field irrigation systems, the water may descend through channels over a kilometer to the farthest plots. On the higher mountain slopes, where runoff harvesting is practiced, a group of terraces will be arranged so that excess flow will be carried off through the channels. Since farmers will not be present when the flooding occurs, it is important to allow for ample drainage of the flow in order to avoid erosion of the plots.
A. Terraces	Terraced fields were constructed in Yemen as early as 5000 years ago. As one of the oldest techniques for conserving water and soil, terracing is common in mountainous regions that are subjected to substantial population pressure. Terraces are built along contour lines to increase the arable surface area and conserve water and soil on mountain slopes in the overall Yemen country. Terraced fields are different shapes and sizes and consist of a flat section and a near-vertical riser, protected by a wall of dry stones, soil, grass, or trees. The height of the riser or wall can be from several decimeters to a few meters, with a continuous or intermittent structure comprised of single walls or a complex series of walls (Arnaez et al., 2015)[12]. The flat surface created by terracing is generally used for cultivation. The influences of geological and land use settings on shallow landslides are triggered by an intense rainfall event in a coastal terraced environment (Cevasco et al., 2014)[13].
Advantages	• Reduced runoff and water conservation • Erosion control and soil conservation • Increase of crop yield • Habitat and protects biodiversity protection • Terracing creates a cultural landscape that reflects human wisdom in understanding the relationship between man and a specific environment
Disadvantages	• Disruption of water circulation • Erosion/mass movement due to poorly designed terraces • Deterioration of soil quality • Soil erosion after terrace abandonment.
B. Tillage	Tillage is the agricultural preparation of soil by mechanical agitation of various types, such as digging, stirring, and overturning. The operation can be done by hand, animal, or machine. Tillage can be to different depth according to the need. Another significant aspect is to choose the proper time for field operations, depending on the soil types. For example, clay ones are better to till after harvesting while other types are better to plow before seeding. Also, handling wet soils lead to their compaction. The tillage has some negative aspects when it is improbably done, which can result in soil erosion or reduce organic matter in the soil.
C. Contour Farming	The soil conservation method proves efficient in slope territories and suggests planting species along the contour. Rows up and down the slope provoke soil erosion due to water currents while rows along the contour restrain it. The impact of contour farming is similar to terraces, it helps to conserve soil and reduce its degradation processes.
D. D. Strip Cropping	In this case, farmers combine high-growing crops with low-growing ones for the sake of wind protection, like when corn grows in strips with forage crops. The strip cropping practice works even better when high-growing crops are intensified in the sides where winds blow most frequently. An extra benefit is the organic matter material from the low crops.

[12] Arnaez, J., Lana-Renault, N., Lasanta, T., Ruiz-Flano, P., & Castroviejo, J. (2015). Effects of farming terraces on hydrological and eomorphological processes. A review. Catena, 128, 1 2 2 e134.
[13] Cevasco, A., Pepe, G., & Brandolini, P. (2014). Bulletin of Engineering Geology and the Environment, 73, 859e875.

E. Windbreaks	This soil conservation practice is used to reduce the power of winds and their disruptive effect on soil. These are trees or bushes to shelter crops from winds planted in several rows. Depending on the number of rows, we can distinguish windbreaks properly (up to five rows) and shelterbelts (six and more). Windbreak vegetation also provides a living environment for wildlife and eliminates soil abrasion on crops due to strong wind blows.
F. Crop Rotation	Crop rotation farming suggests changing agroforestry species instead of planting the same one for many subsequent seasons. Farmers applying this soil conservation method to get numerous benefits. Crop rotation helps them improve the earth's structure with diverse root systems, mitigate pest establishments, and to add nitrogen to the land with legumes known as nitrogen-fixing plants. The choice of crops to rotate is specific for each agricultural enterprise and highly depends on historical weather and productivity data. Some plants proved to be efficient in recent years, and some did not.
G. Cover Crops	This soil conservation technique is another way to avoid bare soils and additionally benefit from planting cover crops – secondary species – in-between growing cash crops for different reasons like to: ✓ produce forage and grazing material for cattle; ✓ provide green manure; ✓ assist in weed control; ✓ retain moisture; ✓ ensure a natural environment for microorganisms and minor animals; ✓ balance nitrogen concentration (either releasing or accumulating it with certain plants).
H. Buffer Strips	These are trees and bushes on the banks of water bodies to prevent sediment, and water wash-offs. Their roots fix the soil to avoid slumping and erosion, canopies protect from excessive sunlight to water inhabitants and falling leaves are a source of organic matter and food for minor aquatic animals.

(4) Reuse of Treated Wastewater and Grey Water

Sector	Agriculture
Technology	Reuse of Treated Wastewater and Grey Water
Technology characteristics	
Technology characteristics	Once freshwater has been used for an economic or beneficial purpose, it is generally discarded as waste. In many countries, these wastewaters are discharged, either as untreated waste or as treated effluent, into natural watercourses, from which they are abstracted for further use after undergoing "self-purification" within the stream. Through this system of indirect reuse, wastewater may be reused up to a dozen times or more before being discharged to the sea. Such indirect reuse is common in the larger river systems of Latin America. However, more direct reuse is also possible: the technology to reclaim wastewaters as potable or process waters is a technically feasible option for agricultural and some industrial purposes (such as for cooling water or sanitary flushing), and a largely experimental option for the supply of domestic water. Wastewater reuse for drinking raises public health, and possibly religious, concerns among consumers. The adoption of wastewater treatment and subsequent reuse as a means of supplying freshwater is also determined by economic factors. Sources of wastewater are from mosques, kitchen water, washbasins, bathtubs and washing machines are ways to reduce, reuse and better manage of water.
Cost:	15000 USD/ UNIT (medium size)
Advantages	1. This technology reduces the demand on potable sources of freshwater. 2. It may reduce the need for large wastewater treatment systems, if significant portions of the waste stream are reused or recycled. 3. The technology may diminish the volume of wastewater discharged, resulting in a beneficial impact on the aquatic environment.

	4. Capital costs are low to medium, for most systems, and are recoverable in a very short time; this excludes systems designed for direct reuse of sewage water. 5. Operation and maintenance are relatively simple except in direct reuse systems, where more extensive technology and quality control are required. 6. Provision of nutrient-rich wastewaters can increase agricultural production in water-poor areas. 7. Pollution of seawater, rivers, and groundwaters may be reduced. 8. Lawn maintenance and golf course irrigation are facilitated in resort areas. 9. In most cases, the quality of the wastewater, as an irrigation water supply, is superior to that of well water
Disadvantages:	1. If implemented on a large scale, revenues to water supply and wastewater utilities may fall as the demand for potable water for non-potable uses and the discharge of wastewaters is reduced. 2. Reuse of wastewater may be seasonal in nature, resulting in the overloading of treatment and disposal facilities during the rainy season; if the wet season is of long duration and/or high intensity, the seasonal discharge of raw wastewaters may occur. 3. Health problems, such as water-borne diseases and skin irritations, may occur in people coming into direct contact with reused wastewater. 4. Gases, such as sulfuric acid, produced during the treatment process can result in chronic health problems. 5. In some cases, reuse of wastewater is not economically feasible because of the requirement for an additional distribution system. 6. Application of untreated wastewater as irrigation water or as injected recharge water may result in groundwater contamination.

(5) Agriculture research, awareness-raising, and extension

Sector	Agriculture
Technology	Agriculture research, awareness-raising, and extension
Technology characteristics	
Introduction	The agricultural sector in Yemen contributes to about 20% of the total internal revenues of the country and employs around 54% of the total workforce. Most of the country's 22 million inhabitants reside in rural areas and work in agriculture or agricultural-related activities. The total agriculture area is estimated at 1 668 858 ha, of which, 1,132,910 ha (68%) is cultivated while the uncultivated area was 535,948 ha (32%). The growth rate in the agricultural sector averaged only 2.4% per year, compared to the population growth rate of 3.7%, one of the highest growth rates in the world.[14] On the other side the producer services especially research and extension are underfunded, and their effectiveness has dropped dramatically. According to Agricultural Research and Extension Authority (AREA), agricultural extension has made considerable contributions towards the qualitative and quantitative improvement of farm production. Examples of these contributions are introducing several high yielding varieties of some crops, disseminating, and encouraging farmers to use modern farm technologies such as fertilizers, machines and equipment, agri-techniques, and pesticides. The number of qualified male and female extension staff has increased along with necessary infrastructures such as buildings of Agricultural Blocks, Extension, training, information, and Rural women improvement centres, and nurseries, but extension is facing several problems stemming from poor financial and organizational position, and unbalanced distribution of human and material resources between regions and areas. Among other pitfalls, extension work in the past has

[14] FAO, Yemen State of plant genetic resources for food and agriculture

	focussed on irrigated, male farmers and cash crops like vegetables and fruits, at the expense of rain–fed farming, male farmers, and livestock production.[15]
Technology characteristics	Despite the numerous means of communications, awareness on the importance of agriculture is still weak, however there was an agriculture extension programme and still have some activities, but these programmes need to be updated and revived to cover more themes and areas and should be design in simple and attractive manner building on the rich endogenous knowledge, traditional approach and new science finding. A combination of endogenous knowledge and modern approaches in raising awareness need to be developed and incorporated in the national campaigns and awareness programmes addressing agricultural issues in national and local level. Research and extension focused on productivity and sustainability, breed Improvement and genetic improvement get low attention from the decision-makers especially with current armed-conflict situation. This technology will focus on. ✓ Research development, and extension on high value crops. ✓ Applied community-based research on productive, drought-tolerant, salinity-tolerant, and high-nutritional value food and fodder crops. ✓ Testing and possibly introducing the Farmer Field Schools (FFS) approach that have been currently experimented by international projects. ✓ Enhanced access for women to inputs and extension services and their involvement in extension activities. ✓ Plant protection with focus on Integrated Pest Management (IPM). ✓ Produce extension and awareness materials for locals and decision-makers. ✓ Support Qat substitution interventions and activities
Advantages	• Low to medium cost • Direct impact and improvement of agricultural sector • Sustainability can be gain by trained staff and knowledge sharing • Possibility of using new telecommunication technology in awareness and extension • Attracting research on climate changes adaptation
Disadvantages	• Needs qualified staff and experiences • Difficulties in measuring the impacts of extension and awareness • Research and its impacts take a long time to obtain • Failure to apply the technology could lead to loss of traditional agricultural knowledge and loss of technology ownership by farmer • Unresponsiveness to the variation in farmers' needs
Cost	to be specified when programmes details setup
Country Social development priority	• Improve community livelihoods • Improve farmers' skills and agricultural knowledge • Empower women participation and involvement
County economic development priority	• Food security • New economic opportunities • improve oriented research towards the development of the agricultural sector
County environmental development priority	• Reducing pesticides by using IPM • Climate change adaptation by introducing crop tolerant varieties • Environmental awareness raising will be part of all awareness packages and activities

[15] Ismail A. Muharram Khalil M. Alsharjabi, The situations of Agricultural Extension in Yemen: A quick Overview, Agricultural Research and Extension Authority (AREA), Dhamar, 2011

(6) Timing of farming practice

Sector	Agriculture
Technology	Timing of farming practice
Technology characteristics	
Technology characteristics	• Traditional farming methods that sequester carbon have existed for millennia. For example, minimizing soil disturbance through no-till farming reduces carbon loss to the atmosphere. Diversifying crops and planting legumes, perennials and cover crops return more carbon to the soil and sustain soil microbes that play key roles in carbon storage. • Early/dry planting, staggered planting, and altered feeding times make use of the shift in the availability of natural resources occurring due to climate change • Changing the timing of farming practice is typically optimized when used in conjunction with other practices, e.g., different seed types and cultivars, and production-enhancing inputs such as fertilizer • Information on likely weather conditions throughout the season is required for early/dry planting, staggered planting and changing feeding times to be successful • Access to inputs, including seeds/feed, labor and machinery determine the likelihood of/extent of success from changing the timing of farming practice • Changing the timing of farming practices and technologies is likely to have positive environmental benefits because it is done with the intention of linking the crop production cycle with the availability and quality of environmental resources to support the growth cycle
Cost	The cost more related to awareness, extension and capacity building programmes
Advantages	1. Higher yield potential 2. More stored soil moisture 3. Longer day length at pollination 4. Early harvest before cotton and peanuts 5. Less insect and disease pressure 6. Lower temperature during pollination
Disadvantages	1. Difficulty to follow up by farmers 2. Presenting the agriculture calendar need to be clear especially for illiterate people. 3. Need times to be implemented

(7) Integrated Pest Management

Sector	Agriculture
Technology	Integrated Pest Management
Technology characteristics	
Introduction	Yemeni farmers traditionally possessed several methods of control suitable to different locations and crops. These different biological, mechanical, cultural methods were both protective and preventive. These methods are known recently as Integrated Pest Management (IPM) Integrated Pest Management (EPM) is an effective and environmentally sensitive approach to agricultural pest management that uses a range of practices to manage the population and maintain a level below at which it can cause economic injury and affect

	agricultural production while providing protection against hazards to humans, animals, plants, and the environment. IPM makes full use of natural, physical and cultural processes and methods, including host resistance and biological control as opposed to synthetic chemicals. IPM emphasises the growth of a healthy crop with the least possible disruption of agro-ecosystems, thereby encouraging natural pest control mechanisms. Chemical pesticides are used only where and when these natural methods fail to keep pests below damaging levels”
Technology characteristics	IPM involves an integrated approach to the prevention and/or suppression of organisms harmful to plants through the use of all available information, tools and methods - Crop rotation - Use of adequate cultivation techniques (e.g. stale seedbed technique, sowing dates and densities, under-sowing, conservation tillage, pruning and direct sowing), - Use, where appropriate, of resistant/tolerant cultivars and standard/certified seed and planting material, - Use of balanced fertilization, liming, and irrigation/drainage practices, - Preventing the spreading of harmful organisms by hygiene measures (e.g., by regular cleansing of machinery and equipment), - Protection and enhancement of important beneficial organisms, e.g., by adequate plant protection measures or the utilization of ecological infrastructures inside and outside production sites[16]. Integrated Pest Management have five basic strategies: 1)Monitor (Insect types and level), 2) Identify the pest, 3) Assess the threats, 4) Implement treatment and 5) Evaluate success. To implement these strategies, the most important factor is availability of experienced staff, so the first intervention is Capacity building of extension officer and farmers (scouting, IPM Principle/ strategies that include a combination of behavioral, biological, chemical, cultural, and mechanical methods to reduce pest populations to an acceptable level.
Cost	For implementing this technology, we need - Intensive capacity building programme - Management materials and equipment - for biological control we need insect breeding station A very rough estimate is that IPM service will cost 7–14 USD per unit per month[17].
Advantages	• Control insect population, thus reducing crop damage, increasing crop yield and income of farmers • In long run, less insecticide will be used/ minimize air and water pollution. • Reduction in public & private expenditures on insecticides and fungicides cost. • Increase the farmer's knowledge and experience in IPM for long-term management. • Reduction in the use of insecticides leads to safer food, improve health of farmers. • Farmers can sell their products as organic and get higher prices
Disadvantages	• Need strong cooperation between neighbouring farmers • Less interest by farmers especially with availability of chemical pesticides and their high efficiency for insect control • Sometimes the farmers have difficulties in understanding the IPM
Challenges	• Farmers prefer pesticides as they are easy to get and apply and provide effective and direct control. • Poor linkage between research and extension • Lack of policy for IPM

[16] https://food.ec.europa.eu/plants/pesticides/sustainable-use-pesticides/integrated-pest-management-ipm_en
[17] http://www.stoppests.org/frequently-asked-questions/how-much-does-an-ipm-programme-cost/

(8) Biological Control

Sector	Agriculture
Technology	Biological Control
Technology characteristics	
Introduction	The Chinese and Yemenis were among the first to use biological methods to control agricultural pests. Traditional farmers in Tehama, Taiz and Hadramout used to collect predatory ants (*qacs*) from mountains to control date palm pests that attack the fruit. This method was described in the 13th century agricultural text of King al-Ashraf Umar bin Rasul Yemeni leader. When we asked old farmers about this practice, they confirmed it. These farmers also said that they used sticks on which the ants travel from one tree to another. Some farmers are still following this practice. Three species of predatory ants used to control infestation of the lesser date moth, and predatory ants are also used in Tehama to control termites[18]. Biological control can be kept in place for a much longer time than other methods of pest control. Biological control can be cost-effective in the long run. Although it may cost a bit to introduce a new species to an environment, it's a tactic that only needs to be applied once due to its self-perpetuating nature. Most important of all, it's effective. Yemeni farmers traditionally possessed several methods of control suitable to different locations and crops. These different biological, mechanical, cultural methods were both protective and preventive. These methods are known recently as Integrated Pest Management (IPM)
Technology Characteristics	Biological control is a green alternative to chemical or mechanical control methods. The Natural enemies can be imported, augmented, or conserved. Natural enemies introduced to the environment can sustain themselves, very little effort is required to keep the system running fluidly.
Cost	A very rough, approximate cost of releasing biocontrol agents is somewhere between $300 to $900/ ha
Advantages	1. Biological control is a green alternative to mechanical or chemical-based pest control. The vast majority of the time, whatever predator is introduced will only control the population of the pest they are meant to target. For example, whereas weed-killing chemicals can also destroy fruit-bearing plants, biological control allows the fruit to continue growing while the weeds are destroyed. 2. Biological control can be kept in place for a much longer time than other methods of pest control. 3. Biological control can be cost-effective in the long run. Although it may cost a bit to introduce a new species to an environment, it's a tactic that only needs to be applied once due to its self-perpetuating nature. 4. It's effective. Whatever pest population you want controlled will no doubt be controlled. Because the predator introduced will be naturally inclined to target the pests, very often you'll see the pest population dwindle.
Disadvantages	1. Biological control can be fickle. While it's supposed to manage one pest, there is always the possibility that your predator will switch to a different get. Not only that, introducing a new species to an environment runs the risk of disrupting the natural food chain. 2. It's a slow process.

(9) Beekeeping and honey production

Sector	Agriculture
Technology	Beekeeping and honey production
Technology characteristics	

[18] https://books.openedition.org/cefas/2879

Introduction	Traditional Yemeni beekeepers characteristically move their hives in search of suitable and desirable pastures for their bees. The diversity of climate and topography plays a vital role in the plant cover diversity. Flowering plant species have different flowering times in different locations, so beekeepers change their honeybee locations according to the environmental rhythms of their bees' food. Some beekeepers stay in one location suitable for their bees throughout the year, sometimes close to their home. Adding supplement liquid during the drought season is a practice done by most beekeepers. The modern introduced Langstroth beehives Production is done in a very traditional manner and lacks the necessary tools and equipment. In 2015, according to data from the Ministry of Agriculture, the number of bee colonies amounted to more than 1.3 million, and Yemen's honey production was approximately 2,600 tons annually. Although, the Sector faces several challenges including the ongoing war and conflicts along with floods and torrents that have destroyed and washed away thousands of Yemeni beehives, and Yemeni beekeepers incurred heavy losses. The battles hindered the beekeeper's ability to move at night, especially the battles that took place near the bee pasture, the restrictions on the movement of foreign trade between governorates, and the difficulties of exporting products outside the country that took part in the decline of the Yemeni honey trade.
Technology Characteristics	• Maintaining the Yemeni honeybee breed pure in isolated areas and preparing programmes to develop bee breeding. Improving honeybee production and marketing. • Planting Al-Sidr trees (*Ziziphus spina-christi*) to replace the cut ones to improve the honeybee pastures and reserving the soil from erosion and water retention to increase the chances of groundwater recharge. • Organize beekeepers in formal or informal groups to discuss their problems and interventions and create suitable projects. • Linking the beekeepers with government, non-government agencies, and private sectors that provide beekeeping goods and services. • Establishing capacity-building programmes in technical and managerial aspects for individuals and farmers' organizations involved in beekeeping value-adding, and honey production.
Advantages	• Increase pollination and improve pasture and yield • Improve people income • Improve nutrition, honey is a highly nutritional food • Low cost and easy to learn
Disadvantages	• Need experience and continues care • Easy to loss the hive if not protected • Low productivity in some season can make farmer less interest • Beehives attached by diseases, other insects, bird and reptiles • Lack of beekeeping materials and bees • Bees sensitive to pesticides and insecticides
Cost	The technical training and financial grant of 350,000 YER (equivalent to US$ 60019, currently 300US$ “2022”) and the money can be returned in one season. Training depends on the number of trainees, location, consultant fee and other related costs.
Social impacts	Source of income for thousands of Yemeni families Health improvement
Economic impacts	Strengthening community resilience

[19] https://www.undp.org/yemen/publications/beekeeping-value-chain

	Improve national income especially that honey exported and have high reputation and value
Environmental impacts	Enhance biodiversity by pollination Increase vegetation cover especially with planting and conserving Sider trees and other trees utilized by bees

(10) Management of natural and animal pasture

Sector	Agriculture
Technology	Management of natural and animal pasture
Technology characteristics	
Introduction	Yemen has about 21 million animals, out of which 90% accounts for small ruminants (Sheep and Goats)[20]in an area of about 16 million hectares as natural range land and pasture. Pastureland forms an important resource in view of its environmental role, provision of forage for herds and flocks and due to its economic significance as a cheap source of livestock feed. Pasture degradation and desertification are among the most serious environmental problems. over-use by grazing animals, uprooting of large quantities of plants for fuel, encroachment of urban and industrial development and lowering of groundwater table due to over-pumping in wadi-bottoms and lower deltas of coastal plains. The consequence of this is reduction in rangelands area, declined forage production and undesirable shift in species' composition (decline in species' diversity" Pasture is an important source of livestock food and herder's livelihood in Yemen. Well managed pasture helps to protect the environment and natural resources and continue to sustain ecological functions and services.
Technology characteristics	Desertification, land degradation and loss of pastureland are integrally linked with land use and the gradual collapse of traditional practices including terraces systems. This leads to further land development incursions which reduce the vegetative cover, and accentuates the consequences both on the terraced, downstream, and coastal plains. The collapse of various production systems results in poverty expansion. Climate change impacts in terms of drought and extreme weather events are serious and often critical in Yemen where agricultural land is limited, holding per family remains small, rainfall and surface water flows are erratic, and groundwater is being overexploited and used inefficiently. The desire to deal with the problems comes at a critical point in the future of the country. The overall objective of the project is to demonstrate in pilot areas a successful and transferable for combating desertification in the mountainous areas and lower lands rangelands through integrated management of natural resources with focus on water and vegetative cover including using low quality water in dryer environments. This can be done through some interventions such as: • Animal health improvement such as vaccination • Improve animal feed and watering • Determining the rangeland carrying capacity, the appropriate range grazing system for the development of intensive rangeland areas and the appropriation of supplementary feeding for each range system. • Awareness and capacity building and institutional strengthening of national institutes and community leaders on degradation processes. • Analysis of status of land degradation in the pilot areas. • Plan, design, and construct of maintaining water and soil conservation measures at selected locations in the pilot areas • Establishing plantation of selected plants species including forage shrubs, wood, and shade and industrial plant species
Advantages	• Improve livelihood and income • Protection of soil and enhance biodiversity

20 Yemen: Rapid Assessment Report on Livestock Sector FAO 2018

	• Low to medium cost • Impacts cover large areas
Disadvantages	• Require large management efforts • Difficulties dealing with dispersed pastoralists • Time consuming process
Cost	The cost will be distributed to: - Management cost (staff, travelling, consultants, extension officers) - Extension, awareness, and capacity building - Community-based projects

(11) Natural fertilizer

Sector	Agriculture
Technology	Natural fertilizer
Technology characteristics	
Introduction	In Yemen farmers for thousands of years use cow dung for fertilizing their farms and in some parts of Yemen such in Tehama they use cow dung replacing fuelwood. It is a very effective's alternatives to chemical fertilizers by enhancing productivity in long term with maintaining the soil health and enhances the microbial population especially for food production and it may be applied directly to soil or pretreated by composting before soil application. Due to the increasing prices of chemical fertilizer and non-efficient role in long term to sustainable production, there is a need of application of organic manure including cow dung for enhancing maximum productivity in sustainable way with better soil health. Compost may be used alone, or as a compliment to commercial fertilizer applications; in some cases, manure and compost offset the amount of commercial fertilizer purchased by farmers or gardeners.
Technology characteristics	Composting is a widely accepted practice as a sustainable practice used in all systems associated with climate-smart agriculture. It offers enormous potential for all sizes of farms and agro-ecological systems and combines environmental protection with sustainable agricultural production. Composting converts the nitrogen contained in the manure into a more stable form. The nitrogen in compost is less susceptible to leaching. Composting materials can be: • Carbonaceous materials such as date palm founds (green), green grass, bark and leaves. There are invasive green herbs such as *Tephrosia sp*. can be tested as green material for compost. • Nitrogenous materials such as livestock manure, dry plant materials, fish scraps and grass clippings
Cost	The cost depends on the source of manure, other composting process will need workforce for collecting, watering and soil turn up. Estimated cost 150 USD/person. Producing compost can be for family or commercial purposes.
Advantages	• Improvement of soil structure • Sustainable and Environmentally Friendly • Reduce chemical Fertilizers and Pesticides • Avoid Plant Damage Threat • Simple and low cost • Depends on existing raw materials • Reduce the impacts of manure on water streams

Disadvantages	• Nutrient Levels Are Low • Composting needs manure collection which can be difficult • Composting needs water so it is not easy to implement it in dry areas • The period between agriculture seasons sometimes is short and not enough to produce compost
Environmental benefits	Improving Nutrient Management to optimize the rate, method and among of fertilizers can reduce emissions of the potent GHG N2O. Organic fertilizers are naturally available mineral sources that contain a moderate amount of plant essential nutrients. They reduce the necessity of repeated application of synthetic fertilizers to maintain soil fertility. The improper use of organic fertilizers leads to over fertilization or nutrient deficiency in the soil. The manure distributed on land cause suppresses plants grow
Social benefits	Support family income by improving agriculture production Reduce the animals' manure and its good impacts on family health
Economic benefits	Increase country income through increase of family income Efficiency of using the manure, which sometimes treated as waste

(12) Genetic Origins and Gen Bank

Sector	Agriculture
Technology	Genetic resources and GenBank
Technology characteristics	
Introduction	The agricultural sector in Yemen contributes to about 20% of the total internal revenues of the country and employs around 54% of the total workforce. Most of the country 22 million (currently in 2022 estimate to be around 30 million) inhabitants reside in rural areas and work in agriculture or agricultural-related activities. The growth rate in the agricultural sector averaged only 2.4% per year, compared to the population growth rate of 3.7%, one of the highest growth rates in the world. This results in a big gap between local food production and needs. The agriculture sector currently meets the country's demand for vegetables and fruits, but only 40% of the domestic demand for grains. Yemen is the richest country in Plant Genetic Resources for Food and Agriculture (PGRFA) in the Arabian Peninsula. It has been estimated that there are about 2,900 plant species belonging to 175 families in Yemen, more than 420 of which are endemic. There are about 521 indigenous PGRFA, belonging to 75 families and 235 genera, out of these 87 are endemic. Forty plant species belonging to 27 genera and 15 families are cultivated in the country; these are cereals, legumes, fruits, vegetables, and industrial and stimulant crops. In many parts of the country traditional small in situ conservation areas can be found. Ex Situ conservation centers for plant genetic resources in Yemen have increased rapidly at the end of the 20th century and the beginning of the current century. These centers mainly affiliated with the governmental sector mainly the agricultural research and extension authority and public universities. The number of conservation facilities has increased from 7 in 1996 to 22 in 2006, conserving more than 6000 accessions[21]. Agriculture Research and Extension Authority (AREA) is the largest public sector that holds most of the ex-situ conservation through its research station network in the various ecological zone of the country. It also houses the National Genetic Resources center (NGRC) at its headquarters in Dhamar governorate. This center besides its conservation role coordinates and supervises other activities such as regeneration, collection and evaluation carried out in the other station of AREA. The center has the capacity for traditional and molecular characterization of germplasm and has relations with regional and international centers. In addition to the NGRC, AREA maintains seven fruit tree field GenBanks in the different agroclimatic zone of the country.

[21] FAO, State of Plant Genetic Resources for Food and Agriculture, 2013

Technology characteristics	landraces have evolved through natural selection and selective breeding by traditional agricultural practices over long periods in the different environmental conditions of the country. Sourced from local or introduced germplasm, many new cultivars have been released in the past ten years mainly of cereal and food legume crops and to a lesser extent of vegetable and fruit crops. Presently there are no legislations or policies in force in Yemen, which deal specifically with PGRFA, and only several provisions related to certain aspects of PGRFA conservation exist. The National Programme on Plant Generic Resources for Food and Agriculture (PGRFA) comprises several sub-programmes linked with the Agricultural Research and Extension Authority (AREA) through its National Genetic Resource Center (NGRC) under the Ministry of Agriculture and Irrigation (MAI), the Universities of Sana'a and Aden (faculties of Agriculture), the Environmental Protection Authority (EPA) in the Ministry of Water and Environment and the General Seed Multiplication Corporation (GSMC) under MAI. The technology to improve the genetic resources and gen bank can include, a) Inventories and surveys, b) ex-situ conservation, ex: GenBank (storage) c) On-farm management and improvement of PGRFA d) Strategic planning, e) Strengthening local authorities and programmes dealing with PGRFA, f) f) Support research, extensions, and awareness.
Challenges	There are some difficulties to explore and inventory of biodiversity in some areas because of insufficient financial resources and lack of experience among the staff engaged in these activities. lack of experience in taxonomists and plant ecologists. Security and access to some areas because of the current war.
Advantages	• Conservation of biodiversity and genetic resources • Results from research can lead to new plant varieties resistant to climate changes. • Existing efforts, institutions and experience related to genetic resources such as AREA which can be improved and upscaled
Disadvantages	• High cost of establishment of GenBank and maintenance • Not all plant species can be stored in GenBank • Field GenBank cannot cover the entire genetic diversity, exposed to pathogen and disasters and need continued maintenance. • Improvement and breeding programmes need a long time • The desperation of data and experiences related to genetic resources
Cost	Capital cost for the establishment of a conservation facility for 25,000 accessions on one-time basis for 25 years estimated to be about 1 million USD, including storage facilities, processing and monitoring, regeneration, testing, maintenance, and administration. Other ex situ conservation intervention can be developed as projects and programmes