Energy Transition Pathways for the 2030 Agenda

Sustainable Energy Transition Roadmap for City of Cauayan, Philippines

Developed using National Expert SDG7 Tool for Energy Planning (NEXSTEP)

The shaded areas of the map indicate ESCAP members and associate members[1]

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Foreword: ESCAP

The City of Cauayan was one of the pioneers in using ESCAP's National Expert SDG Tool for Energy Planning (NEXSTEP) methodology to develop a Sustainable Energy Transition Roadmap. ESCAP is pleased to partner with the City of Cauayan in its endeavour to realize a vision for the city's future based on holistic and sustainable development.

The City of Cauayan, which has been nominated as the Ideal City of the North, has been a strong advocate for the Sustainable Development Goals (SDGs). Much effort has been undertaken in Cauayan in localizing the SDGs at the city level to improve the livelihood of its citizens, and it is regarded as the first smart city in the Philippines. ESCAP's collaboration with the City of Cauayan in developing this Sustainable Energy Transition roadmap further raises the city's sustainable development ambition, by identifying the opportunities for city's sustainable energy transition.

This roadmap takes a holistic approach to Cauayan' s energy system. It evaluates the city's current progress towards the SDG 7 targets, identifies the priorities for action and suggests opportunities for improvement. For instance, the roadmap highlights the current gap in universal access to modern energy in the city and proposes the appropriate long-term solutions in closing this gap, which also enhance socio-economic development.

The roadmap also details a range of technical opportunities and policy options for reducing emissions and saving energy across the residential, transport, commercial and agricultural sectors. These opportunities include transport electrification, adoption of energy efficiency in buildings, as well as substantial reduction in city's emissions through decarbonisation of its power supply, whilst paving the way towards a net-zero society.

ESCAP would like to thank the City of Cauayan and other stakeholders for their continuous support and contribution throughout development of the roadmap, without which this Sustainable Energy Transition roadmap would not be possible. I look forward to the City of Cauayan's continuing leadership in building a sustainable energy future.

Hongpeng Liu

Director, Energy Division, ESCAP

Foreword: City of Cauayan

Abbreviations and acronyms

ADB	Asian Development Bank
BAU	business-as-usual
CBA	cost benefit analysis
CDP	Comprehensive Development Plan
CES	clean energy scenario
CLUP	Comprehensive Land Use Plan
CO_2	carbon dioxide
CPS	current policy scenario
DOE	Department of Energy
DOST	Department of Science and Technology
DPS	decarbonisation of power sector
DPWH	Department of Public Works and Highways
EE	energy efficiency
ESCAP	United Nations Economic and Social Commission for Asia and the Pacific
GB Code	Green Building Code
GDP	gross domestic product
GHG	greenhouse gas
GW	gigawatt
GWh	gigawatt-hour
IEA	International Energy Agency
IFC	International Finance Corporation
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
IRR	Internal Rate of Return
ktoe	thousand tonnes of oil equivalent
kWh	kilowatt-hour
LCOE	Levelized Cost of Electricity
LEAP	Long-range Energy Alternatives Planning
LPG	liquified petroleum gas
MCDA	Multi-Criteria Decision Analysis
MJ	megajoule
$ktCO_2$-e	thousand tonnes of carbon dioxide equivalent
MTF	Multi-Tier Framework
MW	megawatt
MWh	megawatt-hour
NEXSTEP	National Expert SDG Tool for Energy Planning
PHP	Philippine peso
RE	renewable energy
REF	reference scenario
SDG	Sustainable Development Goal
SET	Sustainable energy transition
TFEC	total final energy consumption
TGFA	total gross floor area
TNZ	towards NetZero
TPES	total primary energy supply
TWh	terawatt-hour
UNEP	United Nations Environment Programme
UNSD	United Nations Statistics Division
US$	United States Dollar
WHO	World Health Organization
WorldGBC	World Green Building Council

Executive Summary

Transitioning the energy sector to achieve the 2030 Agenda for Sustainable Development and the objectives of the Paris Agreement presents a complex and difficult task for policymakers. It needs to ensure sustained economic growth as well as to respond to increasing energy demand, reduce emissions and, more importantly, consider and capitalize on the interlinkages between Sustainable Development Goal 7 (SDG 7) and other SDGs. In this connection, ESCAP has developed the National Expert SDG Tool for Energy Planning (NEXSTEP). This tool enables policymakers to make informed policy decisions to support the achievement of the SDG 7 targets as well as Nationally Determined Contributions (NDCs) of the Paris Agreement. The initiative has been undertaken in response to the Ministerial Declaration of the Second Asian and Pacific Energy Forum (April 2018, Bangkok) and ESCAP Commission Resolution 74/9, which was endorsed by member States. NEXSTEP also garnered the support of ESCAP Committee on Energy in its Second Session, with recommendations to expand the number of countries being supported by this tool.

The City of Cauayan (Cauayan) has been a participant of a collaborative project led by ESCAP and UNEP on SDG 7 localization. It aims to engage and support cities in defining, implementing and monitoring strategies for achieving global, national, and subnational sustainable development goals. This Sustainable Energy Transition (SET) roadmap has been developed to identify technological options and policy measures that will help the city navigates the transition of its energy sector in line with the 2030 Agenda for Sustainable Development.

Highlights of the roadmap

Cauayan is an agricultural city in the coastal province of Isabela, on the island of Luzon, the Philippines. A city with a population of just over 150,000, Cauayan is well-known for being the first smart city in the Philippines in 2015, offering its citizens a wide variety of digital services (City of Cauayan, 2021). It has also been selected to host the proposed Isabela Special Economic Zone and the Regional Agro-Industrial Growth Center. The development of the city is guided by the Sustainable Development Goals (SDGs). Various initiatives and programs have been launched in advancing the city's progress across all SDGs (City of Cauayan, 2017), including SDG 7. More can be done to accelerate Cauayan's sustainable development towards meeting the SDG 7 targets by 2030.

This SET roadmap has two main objectives. Firstly, it aims to establish scenario baseline for the year 2019-2030, considering the current policy settings. Secondly, it identifies the measures and technological options that could raise Cauayan's efforts to align with the SDG 7 targets, as well as achieving deep decarbonisation of its energy system. The four scenarios that are presented in detail in this roadmap are:

- The current policy scenario (CPS), which has been developed based on existing policies and plans and used to identify the gaps in existing initiatives in aligning with the SDG 7 targets and the city's ambitions.

- The sustainable energy transition (SET) scenario presents technological options and policy measures that will help the city to align its development with the 2030 Agenda for Sustainable Development, particularly the SDG 7 goal.
- The Decarbonisation of Power Sector scenario (DPS) explores the impact of a decarbonised electricity supply on the city's GHG emissions and presents multiple pathways that the city can undertake in decarbonising its electricity supply.
- The Towards Net Zero (TNZ) scenario, the most ambitious scenario, looks at a pathway of moving towards a net zero society, through decarbonising the electricity supply and the adoption of electricity-based technologies.

An additional scenario - business as usual (BAU) scenario, has also been modelled to provide a BAU baseline where no enabling policies/initiatives are implemented, or the existing policies/initiatives fail to achieve their intended outcomes.

Aligning Cauayan's energy transition pathway with the SDG 7 targets

Access to Modern Energy

As of 2019, 9.6 per cent of Cauayan's population lacked access to electricity, while 23.3 per cent lacked access to clean cooking fuels and technologies. More attention is required to set up initiatives and channel funding in closing the access gap. NEXSTEP proposes that decentralised renewable electricity systems may be the best way forward in electrifying the remaining households.

More attention is required to provide universal clean cooking access to the population of Cauayan. Nearing a quarter of the population relied on unclean cooking fuel and technologies for household cooking, specifically traditional biomass stoves (18.7 per cent) and kerosene stoves (4.7 per cent). The phase out of unclean cooking practices is a means to improve health through reducing household indoor air pollution, as well as ensuring more gender empowered socio-economic development. Electric cooking stoves stand out as the most appropriate long-term solution, due to their cost-effectiveness (relative to the more commonly used LPG stoves), zero air pollution, and require minimal maintenance. In addition to that, coupling this technology with a decarbonised electricity supply, results in a zero-carbon solution.

Renewable Energy

The share of renewable energy (RE) in the total final energy consumption (TFEC) was 5.0 per cent in 2019. Under the CPS, the share of RE will increase to 10.7 per cent by 2030. The increase in the RE share under the current policies is driven by the high growth of renewable energy share in grid electricity, which is projected to increase from 14.0 per cent in 2019[2] to 34.1 per cent in 2030, and a slight increase in biofuel usage in the transport sector. In the SET scenario, RE share in TFEC is increased to 14.9 per cent. This additional increase of 4.2 per cent from the CPS is a result of both increased use of renewable

[2] Based on DOE 2020 Power Statistics, gross generation per grid, by plant type

energy due to higher share of electricity in energy consumption and further reduction of energy demand due to energy efficiency measures.

The RE share in TFEC for the DPS and TNZ scenario is expected to be high, as both the scenarios envision a decarbonised electricity supply. The latter also aims to position the energy system towards net-zero carbon. In the DPS scenario, the RE share in TFEC is further increased to 37.4 per cent as the RE share of electricity supply reaches 100 per cent. As later described in the roadmap, there are several pathways for achieving a decarbonised electricity supply, with the most promising and cost effective one being through renewable energy auctions. On the other hand, the RE share in TFEC increases to 56.5 per cent in the TNZ scenario, as more electricity-based technologies being adopted in the transport and residential sectors, reducing overall energy demand and increasing renewable energy usage with a 100 per cent electricity supply.

Energy Efficiency

Cauayan's energy intensity is estimated at 5.85 MJ/US$_{PPP,2011}$ in 2019. It is expected to reduce to 5.64 MJ/US$_{PPP,2011}$ by 2030 in the CPS, as GDP growth outpaces the growth in energy demand. This corresponds to an annual improvement rate of 0.3 per cent.

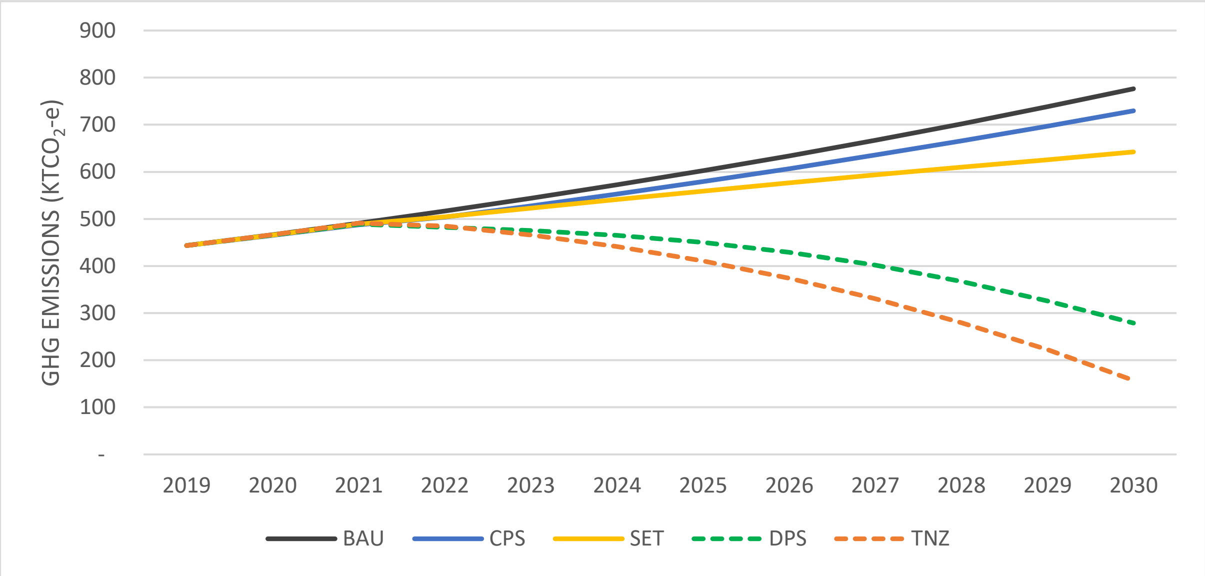
The SET scenario proposes several energy efficiency interventions across the demand sectors, which further decreases the energy intensity to 4.18 MJ/US$_{PPP,2011}$ by 2030. This corresponds to a 3.0 per cent reduction per annum, aligning with the suggested global annual improvement rate of 3 per cent (UNSD, 2021). The transport sector made up around 69.4 per cent of the total energy demand 2019, energy efficiency measures in the sector may provide substantial savings. NEXSTEP proposes an increase of electric vehicle share in the transport fleet to between 25 to 50 per cent, by 2030. The projected result – a 42 ktoe reduction in energy demand from the CPS due the high efficiency of electric vehicles. Other measures include mandating the compliance of national green building code to all new commercial buildings, regardless of floorspace area, as well as phasing out of inefficient lighting appliance in the residential sector. The phasing out of inefficient, polluting cooking practices allows an estimated energy reduction of 7.1 ktoe, clearly demonstrating the positive interaction between clean cooking access and energy efficiency. The proposed measures are further detailed in Chapter 4.

The energy demand reduction can be significant, should Cauayan follow a net zero carbon pathway, as suggested in the TNZ scenario. The energy intensity is projected to reduce to 3.38 MJ/US$_{PPP,2011}$, corresponding to a 4.9 per cent energy efficiency improvement per annum.

GHG emissions

The GHG emissions in 2019 are estimated at 443.6 ktCO_2-e, which considers the direct fuel combustion and emissions attributable to the purchased (grid) electricity. Figure ES 1 shows the GHG emission trajectories for the different scenarios. The GHG emissions from the CPS are projected to reach 730 ktCO_2-e, while these are further decreased to 642 ktCO_2-e in the SET scenario. Drastic decreases can be observed in the DPS and TNZ scenarios. Decarbonizing the electricity supply further reduces the GHG emissions to 279 ktCO_2-e in the DPS scenario. The most ambitious reduction of 157 ktCO_2-e can be achieved with increased adoption of electricity-based technologies in the transport and residential sectors. This entails having 100 per cent electric vehicle sales from 2023 onwards, and phasing out of (almost) all LPG stoves for residential cooking. In the agricultural sector, diesel-power water pumps are replaced with solar irrigation systems. The remaining emissions are from conventional vehicles yet to be phased out within the short nine-year period, a small amount of LPG stove usage in households connected to decentralised RE systems, as well as the use of large scale diesel-powered agricultural machinery (i.e. harvester, rotovators and tractors) where electric-powered versions have not yet reached commercialisation stage.

Figure ES 1 Comparison of emissions by scenarios 2018-2030



Key policy recommendations

As described above, there are ample opportunities for Cauayan to transform its energy system in alignment with the SDGs, while at the same time, substantially reducing its GHG emissions. The key policy recommendations to help Cauayan in its sustainable energy transition, are:

1. **Access to electricity and clean cooking technologies should be the number one priority.** Decentralised RE electrification systems should be considered for quick implementation. Induction type electric cooking stoves is the most appropriate long-term solution in achieving 100 per cent access to clean cooking, while LPG stoves can be considered for households with insufficient power supply to support the use of electric cooking stoves.
2. **Green building code and the use of RE systems can be made mandatory for all new commercial buildings in the city, regardless of the floorspace area.** The existing national green building code is obligatory for buildings above a certain minimum floorspace area. Widening the requirements to all new commercial buildings, regardless of the floorspace area, from 2023 onwards shall allow an estimated savings of 1.2 ktoe. Compulsory use of RE systems (i.e. solar PV) can be similarly introduced.

3. **Transport electrification is key to energy demand reduction and GHG emission reduction.** Setting a high bar for transport electrification shall result in substantial GHG emissions reduction, particularly when coupled with highly decarbonised electricity supply.
4. **Raising the RE share in electricity supply through urban RE electricity generation, PPA and RE auction.** Among the options to increase the RE generation share, RE auctions provide the best financial case and financial savings due to low solar PV generation costs. The opportunity for utilizing the biomass resource potential of the city for energy generation can also be explored.
5. **Moving towards Net-Zero Carbon:** A net-zero society requires concerted effort from both the city authorities and citizens. A total decarbonisation of the power supply is essential, while increased electrification in the demand sectors are required, including the phasing out of internal combustion engine vehicles, LPG stoves and diesel-powered water pumps.

1. Introduction

Background

Transitioning the energy sector to achieve the 2030 Agenda for Sustainable Development and the objectives of the Paris Agreement presents a complex and difficult task for policymakers. It needs to ensure a sustained economic growth, respond to increasing energy demand, reduce emissions, as well as consider and capitalise on the interlinkages between Sustainable Development Goal 7 (SDG7) and other SDGs. In this connection, the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP) has developed the National Expert SDG Tool for Energy Planning (NEXSTEP). This tool enables policymakers to make informed policy decisions to support the achievement of the SDG7 targets as well as emission reduction targets (NDCs). The initiative has been undertaken in response to the Ministerial Declaration of the 2nd Asian and Pacific Energy Forum (April 2018, Bangkok) and the Commission Resolution 74/9 which endorsed its outcomes. NEXSTEP has also garnered the support of the Committee on Energy in its Second Session, with recommendations to expand the number of countries being supported by this tool.

The NEXSTEP tool has been specially designed to support policymakers in analysing the energy sector and developing an energy transition plan in the context of SDG 7. Further details of the NEXSTEP methodology are discussed in the next chapter. While this tool has been designed to help develop SDG 7 roadmaps at the national level, it can also be used for sub-national energy planning.

As a participant of the “SDG 7 localisation project”, City of Cauayan (Cauayan) and UNESCAP has collaborated to develop a Sustainable Energy Transition (SET) roadmap, which seeks to assess Cauayan’s baseline and to identify technological options and policy measures that will help the city navigate the transition of the energy sector in line with the 2030 Agenda for Sustainable Development. The SDG7 localisation project is implemented in collaboration with the United Nations Environment Programme (UNEP) and with support from the Energy Foundation China. ESCAP Energy Division is supporting its member States in Asia and the Pacific to increase the capacity of cities and sub-national governments in the region to accelerate development and implementation of SDG7-related actions. ESCAP directly engages cities and sub-national jurisdictions in collaborative discussions, offers a range of knowledge products and support in developing local sustainable energy policies and projects, as well as in establishing more effective dialogues between national, sub-national and local levels of governance, expert communities, as well as donors and the private sector. See Box 1 for further details.

Box 1: SDG 7 Localization status of City of Cauayan based on ESCAP’s assessment

In 2021, ESCAP conducted a study of 20 cites from 5 ASEAN countries, including City of Cauayan, in order to assess their local situation in terms of the efforts on SDG 7 Localization and provide recommendations for further actions.

The study is based on the methodology developed by ESCAP and answers provided by the local stakeholders in Cauayan to the related SDG 7 Localization questionnaire (more detailed information on the methodology can be found in ESCAP-UNEP report[3]). The key results of this situation assessment are presented in the SDG 7 Localization Snapshots[4] for each city.

The SDG7 Localization Snapshot provides a brief overview of the key areas related to implementation of the Sustainable Goal 7 (SDG 7) to 'Ensure access to affordable, reliable, sustainable and modern energy for all' at the local level based on the answers provided by the jurisdiction to the SDG7 Localization questionnaire. Seven areas, or SDG 7 Localization indicators, were identified for this analysis. Additionally, eight sub-indicators were used to provide more detailed results of the assessment.

It is important to note that these indicators are qualitative and should not be used for assessing cities' achievement of quantitative targets under SDG 7. The results for these qualitative indicators are based on cities' self-assessment of their current conditions, efforts, resources and capacity in relation to supporting SDG 7 localization process and can serve the role of the evidence base for constructing recommendations tailored to the local context, as well as the baseline results for tracking cities' progress of their SDG 7 localization efforts.

The results for each indicator are presented as a nominal score from 0 to 100 (where 100 is the maximum possible score, that can be achieved for each indicator or sub-indicator based on the aggregation of all answers of the questionnaire attributed to this particular indicator or sub-indicator).

As can be seen from the figure and the results below, most of the efforts related to SDG 7 in City of Cauayan are taking place in the areas linked to other SDGs, which corresponds to a relatively high score for the indicator on linkages to other SDGs. That might be an indication that SDG 7 has not been high on the list of the city's policy priorities, which is confirmed by a relatively low result for the indicator on Implementation. This suggests that projects and initiatives directly focused on SDG 7 implementation (i.e., energy efficiency, renewable energy and energy access) are quite limited at the moment and need additional support and acceleration from the local government. This is especially the case when it comes to disbursement of financial resources, improving energy data collection and monitoring as well as more active collaboration with national and international stakeholders in the field of sustainable energy.

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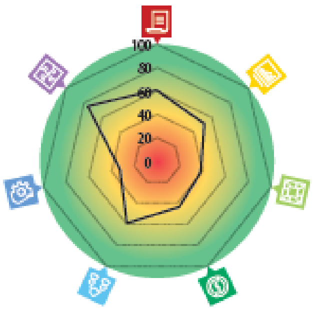
[3] Available at https://www.unescap.org/kp/2021/sdg-7-localization-affordable-and-clean-energy-asean-cities#

[4] Available at https://city.nexstepenergy.org/knowledge/city-snapshots

General information	
Name of the jurisdiction	CAUAYAN
Country of the jurisdiction	Philippines
Population of the jurisdiction	143,443 people
Area of the jurisdiction (in km²)	336.4
Predominant climate	Relatively wet from May to November (29°C-32°C), dry for the rest of the year (35°C-41°C)

SDG7 Localization score



Score
0–33 34–66 67–100

Scores for each SDG7 Localisation indicator are calculated between 0 and 100 to show the assessment of the status in the jurisdiction in each of the respective areas.

Indicators score

61	Available policies and institutions for SDG localization	Availability of specific policies and institutions focused on supporting the SDG 7 implementation.
52	Energy data monitoring	Accessibility and penetration of energy monitoring and smart metering.
39	Cooperation with national and international stakeholders	Efficient communication and collaboration between local stakeholders and various stakeholder groups at the national and international levels.
43	Use of financial resources	Availability of various financial resources and instruments for supporting SDG 7 implementation actions.
59	Awareness raising and capacity- building	Availability of policies of actions to increase the understanding among citizens and build the capacity of professionals for SDG 7 implementation.
32	Implementation	Presence of policies and actions to implement SDG 7 targets.
75	Linkages to other SDGs	Availability of policies of actions with linkages between SDG 7 and other SDGs.

Sub-indicator score

59	Energy access	Policies of actions taken by cities on energy access.
25	Renewable energy	Policies of actions taken by cities on renewable energy.
11	Energy efficiency	Policies of actions taken by cities on energy efficiency.

Sub-indicator score

68	SDG3. Good health and well-being.	The presence of energy-related activities of measures that support the health sector.
20	SDG6. Clean water and sanitation.	The presence of energy-related activities of measures that support water and sanitation.
85	SDG11. Sustainable cities and communities.	The presence of energy-related activities of measures that support development of sustainable cities and communities.
100	SDG12. Responsible production and consumption.	The presence of energy-related activities of measures that support responsible production and consumption.
100	SDG13. Climate action.	The presence of energy-related activities of measures that support climate action.

SDG 7 Targets and Indicators

SDG7 aims to ensure access to affordable, reliable, sustainable and modern energy for all. It has three key targets, which are outlined below.

- Target 7.1. "By 2030, ensure universal access to affordable, reliable and modern energy services." Two indicators are used to measure this target: (a) the proportion of the population with access to electricity; and (b) the proportion of the population with primary reliance on clean cooking fuels and technology.

- Target 7.2. "By 2030, increase substantially the share of renewable energy in the global energy mix". This is measured by the renewable energy share in total final energy consumption (TFEC). It is calculated by dividing the consumption of energy from all renewable sources by total energy consumption. Renewable energy consumption includes consumption of energy derived from hydropower, solid biofuels (including traditional use), wind, solar, liquid biofuels, biogas, geothermal, marine and waste. *Due to the inherent complexity of accurately estimating traditional use of biomass, NEXSTEP focuses entirely on modern renewables (excluding traditional use of biomass) for this target.*

- Target 7.3. “By 2030, double the global rate of improvement in energy efficiency”, as measured by the energy intensity of the economy. This is the ratio of the total primary energy supply (TPES) and GDP. Energy intensity is an indication of how much energy is used to produce one unit of economic output. As defined by the IEA, TPES is made up of production plus net imports minus international marine and aviation bunkers plus stock changes. For comparison purposes, GDP is measured in constant terms at 2011 PPP.

2. NEXSTEP Methodology

The main purpose of NEXSTEP is to help design the type and mix of policies that would enable the achievement of the SDG7 targets and the emission reduction targets (under NDCs) through policy analysis. However, policy analysis cannot be done without modelling energy systems to forecast/backcast energy and emissions, and economic analysis to assess which policies or options would be economically suitable. Based on this, a three-step approach has been proposed. Each step is discussed in the following sections.

Key methodological steps

I. Energy and Emissions Modelling

NEXSTEP begins with the energy systems modelling to develop different scenarios to achieve SDG7 by identifying potential technical options for each scenario. Each scenario contains important information including the final energy (electricity and heat) requirement by 2030, possible generation/supply mix, emissions and the size of investment required. The energy and emissions modelling component use the Long-range Energy Alternatives Planning (LEAP). It is a widely used tool for energy sector modelling and to create energy and emissions scenarios. Many countries have used LEAP to develop scenarios as a basis for their Intended Nationally Determined Contributions (INDCs). Figure 1 shows the different steps of the methodology.

II. Economic Analysis Module

The energy and emissions modelling section selects the appropriate technologies, and the economic analysis builds on this by selecting the least cost energy supply mix for the country. The economic analysis is used to examine economic performances of individual technical options identified and prioritize least-cost options. As such, it is important to estimate some of the key economic parameters such as net present value, internal rate of return, and payback period. A ranking of selected technologies will help policymakers to identify and select economically effective projects for better allocation of resources. The economic analysis helps present several economic parameters and indicators that would be useful for policymakers in making an informed policy decision.

III. Scenario and policy Analysis

Using Multi-Criteria Decision Analysis (MCDA) tool, this prioritised list of scenarios is assessed in terms of their techno-economic and environmental dimensions to convert to a policy measure. The top ranked scenario from the MCDA process is essentially the output of NEXSTEP, which is then used to develop policy recommendations.

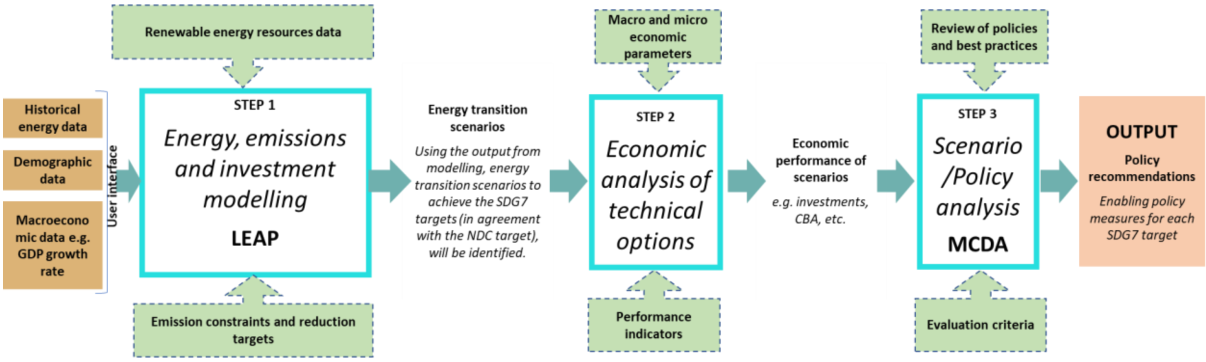


Figure 1 Different components of the NEXSTEP methodology

This tool is unique in a way that no other tools look at developing policy measures to achieve SDG7. The key feature that makes it outstanding is the backcasting approach for energy and emissions modelling. This is important when it comes to planning for SDG7 as the targets for the final year (2030) is already given and thus the tool needs to be able to work its way backward to the current date and identify the best possible pathway.

Scenario definitions

The LEAP modelling system is designed for scenario analysis, to enable energy specialists to model energy system evolution based on current energy policies. In the NEXSTEP model for City of Cauayan, three main scenarios have been modelled: (a) BAU scenario; (b) Current Policy Scenario (CPS); (c) Sustainable Energy Transition (SET) scenario. In addition, two ambitious scenarios, (d) Decarbonisation of Power Sector (DPS) scenario and (e)Towards Net Zero (TNZ) scenario, have been modelled, which explores the possible decarbonisation pathways through decarbonising its power supply, as well as the energy system as a whole:

- **I.** The BAU scenario: This scenario follows historical demand trends, based on simple projections, such as using GDP and population growth. It does not consider emission limits or renewable energy targets. For each sector, the final energy demand is met by a fuel mix reflecting the current shares in TFEC, with the trend extrapolated to 2030. Essentially, this scenario aims to indicate what will happen if no enabling policies are implemented or the existing policies fail to achieve their intended outcomes;
- **II.** CPS: Inherited and modified from the BAU scenario, this scenario considers relevant local and national policies and plans in place. For instance, the proposed B5 biodiesel implementation and the ambition to reach the 100 per cent electrification rate by 2022 set out in the Philippine Energy Plan 2018-2040 and Philippine Development Plan 2017-2022;
- **III.** SET scenario: This scenario aims to align Cauayan's energy transition pathway with the SDG 7 targets. Energy efficiency improvement has been modelled in alignment with the global energy intensity improvement rate, while the renewable energy share has substantially increased with higher energy efficiency and projected increase in the share of renewable electricity of the grid supply;
- **IV.** DPS scenario: this scenario explores the impact of a decarbonised electricity supply on the city's GHG emissions and presents multiple pathways that the city can undertake in decarbonising its electricity supply.

V. TNZ scenario: This is the most ambitious scenario of all, which looks at a net-zero pathway for Cauayan, through decarbonising the electricity supply and the adoption of electricity-based technologies in the demand sectors.

Economic Analysis

The economic analysis considers the project's contribution to the economic performance of the energy sector. The purpose of a Cost-Benefit Analysis (CBA) is to make better informed policy decisions. It is a tool to weigh the benefits against costs and facilitate an efficient distribution of resources in public sector investment.

2.1.1. Basics of Economic Analysis

The economic analysis of public sector investment differs from a financial analysis. A financial analysis considers the profitability of an investment project from the investor's perspective. In an economic analysis the profitability of the investment considers the national welfare, including externalities. Project financial viability is not enough in an economic analysis, contribution to societal welfare should be identified and quantified. For example, in the case of a coal power plant, the emissions from combustion process emits particulate matter which is inhaled by the local population causing health damages and accelerates climate change. In an economic analysis a monetary value is assigned to the GHG emission to value its GHG emissions abatement.

2.1.2. Cost parameters

The project cost is the fundamental input in the economic analysis. The overall project cost is calculated using the following:

a) Capital cost – capital infrastructure costs for technologies, these are based on country-specific data to improve the analysis. They include land, building, machinery, equipment and civil works.

b) Operation and Maintenance Cost consists of fuel, labour and maintenance costs. Power generation facilities classify operation and maintenance costs as fixed ($/MW) and variable ($/MWh) cost.

c) Decommissioning Cost - retirement of power plants costs related to environmental remediation, regulatory frameworks and demolition costs.

d) Sunk Cost – existing infrastructure investments are not included in the economic analysis, since it does not have any additional investment required for the project.

e) External Cost – refers to any additional externalities which place costs on society.

f) GHG Abatement – avoided cost of CO_2 generation is calculated in monetary value based on carbon price. The 2016 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories is followed in the calculation of GHG emission for the economic analysis. The sectoral analysis is based on the Tier 1 approach, which uses fuel combustion from national statistics and default emission factors.

2.1.3. Scenario analysis

The scenario analysis evaluates and ranks scenarios, using the Multi Criteria Decision Analysis (MCDA) tool, with a set of criteria and weights assigned to each criterion. Ideally, the weights assigned to each criterion should be decided in a stakeholder consultation. If deemed necessary, this step can be repeated using the NEXSTEP tool in consultation with stakeholders where the participants may wish to change weights of each criterion, where the total weight needs to be 100 per cent. The criteria considered in the MCDA tool can include the following, however, stakeholders may wish to add or remove criteria to suit the local context.

- Access to clean cooking fuel.
- Energy efficiency.
- Share of renewable energy.
- Emissions in 2030.
- Alignment with Paris Agreement.
- Fossil fuel subsidy phased out.
- Price on carbon.
- Fossil fuel phase-out.
- Cost of access to electricity.
- Cost of access to clean cooking fuel.
- Investment cost of the power sector.
- Net benefit from the power sector.

This step is generally applied to all countries utilizing NEXSTEP in developing the national SDG 7 or the subnational SET Roadmap, as a mean to suggest the best way forward for the countries or cities by prioritising the several scenarios. Nevertheless, it has not been applied to City of Cauayan as a limited number of scenarios have been developed.

3. Overview of City of Cauayan's Energy Sector

3.1. Overview of City of Cauayan

The City of Cauayan (Cauayan) is a landlocked city in the coastal province of Isabela, in the island of Luzon. It has a total land area of 335.4 square kilometers. The city consists of 65 barangays, the smallest political unit in the Philippines. The city was first founded as a town in 1852 and received the status of a third-class component city in 2001, following its rapid economic growth (World Heritage Encyclopedia, 2021).

Cauayan has a total population of 150,118 in 2019, a substantial growth of around 20,600 people from its 2015 population statistics. The city has a rather young population, whereby 50 per cent of its population is under the age 25 (PhilAtlas, 2021). The city's GDP in 2019 is estimated at $344.8 million and has a GDP per capita of $2,297. Cauayan's main economic activities consist of agriculture, commercial and services, industrial, fishery, and mining. Notably, it has been selected to host the proposed Isabela Special Economic Zone and the Regional Agro-Industrial Growth Center. The agricultural sector is highly active in Cauayan, whereby 69.9 per cent of its land area is utilized for rice and corn production (World Heritage Encyclopedia, 2021).

Cauayan was recognized as the first smart city in the Philippines in 2015, offering its citizens a wide variety of digital services (City of Cauayan, 2021). The development of the city is also well guided by the SDGs. Various initiatives and programs have been launched in advancing the city's progress across all SDGs (City of Cauayan, 2017). Initiatives in relation to SDG 7 is, for instance, the Litre of Light Project to help and encourage the citizens in making use of recycled bottles for light, as well as the development of e-tricycles with solar roof with a local manufacturer. Additionally, the city has been an advocate of e-vehicles since 2017 (UNESCAP, 2021a). To date, there are a total of 12 operating e-vehicles in the city. Additionally, the city is part of the launching of the Hybrid Electric Rail Train developed by the Department of Science and Technology (DOST) (Edale, 2019).

Cauayan's vision is to be the **Ideal City of the North**. It has formulated the Comprehensive Land Use Plan (CLUP) 2018-2027. It is also the midst of drafting its Comprehensive Development Plan 2022-2031. The two documents aim to provide blueprints for sustainable development of the city, in all areas including social, economic, infrastructure and institutional development.

Notwithstanding, the findings in (UNESCAP, 2021a) highlighted that there are limited existing projects and initiatives directly focused on SDG 7 implementation (i.e., energy efficiency, renewable energy and energy access). Accelerated effort from the city government is required in advancing progress towards SDG 7.

3.2. City's energy profile

The population of Cauayan in 2019 was reported at 150,118, while the number of households stood at 35,046. In 2019, the percentage of access to electricity was estimated at 90.4 per cent, leaving around 3,364 households yet to be connected to any form of electricity supply. All of these are small residential households. The clean cooking access rate is lower, standing at 76.7 per cent in 2019, corresponding to 8,152 small residential households lacking access to clean cooking fuels and technologies. These remaining households were relying on the usage of traditional biomass stoves (18.6 per cent) and kerosene stoves (4.7 per cent) for residential cooking purposes.

Renewable energy delivered approximately 5.0 per cent of TFEC in 2019, contributed by renewable electricity and the use of biofuels in the transport sector, as further explained in the following. A total of 4.5 MW solar PV system capacity has been installed within the city boundary, which produced 6.34 GWh in 2019, assuming a 16 per cent capacity factor.[5] The electricity requirement of the region is met almost exclusively by purchased electricity from the central grid, i.e. Luzon grid. The percentage share of renewable energy considers the share of renewable electricity of the central grid, which is estimated at 14 per cent in 2019.[6] Other usage of renewable energy includes a small amount of biofuel consumption in the transport sector. The current blend of biofuel in the Philippines is 2 and 10 per cent for biodiesel and bioethanol, respectively (DOE, 2021a). In the agricultural sector, 200kW of solar irrigation systems have been installed to fulfil the irrigation needs for a total land size of 100 hectares.

The energy intensity in 2018 was calculated as 5.85 MJ/US$$_{2011}$.[7] Around 69.4 per cent of the total primary energy supply is used to fulfil the demand from the transport sector.

The GHG emissions in 2019 are estimated at 443.6 ktCO_2-e. The GHG emissions breakdown is as shown in Figure 2. The emission from the residential sector concerns the use of LPG and kerosene in household cooking, as well as kerosene for lighting purposes in non-electrified households. The transport emissions are from direct fuel combustions in internal combustion engines. The agricultural sector contributes around 1 per cent of the emissions, through diesel combustion in the water pumps and agricultural machineries (i.e. tractor, rotovators and harvesters). Emissions related to electricity usage is not attributable to the electricity consuming demand sectors but are attributable to the supply side, i.e. purchased grid electricity. As electricity is the only energy supply in the commercial and industry sectors (see Figure 3), emissions attributable to these sectors are already accounted for in the electricity supply category. The grid emission factor considered for the base year 2019 is 0.641 tCO_2/MWh. This is the average of the combined margin emission factors provided for the Luzon grid 2015-2017 (DOE, 2021b).[8] The transmission and distribution losses of grid electricity is assumed as 9.41 per cent (World Bank, 2021), of which the emissions attributable to such losses are also included in Cauayan's emission profile.

The current progress of Cauayan's energy sector in accordance with the SDG indicators are summarized in Annex I.

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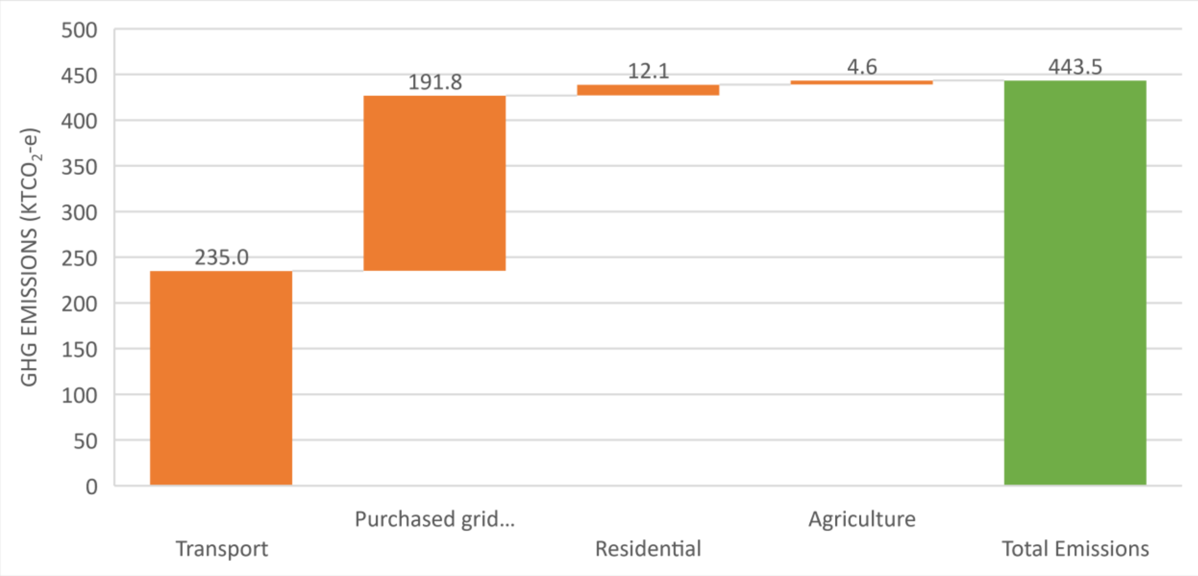
[5] Based on actual national data for 2019-2020, provided by the Department of Energy (DOE) of Philippines (https://www.foi.gov.ph/requests/aglzfmVmb2ktcGhyHQsSB0NvbnRlbnQiEERPRS02MDg5OTkyMDk2OTQM).
[6] Based on DOE 2020 Power Statistics, gross generation per grid, by plant type
[7] Authors' calculation.
[8] More recent emission factor data cannot be found on the public domain.

Figure 2 GHG emissions in 2019



3.3. Regional energy resource assessment

The utilisation of indigenous energy resources (i.e. solar, wind) in local electricity generation within the boundary of Cauayan is currently limited to solar of around 4.5 MW capacity. There is limited assessment done of the renewable energy potential in Cauayan. Nevertheless, it is noted that its geographical location in the tropical zone allows the city to enjoy an estimated annual solar irradiation (in terms of global horizontal irradiation (GHI) of around 1,600-1,800 kWh/m^2.[9] On the other hand, wind energy potential is limited compared to the other parts of Philippines. The mean power densities at 50 metres and 200 metres hub height are estimated at 70W/m^2 and 170 W/m^2 only.[10]

Nearly 70 per cent of the city's area are utilised for agricultural purposes, primarily for rice and corn production. Notwithstanding, agricultural waste potential from Cauayan's active agricultural activities have not been explored through formal studies. Based on NEXSTEP preliminary resource potential quantification, the agricultural waste from rice and corn cultivation may allow up to 5 MW of power generation potential, while electricity generation potential from animal manure is estimated at 2 MW. This is further elaborated in Box 3 (see section 5.1.1).

3.4. City's energy balance 2019

[9] Information obtained from the "Global Solar Atlas 2.0, a free, web-based application is developed and operated by the company Solargis s.r.o. on behalf of the World Bank Group, utilizing Solargis data, with funding provided by the Energy Sector Management Assistance Program (ESMAP). For additional information: https://globalsolaratlas.info

[10] Information obtained from the "Global Wind Atlas 3.0, a free, web-based application developed, owned and operated by the Technical University of Denmark (DTU). The Global Wind Atlas 3.0 is released in partnership with the World Bank Group, utilizing data provided by Vortex, using funding provided by the Energy Sector Management Assistance Program (ESMAP). For additional information: https://globalwindatlas.info

The following describes the estimated energy consumption built up using data collected with a bottom-up approach, based on data such as activity level and energy intensity data. Majority of the following 2019 energy data has been provided UNESCAP's local consultant - Dr. Orlando Balderama and his team, unless stated otherwise. Further details on the data and assumptions used can be found in Annex II.

The **total final energy consumption (TFEC)** in 2019 was 113.1 ktoe. The main energy consuming sector is the transport sector, consuming 78.6 ktoe, around 69.4 per cent of the TFEC in 2019. The existing transport fleet (in 2019) is almost exclusively made up of internal combustion engine vehicles, consuming diesel (87.3 per cent), gasoline (10.4 per cent) and a small amount of biodiesel (1.6 per cent) and ethanol (0.7 per cent). The residential sector comes second in terms of the final energy consumption, consuming 17.7 ktoe, or 15.6 per cent of Cauayan's TFEC. Nearing half (48.1 per cent) of the energy consumed is the form of electricity, while biomass (34.3 per cent) and LPG (16.7 per cent) is used for residential cooking purposes. The energy consumed in the commercial sector and industry sector is exclusively electricity, at 12.3 ktoe (10.9 per cent) and 3.0 ktoe (2.7 per cent), respectively. Figure 3 shows the fuel demand from the demand sectors, while Figure 4 shows the TFEC breakdown by fuel type in 2019.

Figure 3 TFEC breakdown by sector and fuel type, 2019

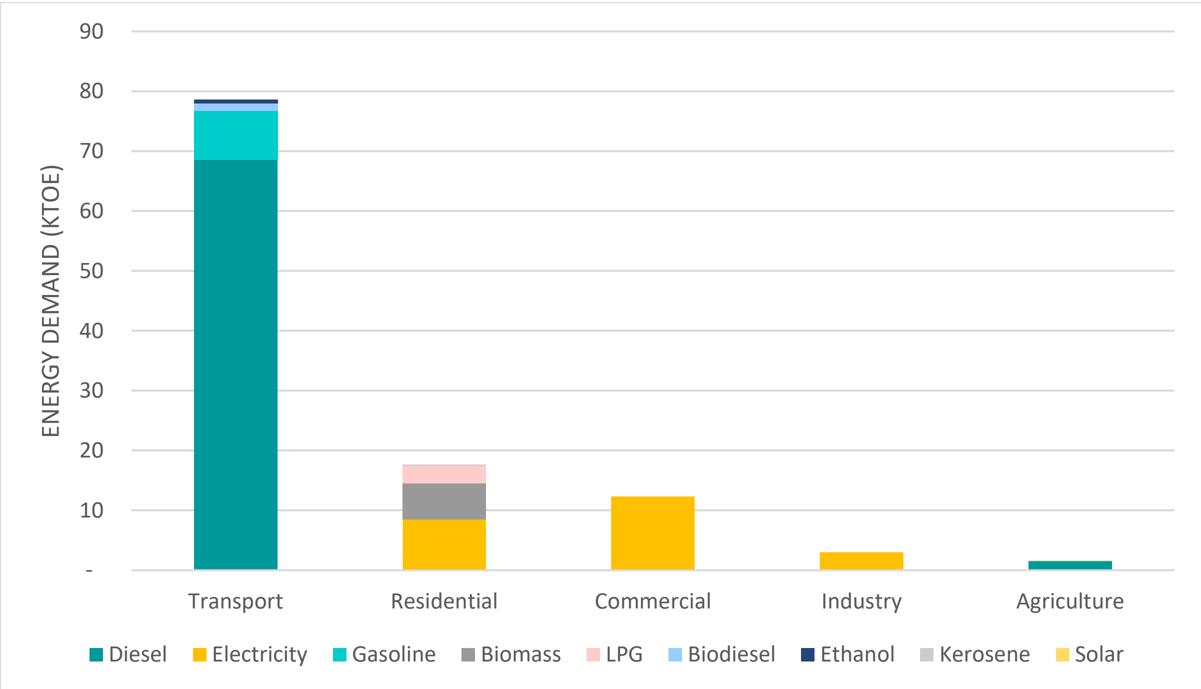


Figure 4 TFEC breakdown by fuel type, 2019

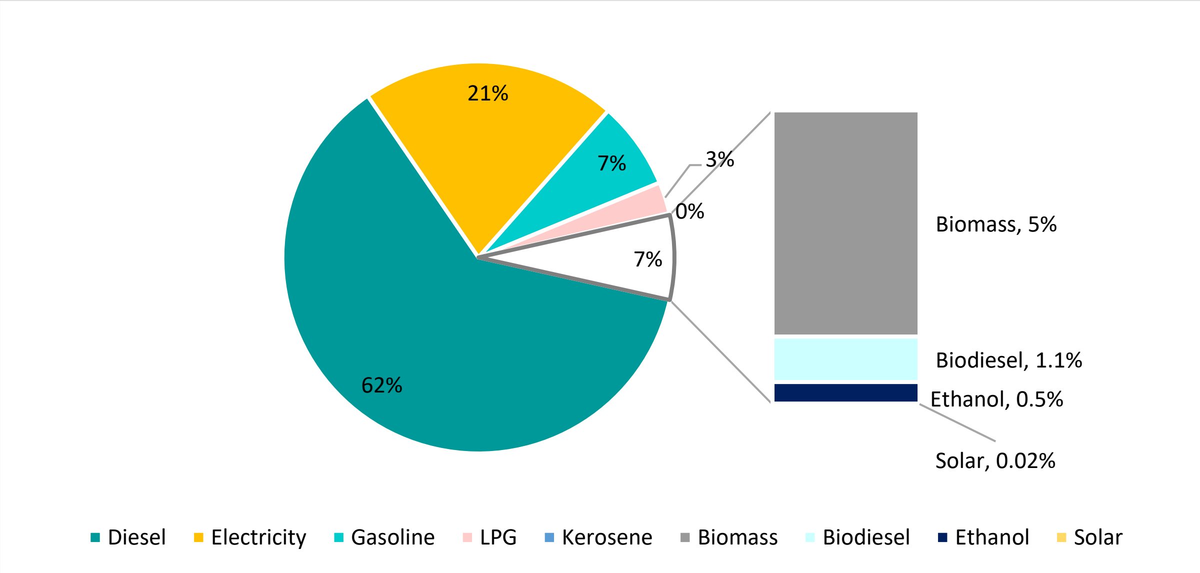
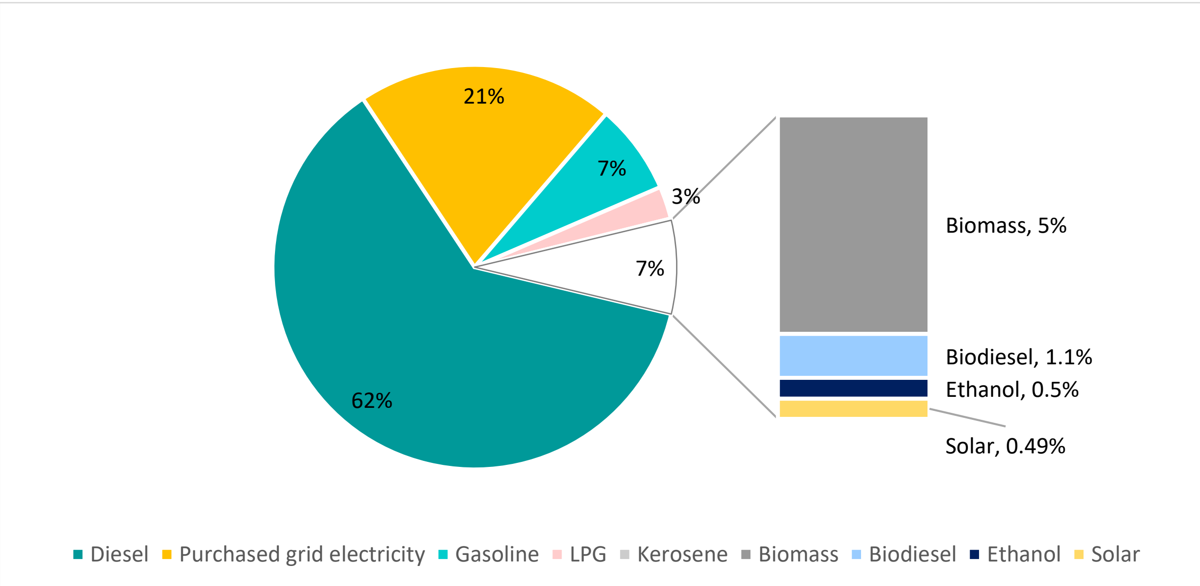


Figure 5 shows the **total primary energy supply (TPES)** breakdown by fuel type in 2019. The total primary energy supply is 113.1 ktoe, similar to the TFEC, as local electricity generation is minimal. Cauayan is connected to the Luzon grid, importing almost all (98 per cent) its electricity required from the central grid. A small amount of electricity is supplied through solar installation within the city boundary, with estimated generation in 2019 at 6.34 GWh.

Figure 5 TPES breakdown by fuel type, 2019



3.5. Energy modelling projections

The future energy demand is projected based on a bottom-up approach, using activity levels and energy intensities, with the LEAP model. The demand outlook throughout the NEXSTEP analysis period is influenced by factors such as annual population growth, annual GDP growth, as well as other demand sector growth projections. The assumptions used in the NEXSTEP modelling are further detailed in 0, while Table 1 provides a summary of the key modelling assumptions for the three main scenarios (i.e. BAU, CPS and SET scenarios).

Table 1 Principal factors, targets and assumptions used in NEXSTEP modelling

Parameters	BAU	CPS	SET
GDP Growth	US$ 344.8 million in 2019, assumed growth rate of 5.5% per annum		
Population Growth	150,118 in 2019, assumed growth rate of 3.18% per annum		
Commercial Floor Space	0.63 million square meter in 2019, assumed growth rate of 5.5% per annum		
Transport Activity	Transport activities in 2019: 2.8 billion passenger-kilometres and 1.4 billion tonne-kilometres, with assumed growth of 5.5 per cent per annum		
Industry	GDP contribution in 2019: US$ 8.5 million; Annual growth rate of 5.5%		
Energy Efficiency	Additional energy efficiency measures not applied	Improvement based on current policies/initiatives	Economy-wide efficiency improvement
Electricity Generation	Based on 2019 existing RE installation within the city boundary. Purchased electricity from the central grid is assumed to have the same fuel mix throughout the period	Based on 2019 existing RE installation within the city boundary. The purchased (grid) electricity mix in 2030 references the projected generation mix in the reference (REF) scenario in the Philippine Energy Plan 2018-2040.[11]	Based on 2019 existing RE installation within the city boundary. The purchased (grid) electricity mix in 2030 references the projected generation mix in the reference (REF) scenario in the Philippine Energy Plan 2018-2040. [11]

3.6. City of Cauayan's energy system projections in the current policy settings

The Current Policy Scenario (CPS) explores how Cauayan's energy system may evolve under the current policy settings. It considers several initiatives implemented or scheduled to be implemented

[11] The estimated generation mix of the grid electricity is used in calculating the RE share in TFEC and GHG emissions attributable to the purchased (grid) electricity. Full details of the calculations are provided in Annex III.

during the analysis period 2020-2030, both on the city level and the national level. The policies/initiatives considered in the modelling of CPS are as follows:

1) Universal electricity access to be realised by 2022

The Philippine Energy Plan 2018-2040 and the Philippine Development Plan 2017-2022 have set out ambitions to provide access to basic electricity for all Filipinos by 2022.

2) Power sector development and future grid emission factor

The power sector development in the Philippines shall evolve over time, with increasing RE penetration. This should also result in reduced grid emission factor throughout the analysis period. The Philippine Energy Plan 2018-2040 stipulates two scenarios for the national power sector, namely the Reference Scenario (REF) and the Clean Energy Scenario (CES). NEXSTEP utilized the projected electricity generation of REF scenario in projecting the emission factor for the year 2030. The estimated emission factor in 2030 by the author is 0.567 tCO_2/MWh. Further details can be found in the Annex III.

3) Philippines Green Building Code (GB Code)

The Philippines Green Building Code was launched in 2015 and is applied to all new construction and/or with alteration of buildings with a minimum total gross floor area (TGFA) as follows (PGBI, 2016):

Table 2 Minimum TGFA for different building types to comply with the Philippines Green Building Code

Building Type	Minimum total gross floor area (TGFA)
Residential condominium	20,000
Hotel/resort	10,000
Educational school	10,000
Institutional hospital	10,000
Business office	10,000
Mercantile mall	15,000
Mixed occupancy	10,000

NEXSTEP assumes that the new and old buildings in Cauayan do not meet the minimum TGFA, hence the mandatory building code does not apply the buildings in Cauayan.

4) Solar and RE technologies in buildings (Department Circular 2020-12-0026)

The recently issued department circular mandates the use of solar PV and other RE technologies in new and existing buildings. This applies to buildings with electrical loads of at least 112.5 kilovolt-ampere or with a total gross floor area of at least 10,000 square meters.

Similar to the above, NEXSTEP assumes that the new and existing buildings do not meet the implementation requirements.

5) Minimum Energy Performance Standards (MEPS) and Energy Labelling Standards

MEPS and/or energy labelling standards have been introduced to various household appliances, covering window-type air conditioners (since 1993) and split-type room air conditioners (since 2000), refrigerators and freezers (since 1999, applicable to sizes between 142-227 litre), compact fluorescent lamp (CFL), linear fluorescent lamp (LFL), ballasts and circular fluorescent lamps (Hemandez, n.d.). As MEPS for the household appliances have been introduced between 1993-2010, NEXSTEP assumes that existing appliances have already conformed to the minimum energy performance standards set out by the DOE, where applicable. Hence, no additional potential savings to be achieved.

6) B5 biodiesel blend target

As noted in (Manila Bulletin, 2021), the DOE is targeting to increase the current biodiesel share from 2 per cent by volume to 5 per cent in 2021. NEXSTEP assumes that this will be implemented from 2022 onwards.[12]

7) Solar Irrigation system programme

Cauayan is advocating the use of solar irrigation system in its agricultural sector. The programme is expected to implement 5 solar irrigation system sets each year.[13]

Cauayan is part of the launching of the Hybrid Electric Rail Train developed by the Department of Science and Technology (DOST) (Edale, 2019). However, there has not been enough data to indicate how the future commercialised deployment of the HERT may affect the structure of city's transport sector, hence it has not been considered in the modelling. Notwithstanding, deployment of HERT may possibly lead to reduced use of other forms of transports, i.e. tri-cycles, passenger cars. Additionally, the City has recently introduced tax incentives for businesses implementing RE electricity system with capacity of 3 kW or more, through its Renewable Energy Ordinance.[14] The expected outcome is challenging to estimate; hence it is not modelled in the CPS.

The following section further describes the energy and emission outlook in the current policy settings.

3.6.1. Energy Demand Outlook

In the current policy settings, TFEC is projected to increase from 113.1 ktoe in 2019 to 196.7 ktoe in 2030, similar to the projected demand in BAU scenario (197 ktoe). The transport sector consumption will remain the largest at 141.1 ktoe (71.7 per cent), followed by the residential sector at 26.2 ktoe (13.3

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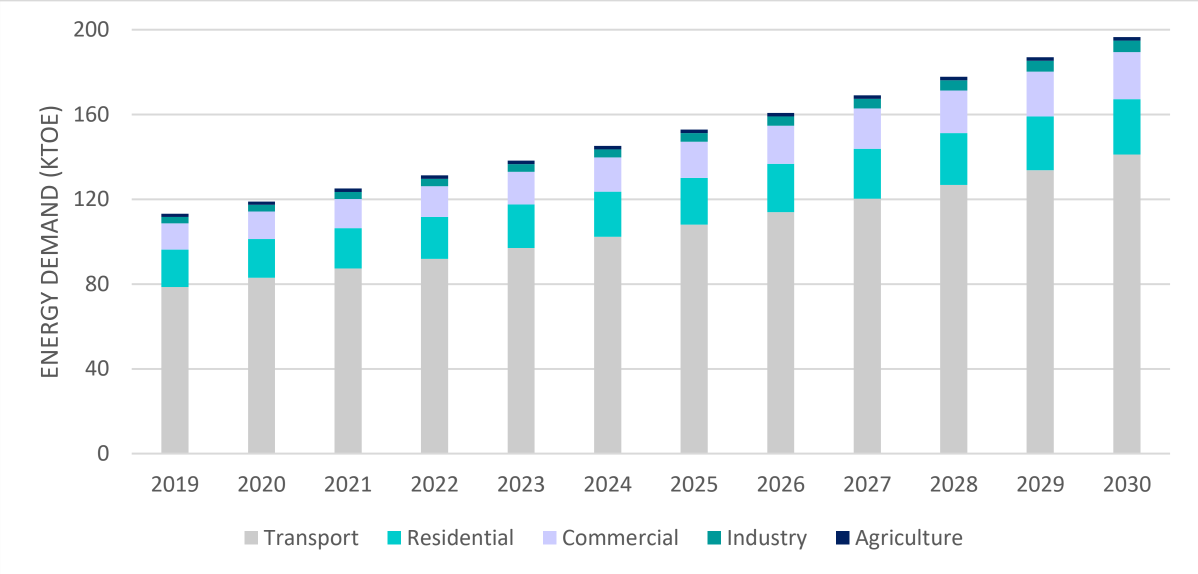
[12] This target has not been implemented yet by June 2021, hence NEXSTEP assumes that the target will take effect sometime around end of 2021 and early 2022.
[13] Each set of solar irrigation system is assumed to have a capacity of 9.6 kW.
[14] https://www.facebook.com/cityofcauayanofficial/photos/pcb.5807656575940953/5807638779276066

per cent) , the commercial sector at 22.2 (11.3 per cent), the industry sector at 5.4 ktoe (2.8 per cent) and the agricultural sector 1.7 ktoe (0.8 per cent).

The sectoral overview of energy demand in the CPS is discussed below and is as shown in Figure 6.

Figure 6 Cauayan's energy demand outlook, CPS 2019 – 2030

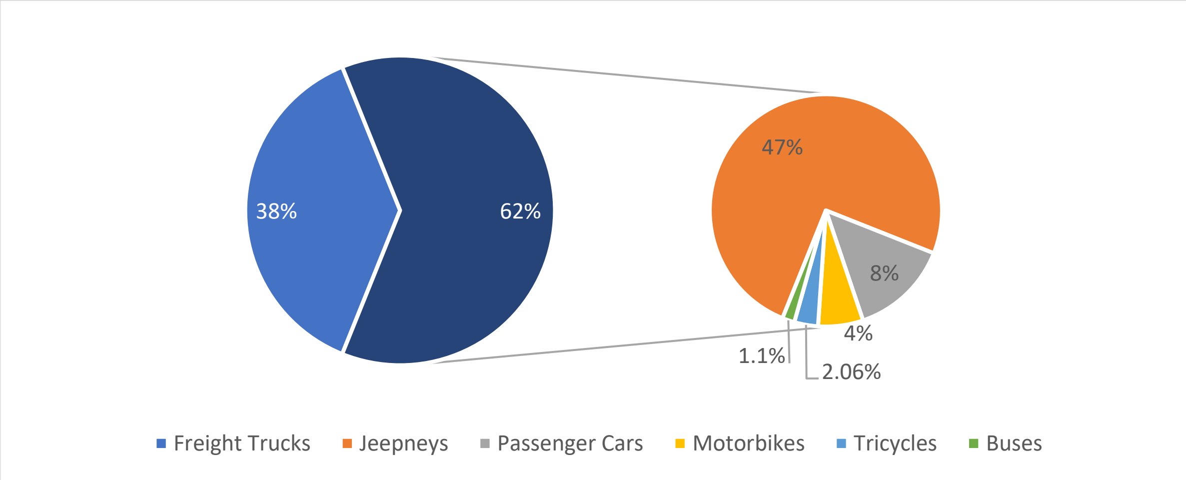


(a) Transport sector

The transport sector energy demand will continue to dominate Cauayan's TFEC and is projected to increase from 78.6 ktoe in 2019 to 141.1 ktoe in 2030. In 2030, the subsector share of transport energy demand is projected to be: road passenger transport 87.8 ktoe (62.2 per cent) and road freight transport 53.3 ktoe (37.8 per cent).

Road passenger transport are subdivided into four subcategories, i.e. private cars, motorbikes, tricycles, jeepneys, and buses, while freight transport consists of only freight trucks. The demand share in 2030 by transport subcategories is as shown in Figure 7. The first chart shows the share of freight transport (i.e. freight trucks) and passenger transport, while the second chart provides the demand breakdown of passenger transport subcategories. As observed, 75 per cent of the passenger transport energy demand is expected to come from jeepneys.

Figure 7 Energy demand distribution by transport sector sub-categories, CPS in 2030



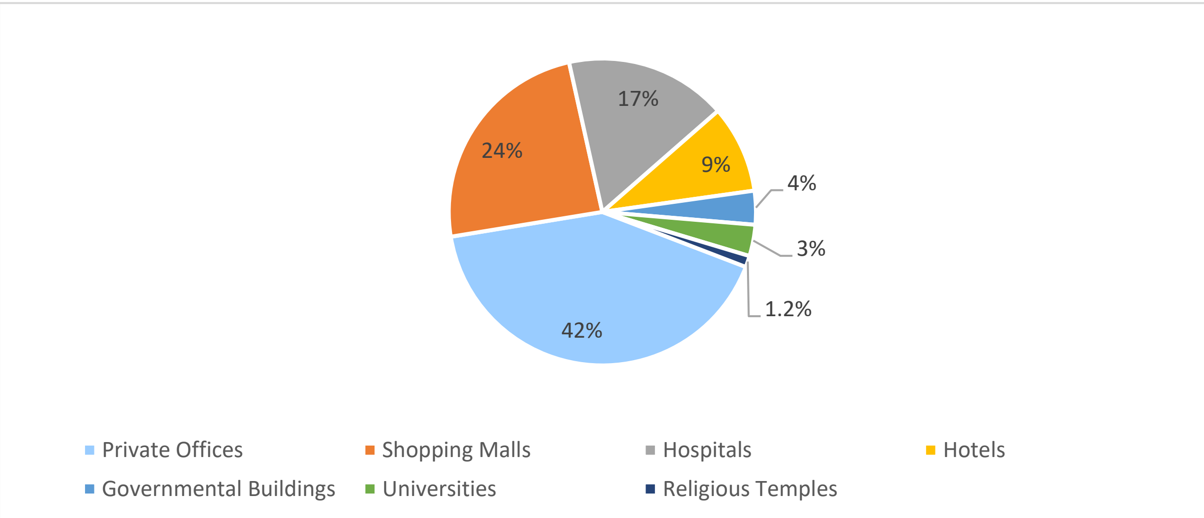
(b) Residential sector

The residential sector energy demand is projected to increase to 26.2 ktoe by 2030, compared with 17.7 ktoe in 2019. The residential sector is further differentiated into three residential categories, classified by sizes, i.e. small, medium and large residential. The energy demand from the small residential category is the highest, at 14.4 ktoe (54.9 per cent), followed by large and medium residential categories, at 6.7 ktoe (25.5 per cent) and 5.2 ktoe (19.6 per cent), respectively.

(c) Commercial sector

The commercial sector energy demand is projected to increase from 12.3 ktoe in 2019 to 22.2 ktoe in 2030. The sector is divided into seven subcategories, of which the floorspace of each category is projected to grow by 5.5 per cent per annum. The energy demand distribution in 2030 is as shown in Figure 8.

Figure 8 Energy demand distribution by commercial sector sub-categories, CPS in 2030



(d) Industry sector

Energy demand from the industry sector is expected to grow from 3.0 ktoe in 2019 to 5.4 ktoe in 2030. The modelling of CPS assumes that the energy intensity of the industrial sector remains constant throughout the analysis period, while industrial energy productivity increases by 5.5 per cent annually. The industry activities are quite limited and can be classified into three main categories. In 2030, the energy demand is projected to be: machinery and transportation equipment (3.5 ktoe, 65 per cent), food and beverage (1.1 ktoe, 20 per cent), and wood and other wood products (0.8 ktoe, 15 per cent).

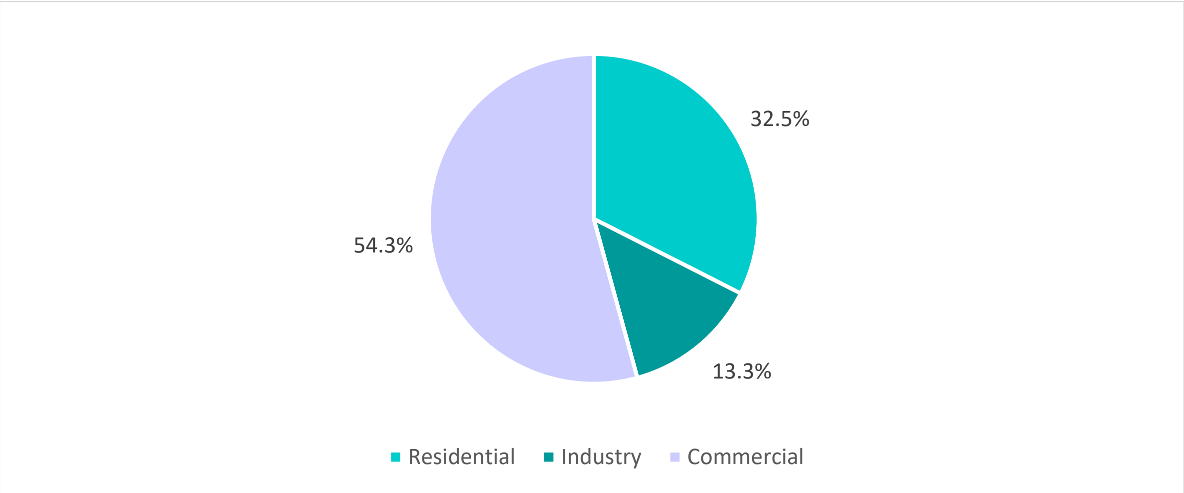
(e) Agriculture sector

The energy demand from the agriculture sector is relatively insignificant, only at 1.7 per cent in 2019. The energy demand is expected to increase from 1.5 ktoe in 2019 to 1.65 ktoe in 2030. The increase in energy demand is mainly stemmed from the increasing need for water pumping to increase crop productivity. As mentioned, the solar irrigation programme is expected to install 5 sets of solar irrigation system each year. At the same time, the demand for small diesel water pump is expected to increase by 100 pumps per annum.

3.6.2. Electricity Generation Outlook

The 2030 demand for electricity in the current policy scenario is projected to be 476.5 Gigawatt-Hours (GWh), increased from 277.5 TWh in 2019. The demand will be the highest in the commercial sector 258.5 GWh (54.3 per cent) followed by the residential sector 154.7 GWh (32.5 per cent) and the industry sector 63.2 GWh (54.3 per cent) (Figure 9).

Figure 9 Electricity demand distribution by demand sector in 2030, CPS

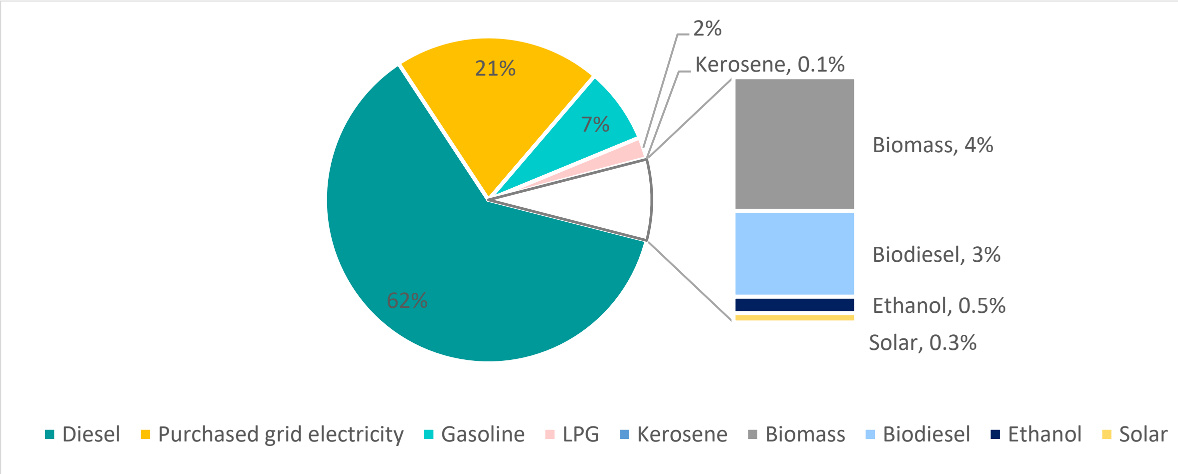


The electricity required to fulfil the demand in Cauayan is almost exclusively purchased from the grid, as local generation units are limited. As of current, installation of RE power capacity on governmental buildings are still in the planning. The recently issued Renewable Energy Ordinance may see rooftop solar PV installation picking up in the city. Notwithstanding, without further information on the future installed capacity, NEXSTEP analysis considers the existing capacity of 4.5 MW solar PV with an annual estimated generation of 6.3 GWh throughout the analysis period, in CPS. The remaining demand is expected to be fulfilled with central grid electricity from Luzon grid.

3.6.3. Energy Supply Outlook

In the CPS, TPES is forecasted to increase from 113.1 ktoe in 2019 to 196.7 ktoe in 2030. The fuel consumptions in 2030 are projected to be: diesel 121.4 ktoe, electricity 40.4 ktoe, gasoline 14.8 ktoe, biomass 8.6 ktoe, LPG 4.2 ktoe, ethanol and biodiesel 5.5 ktoe, solar 0.6 ktoe, and kerosene 0.2 ktoe. Figure 10 further shows the TPES breakdown by fuel type.

Figure 10 TPES breakdown by fuel type, CPS in 2030



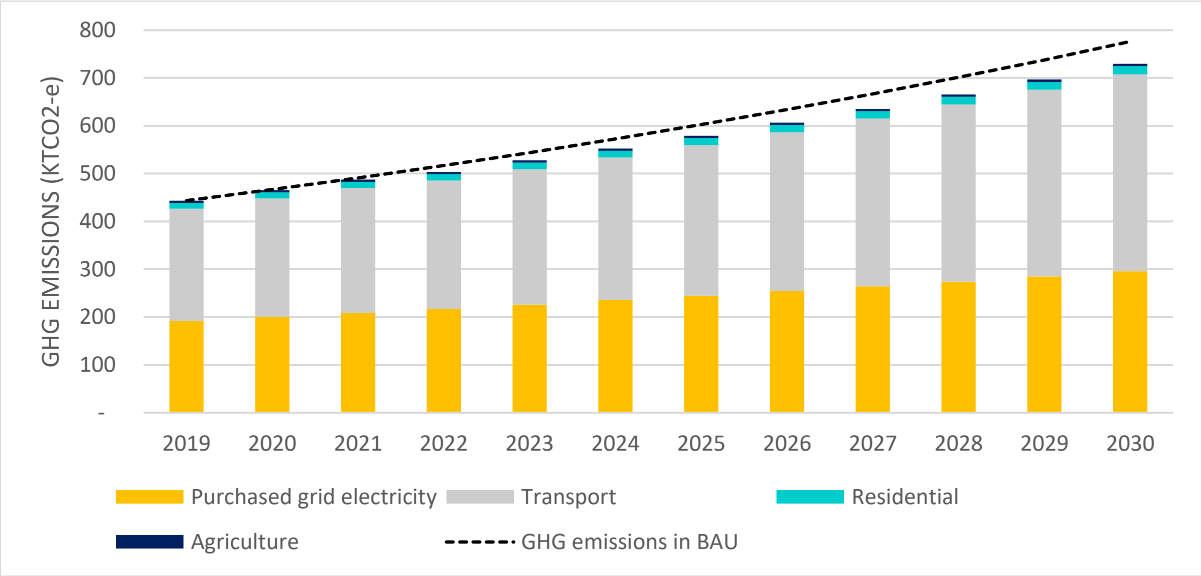
3.6.4. Energy Sector Emissions Outlook

The energy sector emissions, from the combustion of fuels, is calculated based on the IPCC Tier 1 emission factors assigned in the LEAP model. The combustion of biomass products (i.e. biodiesel and ethanol) is considered carbon neutral. The emissions attributable to purchased (grid) electricity has been included, while considering the projected decrease in grid emission factor throughout the analysis period. The grid emission factors have been estimated by the author based on the projected generation mix in 2030 of the REF scenario, stipulated in the Philippine Energy Plan 2030, as well as other assumed factors (i.e. efficiency). Further details on the grid emission factor estimation can be found in Annex III.

In the CPS, the total GHG emissions from the energy sector increases from 443.6 $ktCO_2$-e to 729.6 $ktCO_2$-e (Figure 11). The emissions attributable to purchased (grid) electricity make up about 40.5 per cent of the total emissions. For the demand sectors, the largest contributor of GHG emissions in 2030 is the transport sector (56.5 per cent), followed by the residential sector (2.3 per cent) and the agriculture sector (0.7 per cent).

The emission reduction is 6 per cent, relative to the BAU scenario. The decreasing emission factor of the central grid electricity is the major contributing factor to the emission reduction. Notwithstanding, in the event that the share of RE in the electricity mix increases less rapidly than modelled, the emission reduction will be much less substantial. For instance, the total GHG emissions is estimated to be 766.4 $kTCO_2$-e in 2030, if the emission factor remains similar to the 2019 level, a 10 $ktCO_2$-e reduction compared to the BAU scenario.

Figure 11 Cauayan's energy sector emissions outlook, CPS, 2019-2030



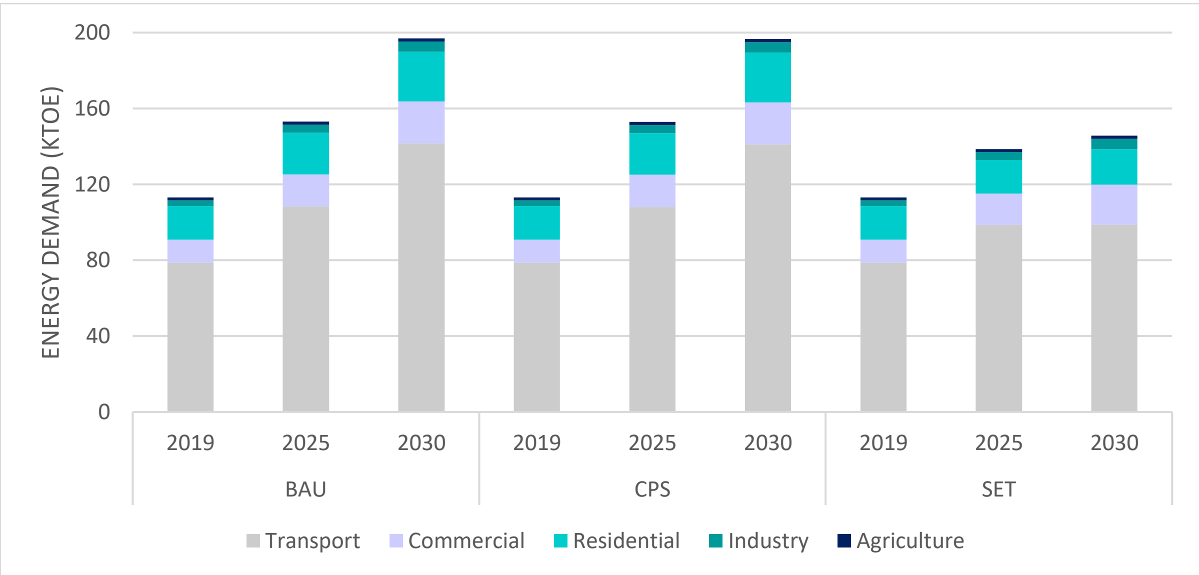
4. SET scenario – sustainable energy transition pathway for City of Cauayan

Both subnational and national efforts are imperative in achieving the 2030 Agenda for Sustainable Development and Paris Agreement on climate change. Particularly, cities around the world contribute around 75 per cent of global anthropogenic emissions and represent about 66 per cent of global energy demand (REN21, 2019). This chapter provides details of the SET scenario, exploring how economy-wide efforts may improve the energy and climate sustainability of the City of Cauayan. It starts with the energy demand forecast and then discusses the energy sector in relation to SDG 7 targets.

4.1. SET Energy Demand Outlook

In the SET scenario, TFEC increases at a much slower pace than CPS, from 113.1 ktoe in 2019 to 145.7 ktoe in 2030. The reduction of 51.0 ktoe in TFEC in this scenario, compared to the CPS, is due to the improvement in energy efficiency across the demand sectors. The proposed energy efficiency interventions are further described in 4.2.3. In 2030, the transport sector will still have the largest share of TFEC at 98.8 ktoe (67.9 per cent), followed by the commercial sector 21.1 ktoe (14.5 per cent), residential sector 18.7 ktoe (12.8 per cent), industry sector 5.4 ktoe (3.7 per cent) and the agricultural sector 1.7 ktoe (1.1 per cent). Figure 12 shows TFEC by scenarios in 2030.

Figure 12 Projection of TFEC by sector 2030



4.2. SDG7 Targets

4.2.1. SDG 7.1.1 Universal access to electricity

The electrification rate is expected to reach 100 per cent by 2022, as set out in the Philippines Energy Plan 2018-2040 and the Philippine Development Plan 2017-2022. NEXSTEP analysis proposes that decentralised renewable electricity systems, such as solar mini-grids and solar home systems, could be provided to the unconnected households. The ease of implementation, compared to extending grid infrastructure, should allow the 100 per cent electrification target to be reached within the stipulated timeline.

4.2.2. SDG 7.1.2 Universal access to clean cooking

Accelerated effort is required to achieve universal access to clean cooking. As of 2019, 23.3 per cent of households relied on polluting cooking technologies, including traditional biomass stoves and kerosene stoves. NEXSTEP analysis proposes the use of (induction-type) electric cooking stove as the most appropriate technology in filling in the gap due to reasons:

a. zero household air pollution,
b. minimal follow up required (as opposed to improved cooking stove), and
c. cost effective compared to the more commonly used LPG stove.

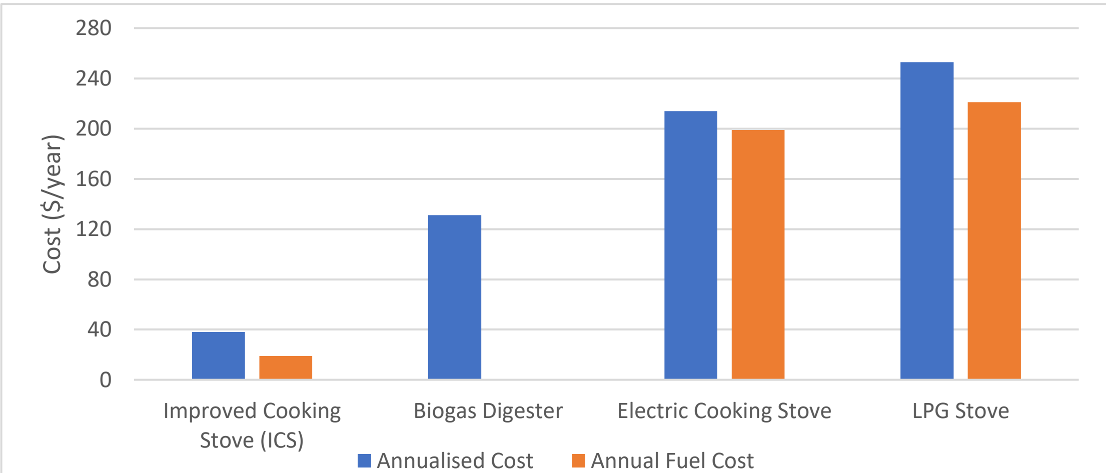
Notwithstanding, the operation of electric cooking stoves requires substantial power supply capacity that may not be met solely with decentralised RE systems proposed for currently unconnected households. In that case, LPG stove is the most appropriate technology.

Box 2 provides the summary of cost analysis and qualitative analysis on the pros and cons of different clean cooking technologies, in supporting the adoption of electric cooking stove and LPG stove as the most appropriate technologies.

Box 2: Cost and qualitative analysis of clean cooking technologies

Figure below summarizes the annualized cost and annual fuel cost of the different cooking technologies in the context of Cauayan. Annex IV summarises the cost and technical assumptions used in the economic analysis.

Annualised cost and annual fuel cost of different cooking technologies



While ICS and biogas digesters are estimated to have a lower annualised cost than electric cooking stoves, concerns have been raised by various studies on their suitability as a long-term clean cooking solution for the general population, particularly the urban population. The following provides short qualitative analysis on the pros and cons of the different clean cooking technologies:

i. *Electric Cook Stoves*

Electric cooking technology is classed as Level 5 in the World Bank MTF for Indoor Air Quality Measurement. Electric cookstoves are more efficient than other cookstoves, including gas stoves. Electric cookstoves can be generally divided into two types – solid plate and induction plate. While solid plate cookstoves use a heating element to transmit radiant energy to the food and reaches about 70 per cent efficiency, induction plate cookstoves, on the other hand, uses electromagnetic energy to directly heat pots and pans and can be up to 90 per cent efficient.

ii. Improved Cook Stoves

Studies suggest that ICS programs often have low adoption rates due to inconvenience of use, preference for traditional cookstoves and the need for frequent maintenance and repairs. ICS programmes initially require strong advocacy to promote adoption, after which they require ongoing follow-up, monitoring, training, maintenance, and repairs in order to facilitate continuing usage (UNESCAP, 2021b). Additionally, based on the World Health Organization (WHO) guidelines for emission rates for clean cooking, only certain types of ICS technology comply, particularly when considering that cookstove emissions in the field are often higher than they are in the laboratory settings used for testing.

iii. Biogas Digester

Biogas digesters have high upfront capital costs (about $1,000 for a standard size that is suited for a four-member family) and require substantial subsidy due to their longer payback period. A standard size biogas digester requires 2 to 4 cows, depending on the size of the cow, to produce enough feedstock for daily gas demand for a household. While the high amount of livestock in Cauayan may provide the necessary feedstock for the biogas digesters, cultural reluctance to using animal or human waste for cooking may be an impediment to successful roll out of biogas digester as a primary cooking method.

iv. LPG Cook Stove

LPG cook stoves generate lower indoor air pollution compared to ICS and are classified as Level 4 in the World Bank Multi-Tier Framework (MTF) for cooking exposure and reduces indoor air pollution by 90 per cent compared to traditional cook stoves. Notwithstanding, the LPG stove is estimated to have a higher cost than the electric cooking stove (see figure above).

4.2.3. SDG 7.2 Renewable energy

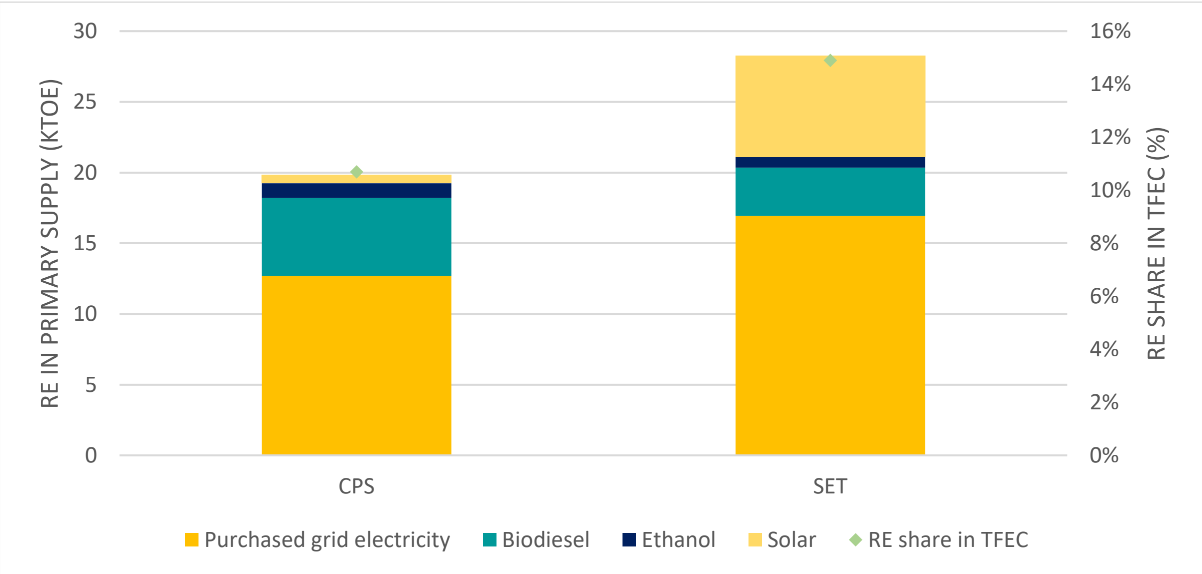
SDG 7.2 does not have a quantitative target but requires a substantial increase of renewable energy share in TFEC. The RE share in TFEC for Cauayan is determined using the required improvement in energy efficiency as a constraint, for which NEXSTEP considers the alignment of Cauayan's annual average energy efficiency improvement with the suggested global improvement rate of 3 per cent per annum (UNSD, 2021) (further detailed in 4.2.3). The RE share in TFEC also considers the increasing RE percentage in the grid electricity mix.

The share of renewable energy in TFEC in 2030 will be 10.7 per cent by 2030 in the current policy scenario (Figure 13). This increases from just 5.0 per cent in 2019. The increase is mainly driven by two factors:

a. projected increase in RE share of the grid electricity, from 14.0 per cent in 2019[15] to 34.1 per cent in 2030, based on the REF scenario in the Philippine Energy Plan 2018-2040, and
b. Increased biodiesel usage in the transport sector.

In the SET scenario, renewable energy share in TFEC is projected to increase to 14.9 per cent by 2030. This is a result of further reduction of energy demand due to energy efficiency measures in the demand sectors (see 4.2.3), and increased use of grid electricity (in the transport sector) which has a relatively high share of RE generation.

Figure 13 Renewable Energy in TPES and TFEC, 2030



4.2.4. SDG 7.3 Energy efficiency

The primary energy intensity, a proxy for the measurement of energy efficiency improvement, is calculated as 5.64 MJ/US$$_{2011}$ in the current policy scenario, which corresponds to an annual rate of improvement of 0.3 per cent. The primary energy intensity is further reduced to 4.18 MJ/US$$_{2011}$ in the SET scenario, made possible through the proposed economy-wide energy efficiency improvement

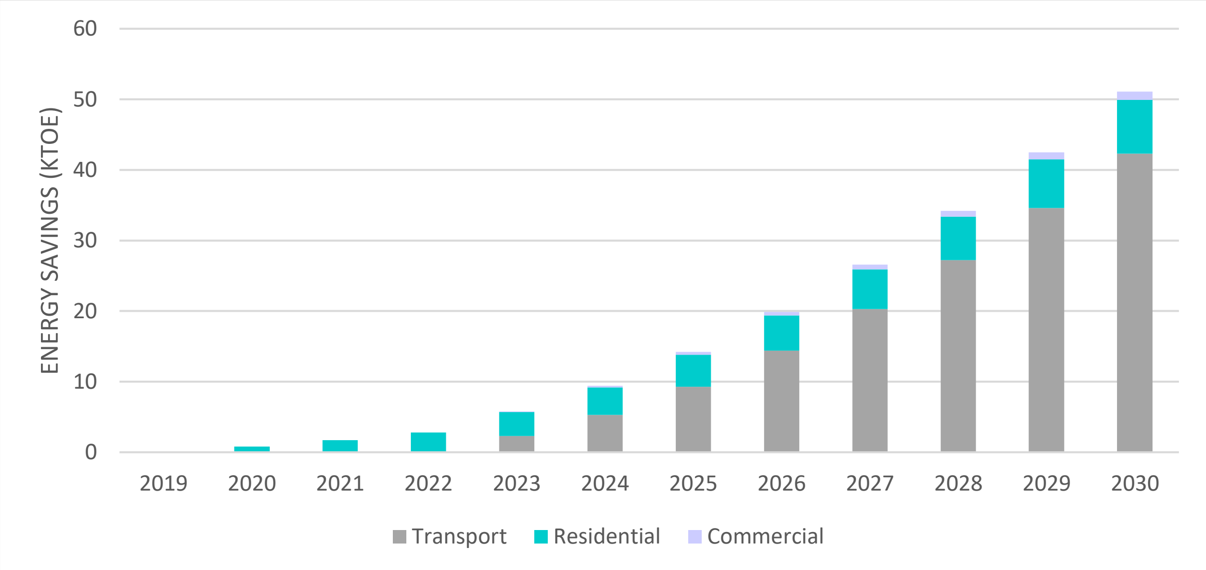
[15] Based on DOE 2020 Power Statistics, gross generation per grid, by plant type

measures. This corresponds to an average annual rate of improvement of 3.0 per cent, on par with the suggested global improvement rate of 3 per cent (UNSD, 2021).

Figure 14 shows the energy savings that may be achieved through the implementation of energy efficiency measures across the demand sectors, compared to the CPS. The transport sector is the largest energy consuming sector in Cauayan, which it can also be expected to have the largest contribution (42.3 ktoe in 2030), through the increased adoption of electric vehicles in multiple transport sub-categories. Energy demand reduction can also be realised through the phasing out of inefficient technologies in residential households. The city may consider a special policy which requires all new commercial buildings to adhere to the national green building code (from 2023 onwards), regardless of floorspace size, allowing an estimated energy demand reduction of 1.2 ktoe in 2030. Similarly, the city may consider mandating the adoption of the department circular on the use of solar and RE systems to all new commercial buildings. This is later discussed in the 4.3.2.

Further details of the energy efficiency measures and their impacts are provided below.

Figure 14 Energy savings in SET scenario, compared to CPS



4.2.4.1. Transport sector

The current share of electric vehicles in the existing fleet is very low. As communicated by the city, the total number of electric vehicles in the city is around 12 vehicles. Notwithstanding, promotion of electric vehicles is an effective way to reduce demand consumption in the transport sector, as well as GHG emissions. In the SET scenario, NEXSTEP proposes that uptake of electric vehicles can be promoted across the different vehicle categories, reaching a considerable share of the transport fleet by 2030. Further details and the estimated annual savings are as shown in Table 3.

Table 3 Energy efficiency measure applied and the estimated annual savings in 2030 (relative to CPS) in the transport sector

Sub-category	Energy Efficiency Measures	Annual Saving in 2030 (ktoe)

Jeepneys	Encouraging the adoption of electric jeepneys, reaching a share of 50 per cent by 2030	29.0
Freight trucks	Encouraging the adoption of electric motorbikes, reaching a share of 25 per cent by 2030	8.7
Private passenger cars	Encouraging the adoption of electric passenger cars, reaching a share of 25 per cent by 2030	2.4
Motorbikes	Encouraging the adoption of electric motorbikes, reaching a share of 25 per cent by 2030	1.1
Tricycles	Encouraging the adoption of electric motorbikes, reaching a share of 50 per cent by 2030	1.1
Total		**42.3**

An increase in market penetration of electric vehicles is required to reach the targeted shares by 2030. For instance, the annual sales of electric-type motorbikes, passenger cars and trucks should slowly pick up from presently zero per cent to 50 per cent by 2028. On the other hand, electric vehicles can be more vigorously promoted to the public transport (i.e. tricycles and jeepneys), quickly ramping up to 100 per cent electric vehicle penetration by 2029.

4.2.4.2. Residential sector

Energy demand reduction can also be realized in the residential sector, particularly through achieving a 100 per cent access rate to clean cooking technologies. As inefficient cooking practices gradually replaced by electric cooking stove and LPG stove usage, substantial energy savings can be expected. Additionally, the use of more efficient household appliances, for instance, LED lighting, provides energy savings opportunities.

Table 4 Energy efficiency measures applied and the annual savings in 2030 in the residential sector

Household Appliance	Energy Efficiency Measures	Annual Saving in 2030 (ktoe)
LED Lighting	Phasing out of compact fluorescent lamps (CFL) with LED lighting	0.5
Cooking	Achieving 100 per cent clean cooking access rate through induction electric cooking stove and LPG stove	7.1
Total		**7.6**

4.2.4.3. Commercial sector

The Philippines has launched its national green building code in 2015, mandatory for buildings above a certain minimum total gross floor area (TGFA) (see Table 2). Notwithstanding, similar effort can be sought from commercial buildings of all floorspace sizes in Cauayan. NEXSTEP proposes a special policy to be implemented by the city, requiring all new commercial buildings to conform to the national green building from 2023 onwards.

Table 5 Energy efficiency measures applied and the estimated annual savings in 2030 by commercial sub-category

Sub-category	Energy Efficiency Measures	Annual Saving in 2030 (ktoe)
Private Office	A special policy by the city which will require, from 2023 onwards, all new buildings, regardless of floorspace size requirements as in the national policy, to conform to the green building code. The expected savings is 15 per cent (IFC, 2017)	0.48
Government Building		0.04
Shopping Mall		0.28
Hotel		0.11
Hospital		0.20
University		0.04
Religious Temple		0.01
Total		**1.16**

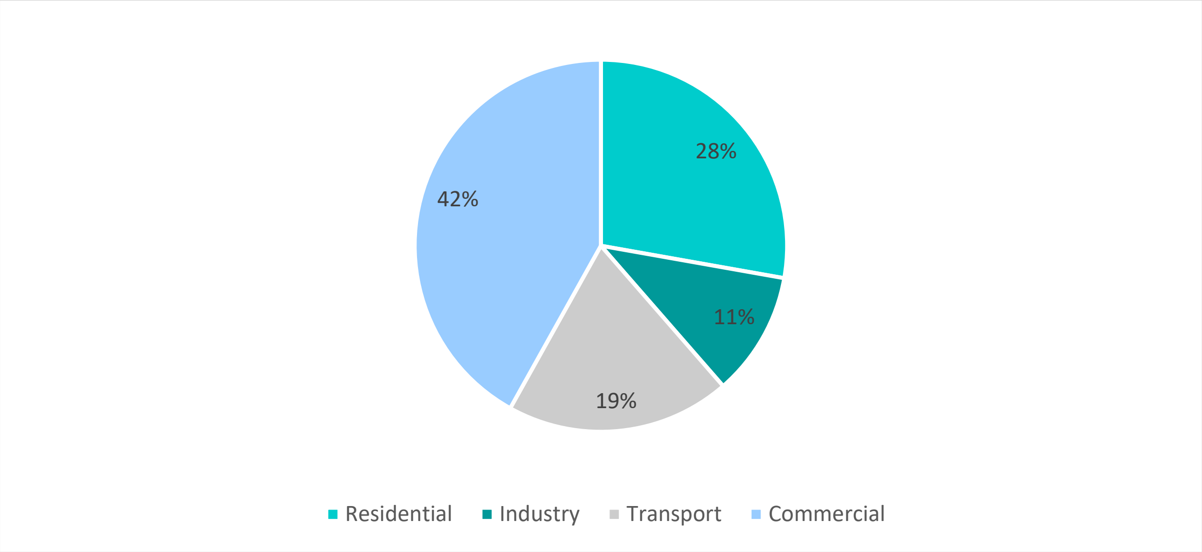
4.3. Electricity supply and demand in the context of sustainable energy transition

4.3.1. Electricity demand in 2030

The demand for electricity in 2030 is projected to be 584.8 GWh in the SET scenario, an increase of 108.3 GWh compared to the CPS. Reduction in electricity demand can be expected from the commercial sector as new buildings get more efficient with the mandatory compliance to the national green building code. On the other hand, electricity demand from the residential and transport sectors increases, due to the adoption of electric cooking stoves and electric vehicles.

The electricity demand in the commercial sector will be 245.0 GWh, the residential sector 162.5 GWh, the transport sector 114.0 GWh, and the industry sector 63.2 GWh (see Figure 15).

Figure 15 Electricity demand in 2030 by demand sector



4.3.2. Electricity supply

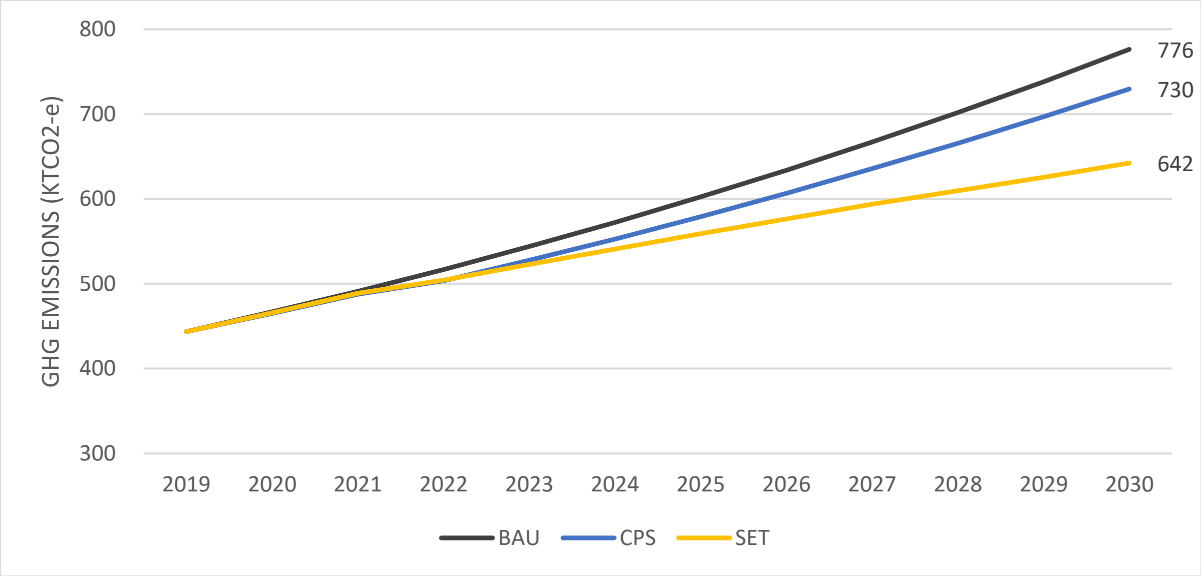
The existing solar PV capacity in the city has an approximate annual generation of 6.3 GWh. NEXSTEP analysis proposes mandating the use of solar and other RE systems to all new commercial buildings, regardless of the floorspace size, in fulfilling (at a minimum) 1 percent of their projected annual energy requirements. With an implementation timeline from 2023 onwards, it is estimated that 765 MWh of electricity demand from the commercial sector will be fulfilled by solar and/or other RE systems. Assuming that the demand is fulfilled by solar PV installation with a capacity factor of 16 per cent, the total installed capacity through this mandate is approximately 546 kW.

The remaining 99 per cent or 577.7 GWh shall be fulfilled by grid electricity from Luzon, assuming no other additional RE capacity within the city.

4.4. GHG emission reduction with sustainable energy transition

The GHG emissions in 2030 is projected to be 642.3 ktCO_2-e, a reduction of 87.3 ktCO_2-e from CPS. This corresponds to a 17.0 per cent reduction from the BAU scenario, or a 12.0 per cent reduction from the CPS (Figure 16).

Figure 16 GHG emission trajectories 2019-2030, by scenario



The GHG emissions reduction by demand sectors, relative to CPS, in 2030 is further explained below, considering the emissions attributable to their respective electricity usage:

- **Residential** – *net increase of 2.5 ktCO$_2$-e*. Phasing out polluting cooking technologies (i.e. biomass and kerosene stoves) through replacement with electric and LPG stove reduces direct GHG emissions from fuel combustion by 2.6 ktCO2-e. Phasing out less efficient lighting reduces electricity demand by 5.4 GWh – a GHG reduction of 3.59 ktCO$_2$-e, while the use of electric cooking stoves increases electricity demand by 13.2 GWh – an increase of GHG emissions by 8.7 ktCO$_2$-e.
- **Transport** – *net reduction of 80.9 ktCO$_2$-e.* Transport electrification measure proposed reduces the GHG emissions from direct fuel combustion by 152.3 ktCO$_2$-e. Notwithstanding, the indirect emissions due to the increased electricity usage is 71.4 ktCO$_2$-e.
- **Commercial** – *net reduction of 8.97 ktCO$_2$-e.* The reduced use of electricity through the implementation of green building measures in new buildings, as well as the installation of solar/ RE systems shall result in reduced GHG emissions.

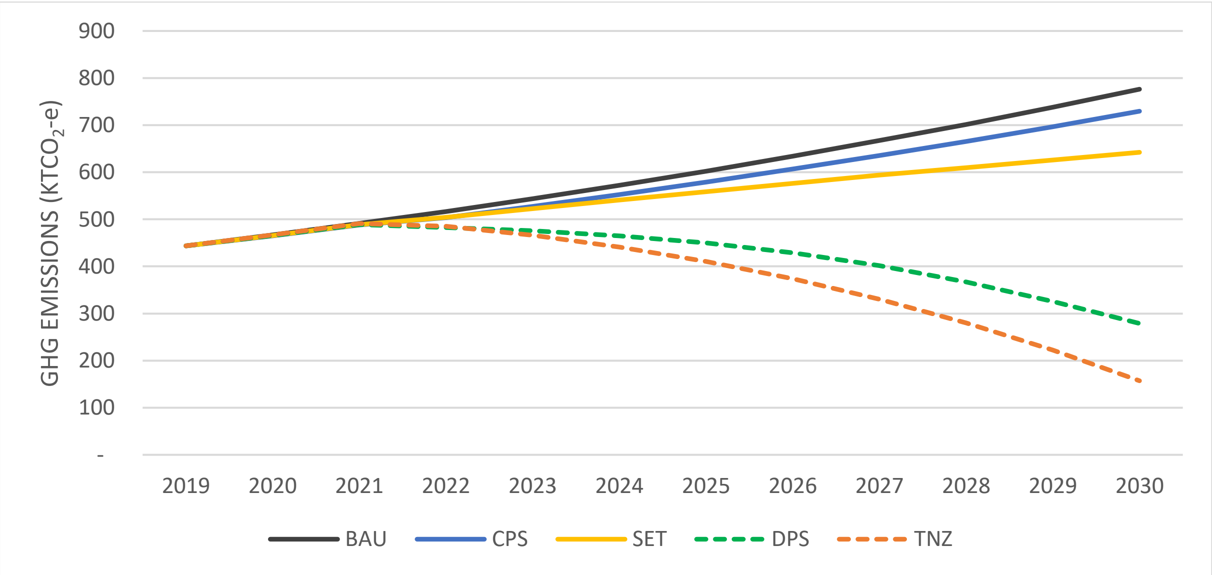
5. Moving towards net zero society with climate ambitious pathways

The SET scenario sets out various strategies in facilitating an economy-wide energy efficiency improvement in alignment with the global goal, as well as appropriate technology options in advancing modern energy access in the City of Cauayan. These have allowed both GHG emissions reduction and increase in renewable energy share in TFEC. Notwithstanding that, the City of Cauayan may consider more climate ambitious pathways, moving towards a net zero society.

Substantial energy demand and emission reduction have been achieved in the SET scenario through energy efficiency improvement measures. These measures have allowed energy demand reduction of 51.0 ktoe and emission reductions of 87.3 ktCO_2-e, (12 per cent) relative to CPS. This corresponds to a 17.0 per cent reduction from the BAU scenario. With countries and cities pledging net-zero emissions by 2050, two ambitious scenarios, the Decarbonisation of Power Sector (DPS) scenario and the Towards NetZero (TNZ) scenario, have been developed to explore how Cauayan can raise its ambitions in moving towards net zero in its power supply, as well as its energy system as a whole.

The DPS scenario focuses on the opportunities in decarbonising the electricity supply by increasing the share of RE electricity. It provides a plausible decarbonisation pathway which seeks commitments from the city in promoting urban electricity generation and RE power supply arrangement through renewable auctions or power purchasing agreements. On the other hand, the TNZ scenario aims to move the whole of Cauayan's energy system towards net zero, which requires cooperation from its citizens, by adopting cleaner, more efficient technologies (i.e. electric vehicles and induction type cook stoves). The GHG emissions that may be achieved with the two ambitious scenarios are as shown in Figure 17. The two ambitious scenarios are further described in the following sections.

Figure 17 GHG emission trajectories 2019-2030



5.1. Ambitious scenario 1: Decarbonisation of Power Sector (DPS) scenario

The Decarbonisation of Power Sector (DPS) scenario investigates how Cauayan may further decarbonise its electricity supply with 100 per cent share of RE electricity. This is in addition to the ambition set forth for the central grids by the national government, in reaching a 35 per cent RE generation share by 2030.

5.1.1. Electricity requirements and pathways for a decarbonized electricity supply

The electricity demand is projected to be 584.8 GWh in 2030. Cauayan currently purchases almost all its electricity required from the Luzon grid. Significant challenges exist for the city to increase the share of renewable energy in purchased electricity as the city currently does not have any control on how the electricity is produced on the Luzon grid. Nevertheless, there are a few pathways that the city may explore, in order to achieve a net-zero carbon power supply objective. These four pathways are further explained in the following:

a) Promotion of agricultural waste-to-energy generation

As previously noted, Cauayan has an active agricultural sector with nearly 70 per cent of its land being utilised for rice and corn production, of which the agricultural residues could possibly be used for electricity generation or other form of energy generation. NEXSTEP's preliminary resource potential estimation found that the available agricultural waste may allow up to 7 MW of power generation (Box 3). A formal feasibility study should be conducted to investigate its biomass resource potential as well as the business case for agricultural waste-to energy facilities. Section 6.4 provides two proposals on how Cauayan may best promote agricultural waste-to-energy generation.

b) ***Rooftop solar PV installation for both new and existing buildings***

Incentivising rooftop solar PV installation provides two benefits to the city – 1) reducing the financial burden on the city for establishing city's own solar PV system, and 2) reduces land use requirement from ground mounted PV. As noted in (IEEFA, 2018), the rooftop solar costs range between PHP 2.50 per kWh ($ 0.052 per kWh; without financing expenses) and PHP 5.30 per kWh ($0.11 per kWh; with financing expenses). By comparison, the average retail electricity tariff in the Philippines is around $0.149 per kWh.[16] This provides a substantial financial gain to the PV owners. Notwithstanding, ground mounted PV on vacant lands within the city boundary can be also considered. While solar PV installation are being promoted through the recently announced Renewable Energy Ordinance, the city government should continuously promote and closely monitor the outcome of the initiative.

c) ***Establishing power purchase agreements (PPAs)***

[16] The average generation cost in Luzon grid in 2018 is PHP 4.3648. The electricity tariff includes many components – generation costs (45.8%), transmission (8.62%), system loss (3.15%), distribution (26.3%), subsidies (0.5%), government taxes (9.41%), universal charges (4.09%), and FiT allowances (2.13%) (Chemrock, 2018).

The city can enter into a special renewable energy power purchase agreement with interested suppliers who are located along the Luzon grid. In turn, the supplier will supply Cauayan with an agreed RE share electricity at agreed price. Notwithstanding, this may not allow the city to take advantage of the lower generation costs available, such as through renewable energy auctions.

d) ***Lowering cost through renewable energy auctions***

A more workable solution and the recent policy instrument is the renewable energy auction. This approach is likely to substantially decrease the cost of electricity supply through a competitive pricing bidding and therefore, return a greater net benefit. The recent auctions e.g. the 60 MW solar PV auction in Cambodia has achieved $0.0387 per kWh (ADB, 2019).

The above options are four different pathways that the city may pursue. A combination of one or more pathways, specifically with urban solar PV and waste-to-energy plants, and renewable energy auction, may be a good solution. Further details of renewable auction can be found in Box 4.

Box 3: Agricultural waste potential in Cauayan

Cauayan has an active agricultural sector, specifically in rice and corn production. The total area of cultivation is estimated at 24,463 hectares in 2017, consisting of 11,461 hectares for rice cultivation and 12,271 hectares for corn production. Other food crops include coconut, mango and vegetables with a total cultivation area of 731 hectares (City of Cauayan, 2018). Several studies have suggested the potential use of agricultural waste (i.e. rice husk and corn corb) for energy-use purposes. For instance, in electricity generation. Additionally, the large number of livestock in Cauayan also provides possible source of feedstock (i.e. manure) for biogas production. Preliminary resource potential analysis by NEXSTEP suggests that the agricultural waste and manure waste potential for electricity generation is around 5 MW and 2 MW as detailed in the following.

Electricity generation potential for different residue types in Cauayan

Residue type	Electricity generation potential
Rice husk	2 MW
Corn cob	2.9 MW
Animal manure	2 MW

Rice husk

The agricultural waste associated with rice production is rice husk and rice straw. Notwithstanding, rice straw is most effectively used if it is incorporated in fields to maintain the soil organic matter levels and to enhance nitrogen fixation, making rice husk the only viable feedstock for bioenergy applications (Ang & Blanco, 2017). The annual rice yield is around 122,000 tonnes, which yields approximately 24,400 tonnes of rice husks upon milling.[17] This assumes that the rice husks make up

[17] Annual rice yield as of 2017 statistics in Table 4 of (City of Cauayan, 2018).

20 per cent of the total grain weight. The realistic potential is dependent on factors such as recovery efficiency and availability of biomass for energy, of which final availability is estimated to be about 16,200 tonnes.[18] Considering an estimated biomass feedstock requirement of 8,150 tonne/MW (Table 7 of (Ang & Blanco, 2017)), the electricity generation potential stands at **2 MW**.

Corn Cob

The cultivation area for corn production is 12,271 hectares, with a total yield of approximately 135,000 tonnes per annum.[19] While maize stalks are abundant, harvesting of maize stalks for bioenergy application are considered unsustainable in the tropic regions due to concerns such as soil erosion and depletion of nutrients and organic matters in the soil. The corn cob, is however, a viable residue for bioenergy applications. The corn cob makes up about 27 per cent of the total grain weight and has a recovery efficiency ranges between 40 to 80 per cent. The recovery efficiency is higher during the dry season (50 to 80 per cent) and low during the wet season (40 to 50 per cent) (Ang & Blanco, 2017). Assuming an average recovery efficiency of 50 per cent, the amount of corn cob available for bioenergy application is approximately 18,200 tonnes/year. This corresponds to an estimated electricity generation potential of **2.9 MW**.[20]

Animal Manure

The total amount of livestock in Cauayan is approximately 580,000 head, consisting of poultry (532,000), swine (34,000) and other large-size livestock (12,200). The animal manure collected from farms has the potential for biogas production, which can be subsequently used for electricity generation. The annual biogas potential and electricity generation potential (assuming a 35 per cent efficiency) are as estimated below.

Biogas and electricity generation potential for different livestock types in Cauayan[21]

Livestock type	Methane yield (GJ/year)	Electricity yield (MWh/year)
Poultry	71,000	2,800
Swine	29,000	6,900
Large-size livestock	54,000	5,300

[18] Both the recovery efficiency (0.91*0.90) and availability of biomass for energy (0.81) are based on estimates provided in Table 8 of (Ang & Blanco, 2017). The recovery efficiency is typical estimate for the Philippines and is dependent on two factors. 3 per cent of the total rice production is used for seed, while another 6 per cent is used for livestock feed and other purposes. The recovery efficiency is again lowered due to the use of "kiskisan" – a small village rice mill which does not produce rice hull. Such milling method is responsible for 10 per cent of all rice produced in the Philippines.

[19] Based on 2017 statistics in Table 4 of (City of Cauayan, 2018)

[20] Based on estimated biomass feedstock requirement of 6,378 tonne/MW in Table 4 of (Ang & Blanco, 2017).

[21] The biogas and electricity generation potential are estimated using the factors provided in Table 3 of (Scarlat, Fahl, Dallemand, Monforti, & Motola, 2018). Estimation for poultry category is based on factors for "laying hens" category in (Scarlat, Fahl, Dallemand, Monforti, & Motola, 2018), swine category is based on "other pigs", while large-size livestock assumes the factors for "other cows".

Assuming a capacity factor of 85 per cent, the electricity generation capacity is approximately **2 MW**, considering 100 per cent utilization of manures from all livestock types.

5.1.2. Cost-benefit of decarbonized power supply

The financial benefits to be gained through a decarbonised power supply is dependable on the pathways the city undertakes. Considering the low auction price that has been reached in the ASEAN region of $0.0387 per kWh and assumed grid generation cost of $ 0.092 per kWh (PHP 4.365 per kWh), the annual saving is $ 31 million in 2030. The financial savings are considered as the difference between the grid generation costs, with the current generation mix of the Luzon grid, and the RE costs for a total electricity demand of 577.7 GWh.[22]

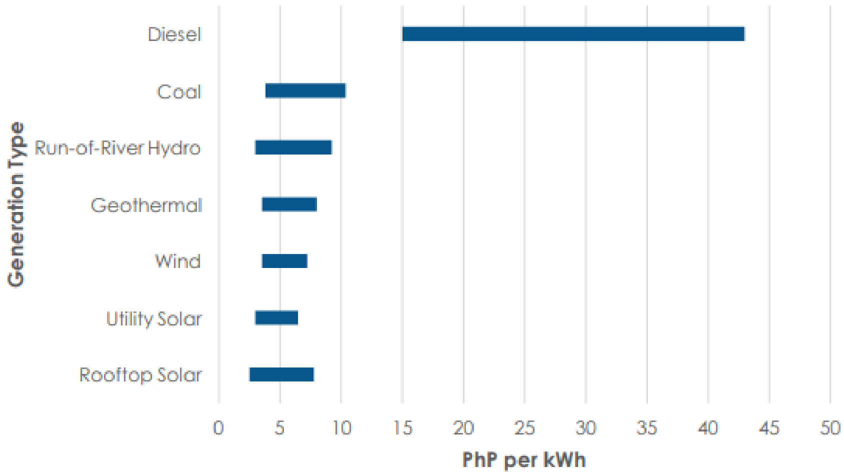
Notwithstanding, the RE price is likely to decrease further in the near future as the technology costs decline. On the other hand, the grid generation cost may also decrease as RE penetration increases, lowering the average generation costs. Table 6 shows the estimated financial savings at different uncertainty points. It can be observed that, in almost all cases, financial savings are positive. Considering the low solar PV generation costs compared to other conventional power plants (see Figure 18), financial gains through a 100 per cent renewable-based electricity are guaranteed.

Table 6 Sensitivity analysis showing financial savings at different RE prices and grid tariff costs

		Financial Savings (million $)				
		Change in RE price				
		50%	**25%**	**0%**	**-25%**	**-50%**
Change in average grid generation	**50%**	46	51	57	63	68
	25%	33	38	44	49	55
	0%	19	25	31	36	42
	-25%	6	12	17	23	29
	-50%	-7	-1	4	10	15

[22] The total electricity requirement in 2030 is projected to be 584.8 GWh, while the local RE self-generation is estimated to reach 7.11 GWh by 2030.

Figure 18 Generation costs by different power technologies in the Philippines *(IEEFA, 2018)*



5.1.3. GHG savings at different level of decarbonization

A 100 per cent RE-based electricity supply shall allow a total decarbonisation of the electricity supply. Notwithstanding, should Cauayan consider a different level of RE ambition, the emission reduction for the whole energy system, compared to the BAU scenario, is as shown in Table 7. The RE target only considers RE installed within the city boundary, as well as RE generation arranged through a PPA and renewable auction exclusively for the city. It should be noted that the remaining electricity supplied by the central energy mix is expected to have a 34.1 per cent share of RE generation.

Table 7 GHG emissions and financial savings at different levels of RE target, DPS

	RE Target			
	25%	50%	75%	100%
City's self-arranged RE supply in 2030 (GWh)	146	292	439	585
Emissions from electricity supply ($ktCO_{2-e}$) from the Luzon grid in 2030	276	184	92	0
Total emissions in 2030 ($ktCO_{2-e}$) (including demand sectors)	555	463	371	279
Emission reduction relative to BAU in 2030	28.5%	40.4%	52.2%	64.1%
Financial savings ($ million) in 2030	7	15	23	31

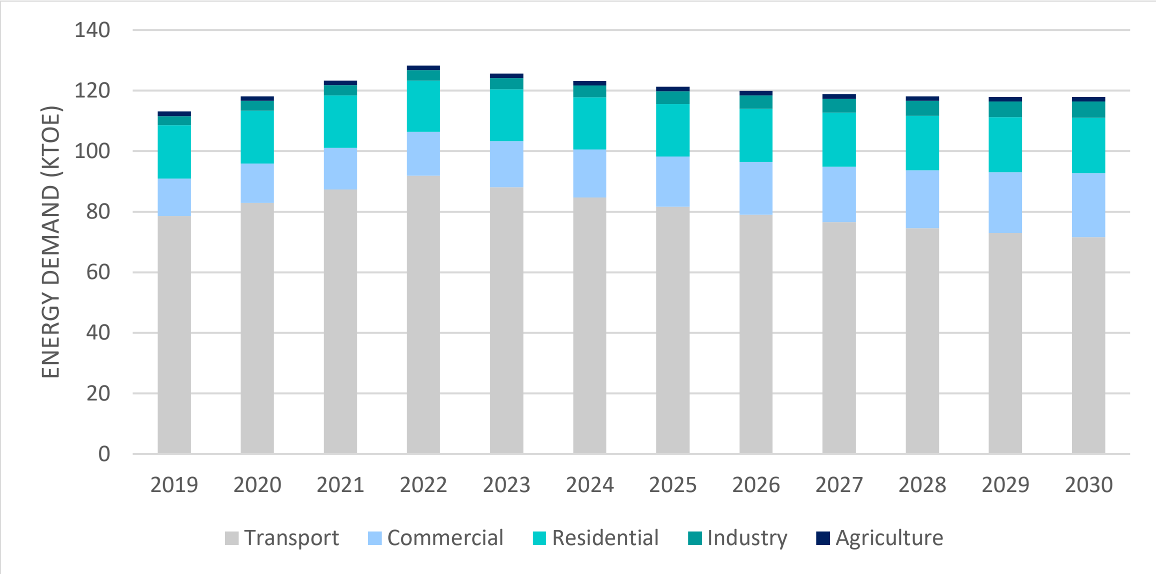
5.2. Ambitious scenario 2: Towards Net Zero (TNZ) scenario

Stepping up from the DPS scenario, the Towards Net Zero (TNZ) scenario aims to not only decarbonise Cauayan's electricity supply but widening the effort to cover the residential and the transport sector, through increased electrification. This requires a collateral effort from both the city government and its citizens, which the latter is required by moving towards the use of cleaner and more efficient technologies. This scenario is further described in the following.

5.2.1. Energy demand and GHG reduction

The total energy demand is expected to increase slightly from 113.1 ktoe in 2019 to 117.9 ktoe in 2030, a reduction of about 27.8 ktoe, relative to the SET scenario. The transport sector consumption will remain the largest at 60.7 per cent, followed by the commercial sector 17.9 per cent, the residential sector 15.5 per cent, and the industry sector 4.6 per cent. The energy demand reduction mainly stems from increased ambition in transport electrification. Figure 19 below shows the projected TFEC by sector under the TNZ scenario.

Figure 19 Energy demand by sector, TNZ scenario



The measures proposed for the TNZ scenario are as summarised in the Table 8 below. The annual GHG emission reduction in 2030 assumes that the electricity supply is carbon free with 100 per cent RE, as it has been proposed in the Decarbonation of the Power Sector scenario.

Table 8 Measures proposed and their respective annual energy savings and GHG emission reduction in 2030, TNZ scenario

Sub-category	Measures	Annual Energy Saving in 2030 (ktoe)	Annual GHG emission Reduction in 2030 ($ktCO_2$-e)
Transport			
Freight Truck	The market sales of electric vehicles should be 100 per cent from 2023 onwards.	13.0	58.9
Jeepneys		7.2	24.2
Private passenger cars		4.1	14.5
Motorbikes		1.9	6.4
Buses		0.7	2.7
Tricycles		0.4	1.4
Total		**27.2**	**108.0**
Residential			

Residential Cooking	Replacement of LPG stove with electric cooking stove[23]	0.4	12.8
Agriculture			
Irrigation System	Replacement of diesel water pumps with solar irrigation system	0.2	0.8

5.2.2. Electricity requirements and supply

The electricity demand 743.9 GWh, an increase of 159.1 GWh from the SET scenario. The increase in electricity demand is as expected with a higher penetration of E-vehicles and electric cooking stove. To reap the full benefits electrification can offer, in terms of GHG reduction, Cauayan should aim to achieve a 100 per cent RE share in its electricity supply. Similarly, the four different pathways (i.e. RE auction, PPA and urban renewable electricity generation) described in 5.1.1 can be considered. Notwithstanding, it should be noted that a higher amount of RE generation is required as electricity demand increases with a higher level of electrification.

5.2.3. Cost-benefit of decarbonized power supply and GHG reduction

Table 9 further shows the financial savings and GHG reduction that can be achieved with different levels of RE target. For instance, at a 100 per cent RE target, the financial savings is the largest, at $36 million, and the GHG emissions is reduced to only 157.2 ktCO_2-e. This remaining GHG emission is attributable to a small usage of LPG stove for residential cooking, existing internal combustion engine (ICE) vehicles yet to be phased out, and the use of diesel-powered agricultural machineries (i.e. tractor, rotovator and harvesters). A net-zero society can be realised in the coming decades as ICE vehicles are gradually retired from the transport fleet, as well as with the commercialisation and adoption of electric agricultural machinery. Additionally, the phase out of LPG may be pursued once in the future, when all population has been provided with sufficient power supply capacity.

Table 9 GHG emissions and financial savings at different levels of RE target, DPS

	RE Target				
	0%[24]	25%	50%	75%	**100%**
City's RE generation in 2030 (GWh)	7.1[25]	186	372	558	744
Emissions from electricity supply (kt$CO_{2\text{-}e}$) from the Luzon grid in 2030	464	351	234	117	0
Total emissions in 2030 (kt$CO_{2\text{-}e}$)	621	508	391	274	157
Emission reduction relative to BAU in 2030	20.0%	34.5%	49.6%	64.7%	79.8%

[23] With the exception of households connected to decentralised network, as the power supply may not be sufficient to support the use of induction type electric cooking stove.
[24] This refers to RE target for the city through self-generated/self-arranged renewable electricity, the central grid is assumed to have a 34.1% share of RE by 2030
[25] This refers to the generation from projected total capacity of rooftop solar PV installation in 2030.

Financial savings ($ million) in 2030	0	9	19	29	39

6. Policy recommendations for a sustainable energy transition

Chapter 4 demonstrates how sustainable energy transition can be accelerated to progress City of Cauayan's development in line with the 2030 Agenda for Sustainable Development, specifically SDG 7. Chapter 5 provides information on tangible low carbon transition pathways for Cauayan, with the most ambitious pathway reaching a GHG emissions as low as 157 ktCO_2-e by 2030. This chapter presents several policy recommendations, which further elaborate on the interventions proposed.

6.1. Achieving modern energy access target allows enhancement of socio-economic development

9.6 per cent and 23.3 per cent of Cauayan's population lacked the access to electricity and clean cooking technologies in 2019, respectively. Hence, providing universal energy access should be the utmost priority for the city to enhance socio-economic development and reduce social inequalities.

The meta-analysis conducted by ESCAP has found that providing electricity access is highly beneficial in enhancing socio-economic development, as well as gender empowerment. Positive impacts can be seen in increased household income and consumption, children's study time and years of schooling, and time spent working, both by men and women. Additionally, the impacts are seen more prominent for women and far-reaching, whereby women experience a higher level of social and economic change, i.e. increasing social participation and financial autonomy (UNESCAP, 2021c). NEXSTEP proposes the use of decentralised renewable energy systems, as a cost-effective and quick solution to close the access gap. Notwithstanding, continuous improvement in the technologies given should be sustained to meet the growing need for better electricity provisions.

Equally important is the access to clean cooking fuels and technologies, yet it generally lacks the attention from the policymakers. In turn, the inaction in closing the gap has led to substantial premature deaths due to the household air pollution caused by unclean cooking practices. Nearly a quarter of Cauayan's population still relies on the use of traditional biomass stoves and kerosene stoves. Positive benefits that can arise from adoption of clean cooking technologies include fuel savings (as evidenced in the SET scenario), less time spent on cooking and cooking fuels, and reduces health risks from indoor air pollution. NEXSTEP proposes that initiatives should be launched in providing electric cooking stoves as a long-term clean technology substitute. LPG stoves are a strong contender, however electric cooking stoves, particularly the efficient induction-type, are more cost effective and cleaner in terms of household indoor air pollution. Additionally, the use of electric cooking stoves paves the way towards net zero emissions when the electricity supply is decarbonised. LPG stoves may however be promoted to households that lack sufficient power supply capacity, i.e. households utilising decentralised renewable energy systems.

6.2. Implementation of national green building code to promote a sustainable commercial built environment

The Philippine Green Building Code (GB Code) was first launched in 2015, with an objective to improve building efficiency through a set of standards that will enhance sound environmental and resource management, without significant increase of cost. The mandatory compliance to the GB Code is currently limited to buildings above a minimum total gross floor area (TGFA). The energy reduction that may arise from the GB Code compliance is estimated at 15 per cent, a substantial savings for the benefits of the environment by reducing GHG emissions, while at the same time, reducing electricity bills (IFC, 2017). With the proposed measure in the SET scenario, introducing GB Code to all new commercial buildings from 2023 onwards may allow an estimated energy demand reduction of 1.6 ktoe, and GHG emissions of 8.5 ktCO_2-e. The provisions set out in the GB code in reducing energy demand involve the adoption of efficient practices, designs, methods, technologies. In addition, the adoption of the Department Circular 2020-12-0026, which calls for the use of solar PV and/or other RE systems in meeting at minimum 1 per cent of the projected requirements, further reduces the need for imported electricity.

The benefits of GB Code compliance do not end with just energy demand and GHG emission reduction. The GB Code stipulates a set of standards for areas including water efficiency, material sustainability, site sustainability and indoor environmental quality. For instance, an estimated 30 per cent of water savings may be realised with the adoption of water efficiency measures set out in the GB Code (IFC, 2017). The GB Code also promotes the efficient use of resources and non-hazardous material selection and use, as well as efficient waste management practices. Conserving the well-being of the existing ecosystems and water resources is also part of objective of the GB Code (DPWH, 2015).

Active promotion of sustainable built environment could lead to indirect socio-economic benefits. For instance, a growing green building industry in the city and increased employment. From the building owner's and operator's perspective, benefits come in the form of increased building valuation and reduced electricity bills. Socially, sustainability-guided building designs also promote better well-being and health, as well as increase work productivity (WorldGBC, 2021).

6.3. Transport electrification for a more sustainable transport sector

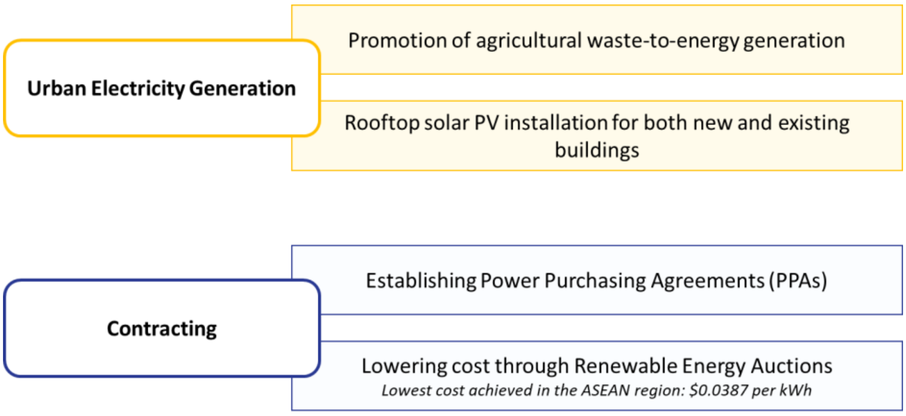
Cauayan's transport sector makes up about 66 per cent of the total energy demand and contributes nearly half of the city's GHG emissions in 2019. Hence, ambitious policy actions for the transport sector are critical for Cauayan to realise substantial energy efficiency improvement and to contribute towards climate mitigation. Transport electrification is one critical strategy that allows energy demand savings and GHG emission reduction.

Electric vehicles have garnered great interest globally, growing exponentially over in the past decade. The electric car sales have passed 2 million globally in 2019, with a projected compound annual growth rate of 29 per cent through 2030 (Deloitte, 2020). Several governmental policies have been introduced, which directly or indirectly promote the adoption of electric vehicles as a means to achieve environmental and climate objectives. For instance, 17 countries have ambitioned to phase out internal combustion engine through 2050, while the European Union's stringent CO_2 emissions standard have accelerated the electric vehicle adoption (IEA, 2020). \. NEXSTEP proposes that adoption of electric vehicles should be promoted. For instance, in the SET scenario, increasing the share of electric vehicles to between 25 to 50 per cent in a number of vehicle categories would allow an estimates energy savings of 42.3 ktoe, or 30 per cent, relative to CPS. The annual net reduction in GHG emissions is estimated to be 80.9 ktCO_2-e. Notwithstanding, it is important to note that GHG emission reduction using electric vehicles and can only be realised with sufficient share of zero emission energy mix. Not only that, the full potential of GHG emission reduction shall be realised when the electricity supply is decarbonised. Other positive impacts include reducing pollutant emissions due to its zero-tailpipe emissions.

6.4. Pursuance of high renewable power share through cost effective pathways

Renewable capacity has increased significantly across the globe amid climate change concerns. The decarbonisation of the power sector is generally regarded as the low-hanging fruit, as the cost of renewable power technologies decreased rapidly over the past decade. With the electricity constituting around a quarter of the total fuel consumption and more than 40 per cent of GHG emissions in 2019, decarbonising the electricity supply provides a quick decarbonisation pathway, reaching a substantial GHG emissions reduction, while providing financial benefits. NEXSTEP proposes four different pathways that may be considered in decarbonizing the electricity supply, as described in 5.1.1. A combination of these four pathways can be adopted.

Figure 20 Four different pathways in decarbonizing the electricity supply



Urban renewable electricity generation may also be promoted. The local stakeholders of Cauayan have a keen interest in utilizing their local agricultural waste for energy generation. As noted, there are currently industrial scale agricultural waste-to energy plants and ethanol plants in neighbouring towns, which receive process feedstock from Cauayan. Similar establishments may be replicated in Cauayan, using the potential biomass resources from its agricultural sector, which has an electricity generation potential of approximately 7 MW (see Box 3). Such initiatives may come in two forms of arrangement, to be considered by the City Government. Firstly, the City Government may opt to self-invest and self-govern the biomass facility. This may, however, requires huge investment and operational responsibilities. A better solution may be attracting potential investors to establish the facilities, while contributing positively to the city's economy and providing job opportunities. A power purchase agreement can be set up with the respective suppliers, supplying the city with renewable electricity at an agreed price. On the other hand, citizen's initiatives in setting up rooftop installation on both new and existing buildings should be promoted. For instance, the City Government is providing a tax incentive to small businesses establishing a minimum of 3 kW of RE systems, in the form of 10 per cent discount from their gross sales for their corresponding business taxes in the city. The outcome of the initiative should be closely monitored, making sure that it aligns with the city's aspirations.

Renewable energy auctions may however be the best and cheapest option, whereby contracts and agreements are awarded through competitive bidding. The Department of Energy of the Philippines is planning to launch a 2,000 MW renewable energy auction around mid-2021 (Rivera, 2020). While the renewable energy auction mechanism and its associated standards are set at the national level, the City of Cauayan can work with the central Government to implement RE auctions at the city level, with the help of the central Government. Box 4 further explains the renewable energy auction in detail.

Box 4: Mechanism of renewable energy auction

A renewable energy auction, also known as a "demand auction" or "procurement auction", is essentially a call for tenders to procure a certain capacity or generation of renewables-based electricity. The auction participants submit a bid with a price per unit of electricity at which they are able to realize the project. The winner is selected on the basis of the price and other criteria, and a power purchase agreement is signed. The auctions have the ability to achieve deployment of renewable electricity in a well-planned, cost-efficient and transparent manner. Most importantly, it makes the achievement of targets more precise than would be possible by other means, such as a Feed-in-Tariff (FiT). Auctions are flexible and they allow Governments to combine and tailor different design elements to meet deployment and development objectives. Unlike FiTs, where the Government decides on a price, auctions are an effective means of discovering the price appropriate to the industry, which is the key to attracting private sector investment. In addition, an auction provides greater certainty about future projects and is a fair and transparent procurement process. However, the administrative and logistic costs associated with auctions are very high unless multiple auctions are undertaken at regular intervals.

It is imperative that an auction be appropriately designed to (a) avoid the risk of underbuilding and project delays, and (b) allow sufficient competition among different levels of bidders in order to drive down the cost. IRENA suggests the following key design elements:

- Auction demand. Governments need to clearly indicate the scale or size of each auction, the preferred technology (technology neutral of a specific technology), auction frequency, and the upper and lower limits of projects size and price.
- Pre-qualification. A strict or high pre-qualification for bidders will leave out the smaller entities, while a relaxed pre-qualification may undermine the quality of the project and increase the administrative costs. Governments need to make a trade-off, depending on the project size and other development objectives.

- Selection criteria. Commonly two selection criteria are used: (a) the lowest bid where only the lowest bidder will win; and (b) lowest bids plus other objectives where in addition to the price, other objectives such as local content and jobs are taken into consideration.
- Payment modalities. The pay-as-bid model is good to minimize the cost; however, the marginal cost payment model, where the same price (selected based on the highest cost winner) is paid to all winners is also practised.
- Penalties for non-compliance. There could be cases where the developer either delays the project or fails to complete. To avoid such cases, penalties should be in place. There are two modes of penalty. In the monetary penalty, money will be deducted from bidder's "bond" or the price of energy will be reduced for a delayed completion. A form of non-monetary penalty can be the exclusion of the bidder from future auctions.

6.5. Moving towards NetZero Carbon

Limiting temperature rise to 1.5ºC requires climate mitigation effort on an unprecedented scale and speed to reduce GHG emissions by about 45 per cent from 2010 levels by 2030, reaching net zero around 2050. Failing to act on the most pressing issue of this generation may leads to catastrophic impact to livelihoods and the environment. The Philippines is highly vulnerable to the impacts of climate change. These includes more frequent extreme weather events and natural hazards, as well as sea level temperature rise. The agricultural sector is one of the many areas to be adversely impacted by climate change (Climatelinks, 2021).

Efforts from all levels and sectors are imperative in the emissions race to net zero. Particularly, cities can play a significant role as around the world they contribute around 75 per cent of global anthropogenic emissions and represent about 66 per cent of global energy demand (REN21, 2019). As of April 2021, more than 700 cities in 53 countries have now committed to a net zero target by 2050, with a medium target to halve emissions by 2030 (C40 Cities, 2021). The energy system of Cauayan is well positioned for an accelerated decarbonisation effort as the required net-zero technologies in decarbonising its energy systems are readily available and mature - electric vehicles, electric cooking stoves, solar irrigation systems and renewable power technologies. As detailed in section 5.1 and 5.2, decarbonising its electricity supply is key for deep decarbonisation as it contributes around 43 per cent of the total GHG emissions in 2019. A decarbonised electricity supply is also required to complement the rapid adoption of electricity-based technologies, such as electric vehicles and electric cooking stoves. Notwithstanding, further study should be conducted to identify possible challenges on the electricity grid resulting from a high electricity load and a high level of RE penetration. Possible mitigating solutions may be required, such as integrated energy storage, demand side management and smart ICT solutions in managing the possible burden a large-scale demand electrification may pose on the electricity grid.

7. Conclusions

The 2030 Agenda for Sustainable Development and Paris Agreement provide a common goal to achieve sustainability and climate objectives. While achieving the SDG 7 targets is principally a national effort, it requires combined contributions from stakeholders at various levels, such as subnational jurisdictions and cities. Cauayan is an active advocate for localizing SDGs, by various initiatives and programmes benefiting its citizens. As a participant of the “SDG 7 localisation project”, Cauayan and UNESCAP have collaborated to develop a Sustainable Energy Transition (SET) roadmap, which aims to inform the city on sustainable energy transition pathways tailored to its local context.

Cauayan is best recognised for its smart city initiatives and agricultural-centric economy. The GDP of Cauayan is projected to grow at 5.5 per cent per annum, while the population is expected to increase by 3.18 per cent each year. Under the current policy settings, Cauayan shall benefit from the national Government’s aspiration to provide universal electricity access by 2022. On the other hand, it may fall short of achieving universal clean cooking access. The overall energy demand is projected to rise by an annual average rate of 5.2 per cent, to 196.7 ktoe. Considering the renewable energy generation share in the grid generation mix reaching the aspirational target of 35 per cent, the GHG emissions is projected to be 729.6 ktCO_2-e, a GHG emission reduction of 46.7 ktCO_2-e, compared to a business-as-usual baseline.

The SET scenario proposes an energy transition pathway that strategically allow Cauayan to close its existing gaps in electricity and clean cooking access. It also suggests several energy efficiency opportunities that would lead to energy savings and GHG emission reduction. NEXSTEP proposes decentralised renewable electricity systems as the most appropriate and time-efficient solution to electricity the remaining unelectrified households. Qualitative and quantitative analyses have suggested that electric cooking stoves may be the best way forward in closing the clean cooking gap. Yet, clean cooking technology selection between electric cooking stove and LPG stove should be done basing on the households’ power supply capacity. Closing the clean cooking gap also provides a substantial energy demand reduction by phasing out polluting, inefficient cooking technologies (i.e. traditional biomass stoves and kerosene stoves).

The transport sector provides the greatest sustainable energy potential. The promotion of electric vehicle adoption in multiple vehicle subcategories is estimated to provide a total energy savings of 42.3 ktoe. On the other hand, the national green building code provides a readily available sustainable building framework that can be promoted to all new commercial buildings. Mandating the compliance to the national green building code shall lead to not only energy and GHG emissions reduction, but also helps facilitating a more efficient resource (i.e. water, material usage) and solid waste management. On the other hand, mandating the use of solar and/or RE systems reduces the need for purchased grid electricity. At the household level, energy savings can be realised through the adoption of more efficient appliances, specifically lighting appliances. With the proposed measures, the final energy demand and GHG emissions in SET scenarios are projected to be 145.7 ktoe and 642.3 ktCO_2-e, respectively.

Climate change is one of the most pressing issues of this century, requiring rapid and widespread climate mitigation from all sectors. Cauayan may play its part by raising its climate efforts through decarbonizing its electricity supply. This roadmap further explores several pathways that the city may undertake in decarbonizing its electricity supply. Renewable energy auctions stand out as the cheapest option, at the same time. without the operational burden from the city government. More can be done with co-operation from its citizens in adopting more electricity-based technologies, i.e. electric vehicles and electric cooking stoves, as explored in the most ambitious Towards NetZero scenario.

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Annexes

Annex I. Cauayan's status against the SDG 7 indicators

The following table summarises Cauayan's status against the SDG 7 indicator in 2019 and 2030. The projection for 2030 is based on the SET scenario. The following sections further describe the calculation methodologies in determining the 1) energy intensity 2) energy efficiency improvement rate and 3) renewable energy share in TFEC.

Table 10 Targets and indicators for SDG 7

Target	Indicators	2019	2030
7.1. By 2030, ensure universal access to affordable, reliable, and modern energy services.	7.1.1. Proportion of population with access to electricity.	90.4%	100% access rate already achieved
	7.1.2. Proportion of population with primary reliance on clean fuels and technology for cooking.	76.7%	100% access rate already achieved
7.2. By 2030, increase substantially the share of renewable energy in the global energy mix.	7.2.1. Renewable energy share in total final energy consumption.	5.0%	14.9%
7.3. By 2030, double the global rate of improvement in energy efficiency.	7.3.1. Energy intensity measured as a ratio of primary energy supply to gross domestic product.	5.85 MJ/US$ (2011) PPP	4.18 MJ/US$ (2011) PPP

SDG 7.3. Energy Efficiency. "By 2030, double the global rate of improvement in energy efficiency", as measured by the energy intensity of the economy. This is the ratio of the total primary energy supply (TPES) and GDP. Energy intensity is an indication of how much energy is used to produce one unit of economic output. As defined by the IEA, TPES is made up of production plus net imports minus international marine and aviation bunkers plus stock changes. For comparison purposes, GDP is measured in constant terms at 2011 PPP.

Energy intensity ($MJ/US\$_{2011}$) is calculated with the following formula:

$$Primary\ energy\ intensity = \frac{Total\ Primary\ Energy\ Supply\ (MJ)}{GDP\ (USD\ 2011\ PPP)}$$

Energy efficiency improvement rate is calculated with the following formula:

$$CAGR = \left(\frac{EI_{t2}}{EI_{t1}}\right)^{\frac{1}{(t2-t1)}} - 1$$

where EI_{t1} is Energy intensity in year t1 and EI_{t2} is energy intensity in year t2. In the case of Cauayan, t1 refers to the baseline year (2019) and t2 refers to the analysis end year (2030)

SDG 7.2. Renewable Energy Share of renewable energy in Total final energy consumption is calculated with the following formula, where TFEC is total final energy consumption, ELEC is gross electricity production.

$$\%TFEC_{RES} = \frac{TFEC_{RES} + \left(TFEC_{ELEC} \times \frac{ELEC_{RES}}{ELEC_{TOTAL}}\right)}{TFEC_{TOTAL}}$$

Annex II. Key assumptions for NEXSTEP energy modelling

a. General parameters

Table 11 GDP and GDP growth rate

Parameter	Value
GDP (2019, current US dollar)	344.8 million
PPP (2019, constant 2011 US dollar)[26]	809.81 million
GDP growth rate[27]	5.5%

Table 12 Population, population growth rate and household size

Parameter	Value
Population (2019)	150,118
Population growth rate[28]	3.18%
No. of Households (2018)	35,046
Household size (constant throughout the analysis period)	4.28

b. Demand-side assumptions

Industry:

There are three industry subcategories in Cauayan, namely 1) Food and Beverages, 2) Machinery and Transportation Equipment and 3) Wood and Other Wood Products. The fuel consumption data provided for 2019 is as follows, of which the fuel consumed is exclusively electricity[29]:

Table 13 Consumption in 2019

Industry subcategory	Electricity consumption in 2019 (ktoe)	Consumption share
Food and Beverages	0.603	20%
Machinery and Transportation Equipment	1.961	65%
Wood and Other Wood Products	0.452	15%

[26] The GDP in 2019 is recorded as RM94.2 billion. The figure is converted into PPP (current US dollar) with a conversion factor of 1.6 (https://data.worldbank.org/indicator/PA.NUS.PPP?locations=MY), and adjusted to 2011 US$ based on consumer price index (CPI) provided in https://www.inflationtool.com/us-dollar?amount=100&year1=2011&year2=2019
[27] The CDPii stipulates a GDP growth target of 6-8 per cent. The modelling considers a conservative growth rate of 6 per cent, considering the impacts of the COVID-19 crisis, as suggested by IRDA.
[28] Based on historical growth between 2006 and 2019.
[29] it is noted that oil products are sometimes used for electricity self-generation during power outages.

The industrial GDP is assumed to grow at an annual rate of 5.5 per cent, similar to the GDP growth rate. The energy intensity is assumed constant throughout the analysis period in the absence of energy efficiency interventions.

Transportation:

Road Transport

Road transport sector is modelled with a bottom-up approach, using vehicle statistics, passenger load factor, annual travel mileage and estimated fuel economy. Transport activities in 2019 are estimated at 2.8 billion passenger-kilometres and 1.4 billion tonne-kilometres. The growth in both passenger transport and freight transport activities is assumed growing at the same rate as the GDP, i.e. 5.5 per cent per annum. The breakdown of passenger-km and tonne-km share is as shown in Table 14:

Table 14 Passenger-km and Tonne-km distribution

Passenger Transport	No. of vehicles	Annual mileage (km)	Load Factor (pass-km/veh-km)	%share of passenger-km
Passenger Car	2,442 (gasoline) 1,366 (diesel)	24,000	2.5	8.1%
Motorbikes	17,927	9,000	1.6	9.1%
Tricycles	5,790	24,000	12.5	2.9%
Buses	30	80,000	50	4.2%
Jeepneys	7,134	24,000	12.5	75.6%
Freight Transport	**No. of vehicles**	**Annual mileage (km)**	**Load Factor (tonne-km/veh-km)**	**%share of tonne-km**
Freight Truck	4,238	56,000	9.3	100%

Residential:

The residential sector is further divided into small, medium and large households. Breakdown of the distribution, as well as their respective electrification rate in 2019 is as presented in Table 155.

Table 15 Household distribution and electrification rate

Residential Type	Percentage share	Electrification rate
Small	71.4%	86.6%
Medium	17.74%	100%
Large	10.56%	100%

The residential appliance ownership data, cooking distribution, and energy use intensity in the baseline year are provided by the local consultant. The appliance ownership is projected to grow a rate similar to the growth in GDP per capita.

The average electrical demand per owning household for the different appliances are assumed constant throughout the analysis period, unless further energy efficiency measures are implemented (i.e. as discussed in the SET scenario).

Commercial:

The total commercial floor space is 0.625 million m^2 in 2019 and is projected to grow at an annual rate of 5.5 per cent, similar to the GDP growth rate. The energy intensity is assumed constant throughout the analysis period in the absence of energy efficiency interventions. Commercial sector further differentiated into 7 categories, modelled based on approximated commercial floor space and electricity consumption data, as shown below:

Table 16 Commercial floor space and energy consumption

Category	Floor space in 2019 (million m^2)	Electricity intensity (kWh/m^2)	Consumption in 2019 (ktoe)
Private Office	0.2277	262	5.13
Government Building	0.0195	262	0.44
Shopping Mall	0.1002	345	2.97
Hotel	0.0876	151	1.14
Hospital	0.0757	323	2.10
University	0.0398	119	0.41
Religious Temple	0.0745	23	0.15

Agriculture:

The energy demand from the agricultural sector is associated with the irrigation and the use of agricultural machinery. The energy demand breakdown for the year 2019 is as shown in Table 17.

Table 17 Energy demand from the agricultural sector in 2019

Category	Energy demand in 2019 9 (toe)	Description
Irrigation (total: 221 toe)		
Diesel water pumps – small	7.8	120 water pumps, consuming 72 liters of diesel annually per pump
Diesel water pumps – large	196.7	670 water pumps consuming 326 liters of diesel annually per pump
Solar Irrigation system	16.5	Existing capacity of 200 kW
Agricultural Machinery (total: 1315 toe)		
Tractors	493.9	
Rotovators	450.7	
Harvesters	370.3	

Annex III. Estimating the Central Grid Emission Factor

NEXSTEP utilizes the projected electricity generation of the Reference Scenario (REF) stipulated in the Philippine Energy Plan 2018-2040. Figure A.1 below shows the definition of the REF scenario, which considers the existing indicative projects and the national RE ambition, while Figure A.2 shows the expected generation in 2030. The emission factor is further calculated using the assumptions listed in Table 18.

Figure A.1 Definition of REF scenario, Philippine Energy Plan 2018-2040

Scenarios	Assumptions	
	Reference Scenario ***(Business as Usual)***	**Clean Energy Scenario** ***(Alternative Scenario)***
Energy Demand	• Response to the requirements of the *Build, Build, Build* infrastructure program and *AmBisyon Natin 2040.* • Maintain 2.0 percent biodiesel and 10.0 percent bioethanol until 2040.	• Assumptions under the Reference Scenario, including the following: √ 10.0 percent penetration rate for electric vehicles for road transport (motorcycles, cars, jeepneys) by 2040; √ 3.0 percent increase in aggregate natural gas demand between 2018 and 2040; and, √ 5.0 percent aggregate energy savings from oil and electricity by 2040.
Energy Supply	• Present development trends and strategies continue. • Consider 6,300 MW committed and 33,200 MW indicative power projects as of December 2018. • Increase renewable energy (RE) installed capacity to at least 20,000 MW by 2040. • Consider the aspirational target of 35.0 percent share of renewables to the generation mix by 2030. • Adopt 25.0 percent reserve margin. • Assume 70.0 percent load factor for the total Philippines	• Assumptions under the Reference Scenario, including the following: √ Highly-efficient power technologies; √ 10,000 MW additional RE capacity by 2040; and, √ 1,200 MW from other emerging technologies by 2035.

Figure A.2 Electricity generation in 2030, REF scenario

Fuel Type	2018	2030	
	Actual	REF	CES
Coal	**51.93**	**126.31**	**121.13**
Natural Gas	**21.33**	**14.91**	**24.40**
Oil-based	**3.17**	**1.35**	**1.35**
Renewable	**23.33**	**73.86**	**68.80**
Geothermal	10.44	12.35	12.84
Hydro	9.38	31.92	28.89
Wind	1.15	6.39	7.41
Solar	1.25	21.39	18.19
Biomass	1.10	1.81	1.48
Other Technology	**0.00**	**0.00**	**0.00**
Total	**99.76**	**216.43**	**215.68**

Table 18 Grid emission factor calculation assumptions

Fuel	Efficiency	Emission factor (kgCO2/GJ primary fuel)
Natural Gas	35%	55.8
Coal	37%	92.6
Oil-based	38.5%	73.3

It is noted that the projected electricity generation is provided on the national level, covering the Luzon, Visayas and Mindanao grids. However, due to the lack of distinction in the data, NEXSTEP assumes that the electricity generation share is the same across all three grids. The estimated emission factor in 2030 is 0.57 tCO_2/MWh.

Annex IV. Clean Cooking Technologies Key Assumptions

The annualised cost of the different clean cooking technologies is calculated with the parameters below, as well as a cooking heating requirement of 3840 MJ/household-year (Putti, Tsan, Mehta, & Kammila, 2015).

Table 19 Clean cooking technologies key assumptions

Technologies	Efficiency[30] (%)	Lifetime[31] (years)	Stove Cost [32](US$)	Variable O&M [33](US$/year)	Fuel Cost[34] (US$)
ICS	35	4	35	10	0.03 per kg
LPG Stove	56	7	56	10	1.49 per kg
Biogas Digester	50	20	950	50	-
Electric Stove	84	15	40	10	0.149 per kWh

[30] Sourced from: ICS – own estimation, LPG stove and biogas digester efficiency ranges - (World Bank, 2014), electric cookstove (induction stove) - (IEA, 2012)
[31] Sourced from: ICS – own estimation, LPG stove – (Clean Cooking Alliance, 2021), biogas digester - (Wang & Zhang, 2012), electric stove - (IEA, 2012)
[32] Sourced from: ICS – own estimation, LPG stove and biogas digester – (IRENA, 2017), electric cookstove cost range - (Putti, Tsan, Mehta, & Kammila, 2015)
[33] Variable O&M is based on own assumptions, with the exception of biogas digester (IRENA, 2017)
[34] Wood cost is assumed opportunity cost related to wood collecting activities, LPG price is based on quoted common price of PHP 784 for April 2021 (https://www.doe.gov.ph/sites/default/files/pdf/price_watch/%20lpg_auto-lpg_mm_2021-apr-07-14.pdf), Electricity price is based on the average tariff for August 2020 in Philippine Energy Plan 2018-2040.

Annex V. Summary result for the scenarios

	CPS Scenario	SET Scenario	DPS Scenario	TNZ Scenario
Universal access to electricity in 2030	100%	100%	100%	100%
Universal access to clean cooking in 2030	76.7%	100%, via electric and LPG stoves	100%, via electric and LPG stoves	100%, via electric and LPG stoves
Energy efficiency in 2030	5.64 MJ/US$	4.18 MJ/US$	4.18 MJ/US$	3.38 MJ/US$
Renewable energy share in TFEC in 2030	10.7%	14.9%	37.4%	56.5%
GHG emissions in 2030	730 ktCO_2-e	642 ktCO_2-e	279 ktCO_2-e	157 ktCO_2-e
Power supply	4.5 MW of local solar PV, remaining supplied by Luzon grid	4.5 MW of local solar PV, remaining supplied by Luzon grid	100 per cent through city's self-arranged/generated RE	100 per cent through city's self-arranged/generated RE
Share of city's self arranged/generated RE electricity	1.3%	1.2%	100%	100%