Final Report

Economic Analysis of Climate-Proofing Investment in Road and Rail Transport Sectors (Investment and Financial Flows Assessment)

UNDP Thailand/NDC Support Project: Delivering Sustainability through Climate Finance Actions in Thailand (NDC Support)

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List of Abbreviations

BAU	Business as usual
BB	Bureau of the Budget
BOI	Office of Board of Investment
BOT	Bank of Thailand
CBA	Cost-Benefit Analysis
CFE-DM	Center for Excellence in Disaster Management and Humanitarian Assistance
CGD	Comptroller General's Department
CIF	Climate Investment Fund
CoP	Conference of the Parties (to the UNFCCC)
DDPM	Department of Disaster Prevention and Mitigation
DOH	Department of Highways
DMC	Disaster Management Center
DPM Act	Disaster Prevention and Mitigation Act 2007
DPSIR	Driving Force-Pressure-State-Impact-Response Framework
DPT	Department of Public Works and Town & Country Planning
DRM	Disaster Risk Management
DRR	Department of Rural Roads
EHIA	Environmental and Health Impact Assessment
EIA	Environmental Impact Assessment
ETS	Emission Trading System
FF	Financial Flows
FTI	Federation of Thai Industries
GCF	Green Climate Fund
GEF	Global Environment Facility
GHG	Greenhouse Gas
HDPE	High-Density Polyethylene
I&FF	Investment and Financial Flows
IF	Investment Flows
INDC	Intended Nationally Determined Contribution
LAO	Local Administrative Organization
LEDS	Low Emission Development Strategy
LT-LEDS	Long-Term Low Emission Development Strategy
MOF	Ministry of Finance
MSE	Mechanically Stabilized Earthwall
MNRE	Ministry of Natural Resources and Environment
NAMA	Nationally Appropriate Mitigation Action
NAP	National Adaptation Plan
NDC	Nationally Determined Contribution
NESDB	Office of the National Economic and Social Development Council
O&M	Operation and Maintenance
OECD	Investment Framework for Green Growth
ONEP	Office of Natural Resources and Environmental Policy and Planning
OTP	Office of Transport and Traffic Policy and Planning
PISU	Private Investments in State Undertakings
PPP	Public-Private Partnership
RID	Royal Irrigation Department

SCCF	Special Climate Change Fund
SDGs	Sustainable Development Goals
SEC	Securities and Exchange Commission
SEP	Sufficiency Economy Principle
SEPO	State Enterprise Policy Office
SLB	Sustainability-linked Bond
SRT	State Railway of Thailand
TD	Treasury Department
TGO	Thailand Greenhouse Gas Management Organization
TMD	Thai Meteorological Department
UNFCCC	United Nations Framework Convention on Climate Change

Executive Summary

Climate change has emerged as a critical threat to the world, and countries have been searching for ways to implement countermeasures to mitigate its consequences and adapt to the changes. Climate-proofing countermeasures generally require significant investment and an enabling financial mechanism. In Thailand, transportation sector has a great potential in reducing the greenhouse gas emission and has played an important role in addressing the threat. On the other hand, the sector itself is prone to climate change impacts, and suffered a number of climate events, though there has not been a concrete national strategy or action plan for climate-proofing investment in the sector. Under the UNDP Thailand/NDC Support Project: Delivering Sustainability through Climate Finance Actions in Thailand, a cost-benefit analysis (CBA) of climate-proofing investments in particular roads and rails at risk was performed, and the selected countermeasures were proved economically feasible with high benefit-cost ratio and short payback period. However, CBA delivers insights only for specific cases, and it calls for an alternative tool to deliver a bigger picture of the climate-proofing investment in the transportation sector in Thailand.

Investment and financial flows (I&FF) assessments, which can provide information on existing and required investment, as well as necessary changes and increases in investments, is performed, targeting climate adaptation countermeasures in the transportation sector in Thailand. These assessments consider all roads under the purview of the Department of Highways (DOH) or the Department of Rural Roads (DRR) and all rails responsible by the State Railway of Thailand (SRT). The baseline scenario and adaptation scenarios are determined following the UNDP guidelines. The baseline scenario includes general and planned emergency investments by government on roads through DOH and DRR, and on rails through SRT. Unfortunately, since climate related investment in transportation sector have not been distinguished from other investments, government investment and financial flows are forecasted based on average total budget in the past. The scenario also includes funding under the public private partnership (PPP) scheme, and foreign loans and aids. Literature review shows that Thailand has a clear policy direction and a detailed plan for climate mitigation in all relevant sectors, though the information on adaptation targets and plans is limited, and it is nearly nonexistent for the transportation sector. Therefore, rather than determining a specific adaptation scenario, this assessment proposes a matrix of possible and viable climate adaptation countermeasures along with their resulting investments, and target roads and rails that are prone to climate change impacts being classified into tiers. The matrix is consulted with key stakeholders including the Office of Transport and Traffic Policy and Planning (OTP), DOH, DRR, and SRT to determine the reasonable total investment to be used for the development of investment and financial flows of the adaptation scenario. For both scenarios, two different timeframes are adopted based on the milestones in the NDC, namely 2022 – 2030 (progressive adaptation case) and 2022 – 2050 (moderate adaptation case).

In the course of the selection of climate-proofing countermeasures, technical and political viability is thoroughly inspected. Technically and economically viable countermeasures for roads are: drainage system improvement, ditch lining, installation of box culverts, laying the road higher, asphalt concrete resurfacing, and mechanically stabilized earthwall (MSE). Viable countermeasures for rails are: installation of box culverts, construction of a steel or concrete bridge, sleeper replacement, and ballast refill. The unit price of each countermeasure is also estimated. In order to evaluate political viability of the investment, a map of involved stakeholders is developed. Based on the map, issues that may arise from

political and social perspectives are identified, including construction right and ownership of target sites, political and regulatory risks, cooperation with local administrative organizations, project delay, public acceptance and competing benefits, and patronage or clientelistic relation between politicians and citizen.

In order to formulate the aforementioned climate-proofing investment matrix, criteria for the selection of target roads and rails are established. Target roads are those owned by DOH and DRR and located near a canal or a river. Target rails should either be close to a mountain or run perpendicular to a waterway. Target roads are classified into three tiers: tier 1 includes one- and two-digit national highways, tier 2 includes three-digit national highways, and tier 3 includes four-digit national highways and all rural roads. Target rails are classified into two tiers: tier 1 covers Northern, North-eastern, and Southern lines, and tier 2 covers Eastern and Maeklong lines. The matrix can then be developed by matching the categorized countermeasures with the classified roads and rails and identifying the total investment corresponding to the combination of each countermeasure and each tier into each cell.

The matrix is presented individually to OTP, DOH, DRR and SRT to select the appropriate scope of investment. It is suggested that road countermeasures should be applied only to tiers 1 and 2 roads. Only MSE should be implemented to all target roads, while drainage system improvement, ditch lining, installation of box culverts, and road leveling and resurfacing are assumed to be applied only to 5% of the target roads. For target rails, only the installation of box culverts and the construction of a steel or concrete bridge are assumed to be applied to tier 1 rails. Table S1 and S2 shows the estimated investments for climate adaptation in roads and rails, respectively. Total investments for climate adaptation in roads and rails become 13.1 and 0.4 billion THB, respectively.

Table S1 Matrix for climate adaptation investment on road infrastructures (million THB)

Tier	Flood management		Flood avoidance		Structure reinforcement
	Drainage system improvement	Ditch lining	Water passage (box culvert)	AC resurfacing & laying the road higher	Mechanically stabilized earthwall
1	420	11	4	112	2,426
2	1,427	37	13	379	8,238

Table S2 Matrix for climate adaptation investment on rail infrastructures (million THB)

Tier	Flood management	
	Water passage (box culvert)	Water passage (concrete bridge construction) and water passage (steel bridge construction)
1	332	110
2	N/A	N/A

The cumulative discounted investment flow (IF), financial flow (FF), and operation and maintenance (O&M) cost estimates by investment type, investment entity, and funding source of the baseline scenario are then developed. Figures S1 and S2 show the estimates for progressive adaptation case and moderate adaptation case, respectively. Figures S3 and S4 show the annual IF, FF, and O&M estimates. The investments from domestic governmental organizations, i.e., DOH, DRR, and SRT, are substantially larger than international loans/aids or investment from private corporations through public-private partnership (PPP). Since Thailand heavily relies on road transportation, cumulative IF, FF, and O&M estimates of DOH and DRR are significantly larger than those of SRT. Emergency budgets planned for unexpected climate events are several orders smaller than the total budget. Yet the emergency budget can be hidden in other budget items which makes it impossible to distinguish it from the total budget. In addition, in an event of a devastating disaster, such as the 2011 Thailand floods, a separate emergency budget is approved by the cabinet to be used for the aftermath. Therefore, the small amount of the emergency budget does not necessarily mean that the actual emergency expenses are small.

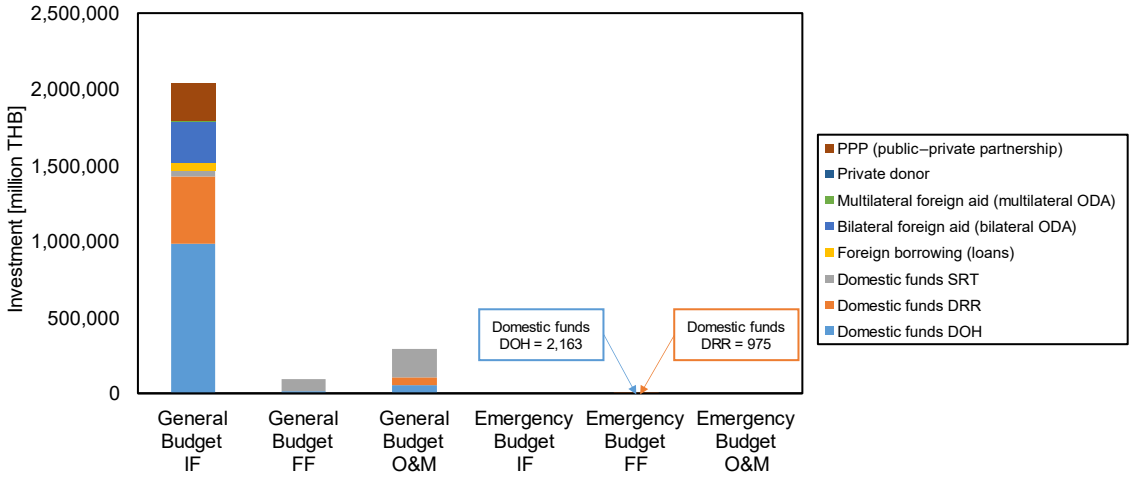

Figure S1 Baseline scenario: cumulative discounted IF, FF, and O&M estimates by investment type, investment entity, and funding source (progressive adaptation case)

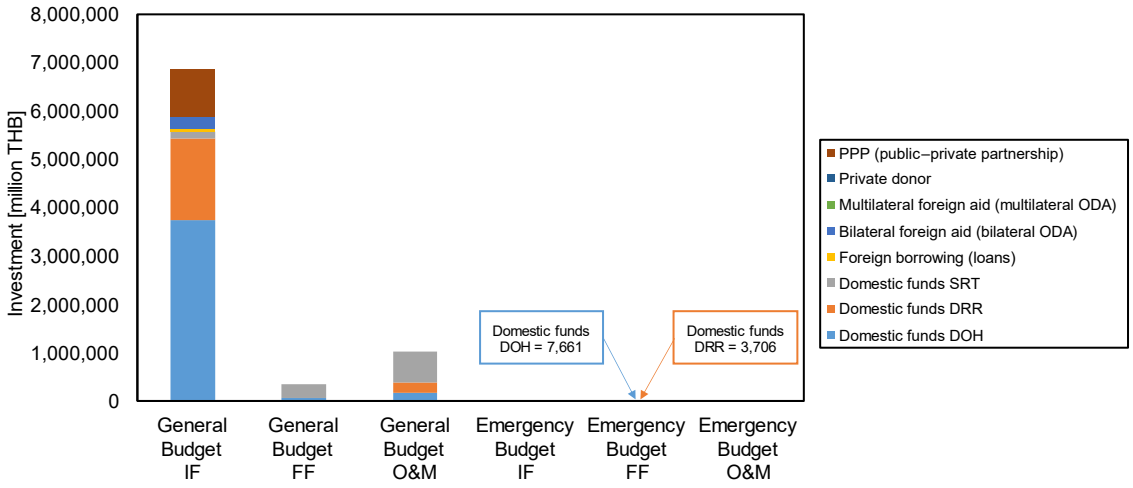

Figure S2 Baseline scenario: cumulative discounted IF, FF, and O&M estimates by investment type, investment entity, and funding source (moderate adaptation case)

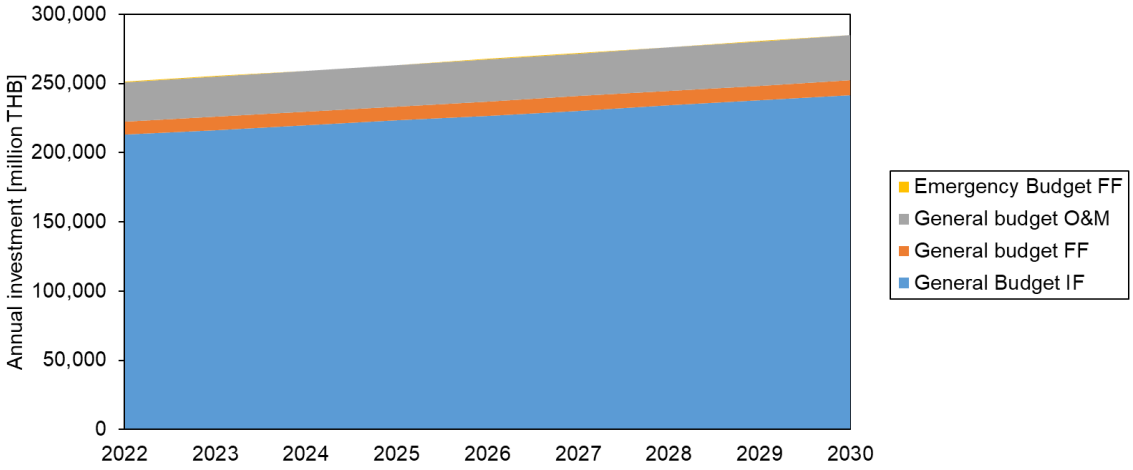

Figure S3 Baseline scenario: annual IF, FF, and O&M estimates by investment type (progressive adaptation case)

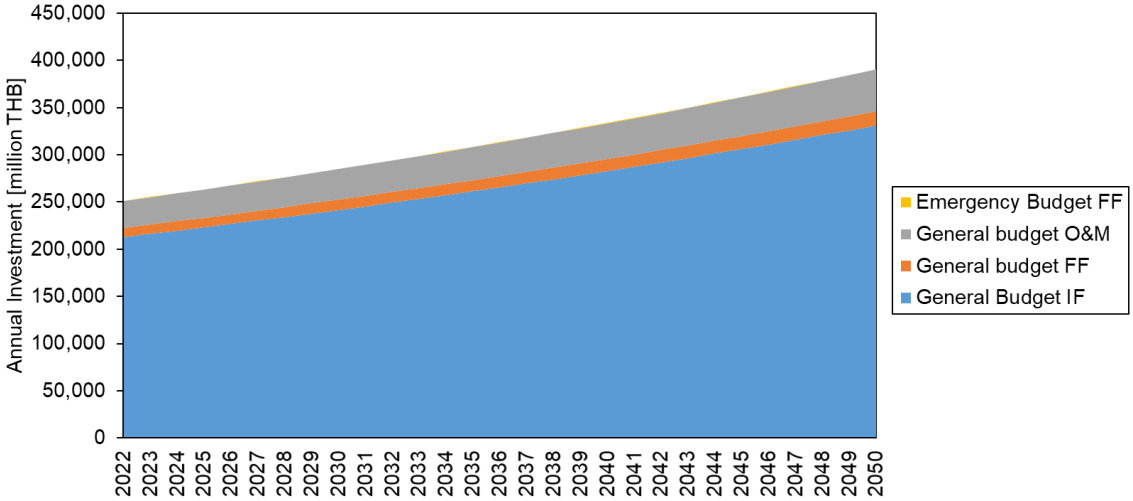

Figure S4 Baseline scenario: annual IF, FF, and O&M estimates by investment type (moderate adaptation case)

Taking into account the investment on climate-proofing countermeasures based on consultation with OTP, DOH, DRR, and SRT, the cumulative discounted investment flow (IF), financial flow (FF), and operation and maintenance (O&M) cost estimates by investment type, investment entity, and funding source of the adaptation scenario are developed. Figures S5 and S6 show the estimates for progressive adaptation case and moderate adaptation case, respectively. Figures S7 and S8 show the annual IF, FF, and O&M estimates. The total investment on climate-proofing countermeasures is smaller than the general budget by one to two orders, and the emergency budget is smaller than the investments in countermeasures by an order. Gradual decrease of the emergency budget is illustrated in Figures S7 and S8. Note that the decrease in the moderate adaptation case is much slower than the progressive adaptation case. The total investment on climate adaptation countermeasures is stretched to the period of 2022 – 2050 in the moderate adaptation case, which is the reason to the smaller annual IF, FF and O&M estimates.

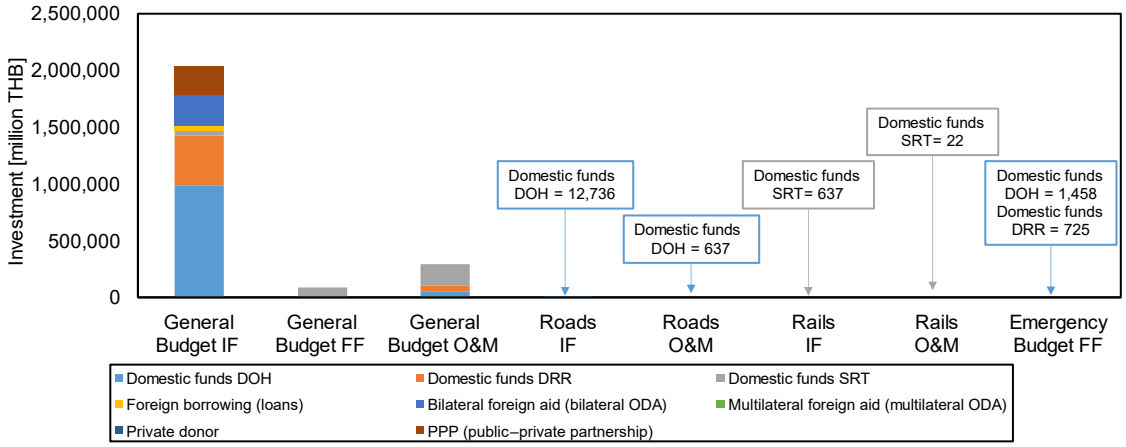

Figure S5 Adaptation scenario: cumulative discounted IF, FF, and O&M estimates by investment type, investment entity, and funding source (progressive adaptation case)

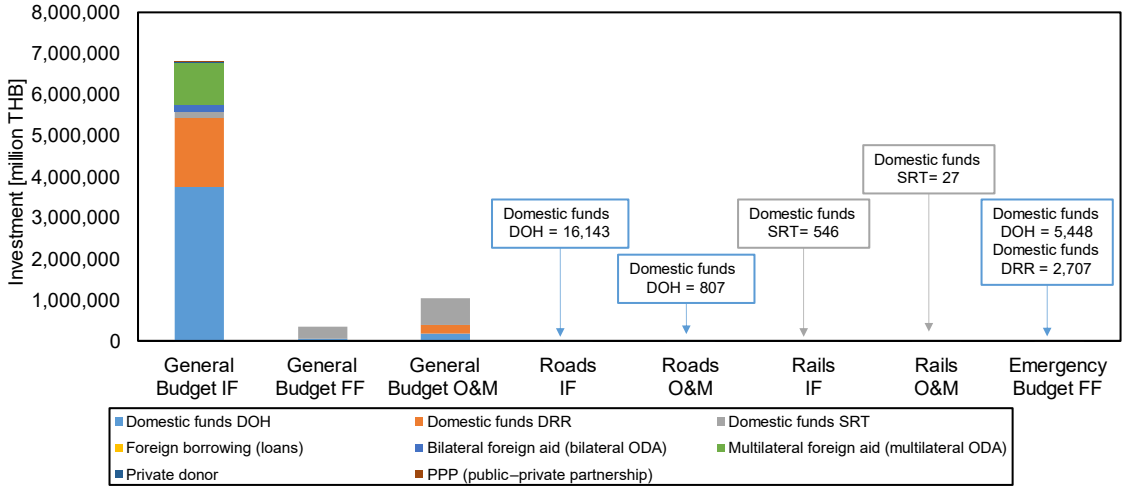

Figure S6 Adaptation scenario: cumulative discounted IF, FF, and O&M estimates by investment type, investment entity, and funding source (moderate adaptation case)

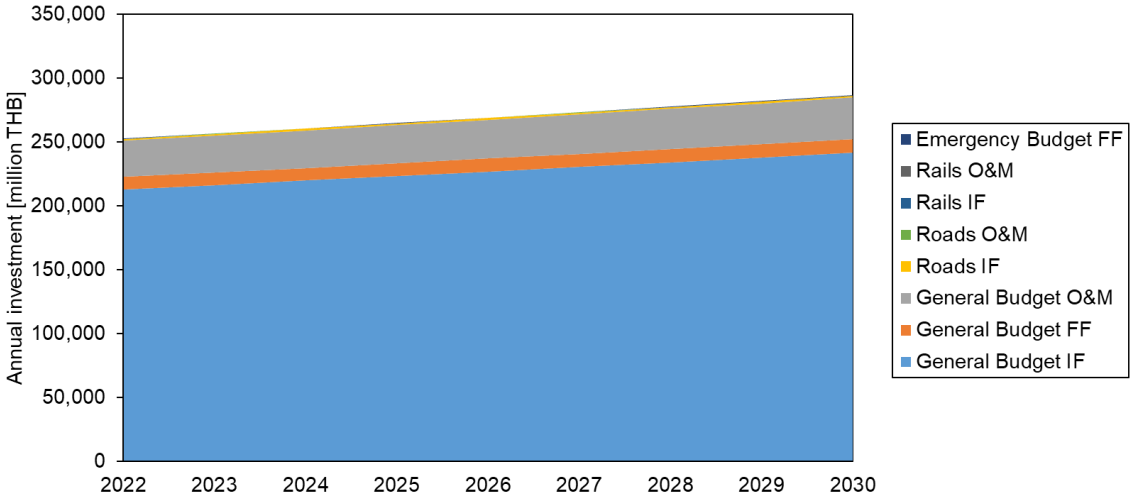

Figure S7 Adaptation scenario: annual IF, FF, and O&M estimates by investment type (progressive adaptation case)

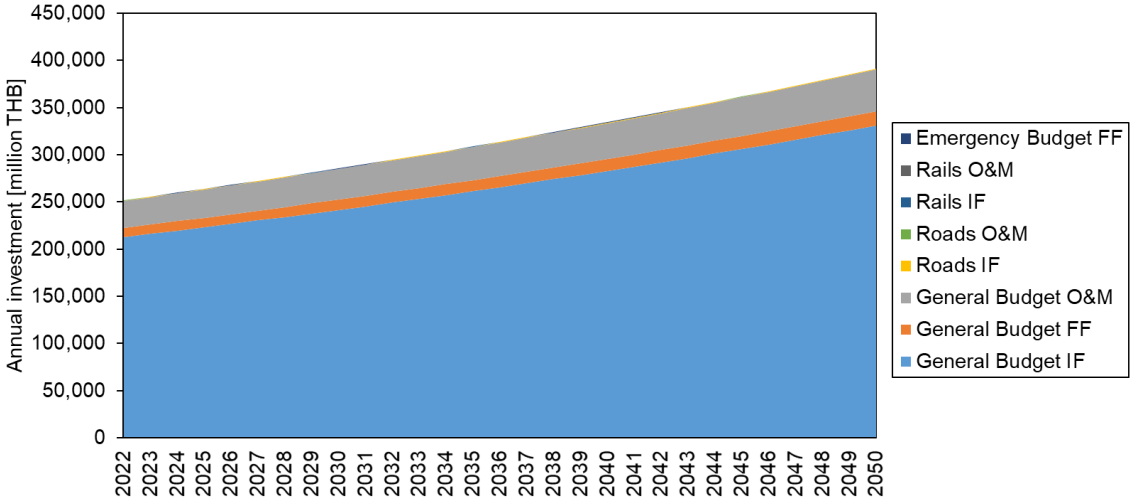

Figure S8 Adaptation scenario: annual IF, FF, and O&M estimates by investment type (moderate adaptation case)

Finally, the incremental investment can be obtained by subtracting annual IF, FF, and O&M estimates of the baseline scenario from the adaptation scenario. Incremental annual IF, FF, and O&M estimates by investment type of progressive adaptation case and moderate adaptation case are shown in Figures S9 and S10. General budgets are balanced out, the investments on climate-proofing countermeasures remain, and the emergency budgets return negative values. In the moderate adaptation case, the incremental annual investments are smaller, and the decreases in emergency expenses are slower. However, with increasing intensity of climate change, the non-quantifiable emergency expenses might significantly increase. In total, approximately 13 – 14 billion THB is additionally needed to enhance the climate adaptability of the transport infrastructure.

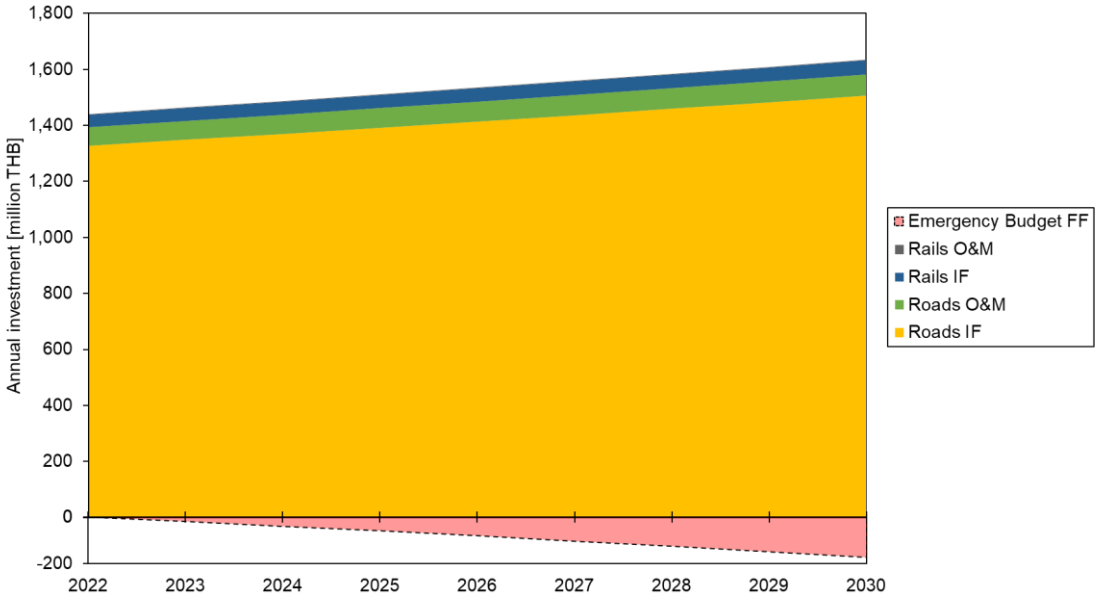

Figure S9 Incremental annual IF, FF, and O&M estimates by investment type (progressive adaptation case)

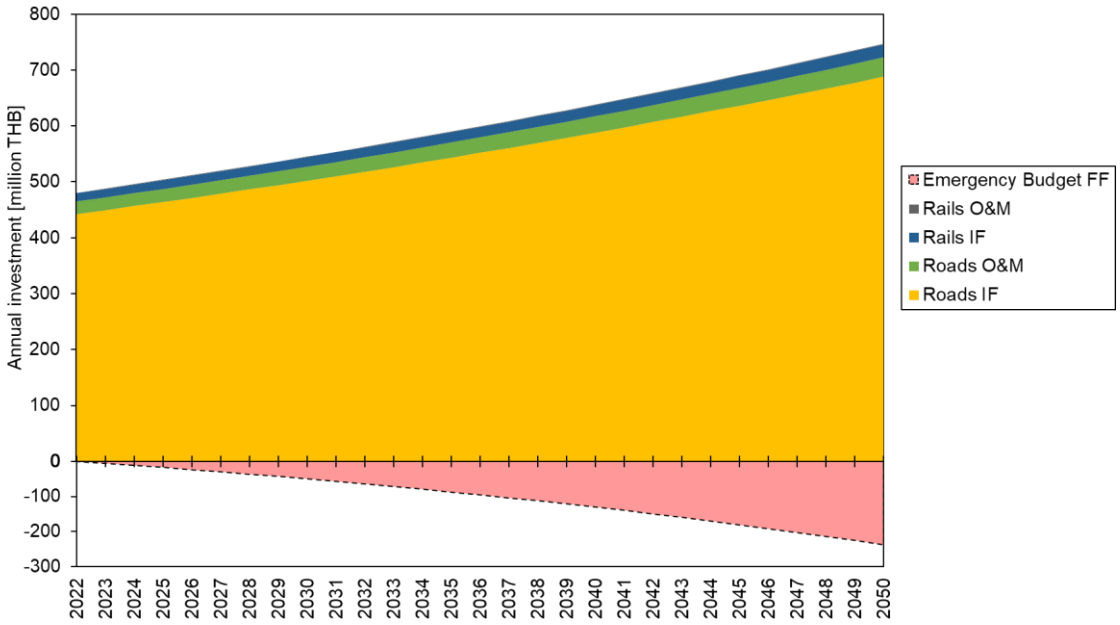

Figure S10 Incremental annual IF, FF, and O&M estimates by investment type (moderate adaptation case)

Since the annual government investment budget allocated for DOH, DRR, and SRT is much larger than the annual investment and operation and maintenance expenses for the proposed climate adaptation countermeasures, it would not be very difficult to allocate budget to climate adaptation investment once the relevant stakeholders realize the necessity and the benefits from the investment. In addition, there are several policy options to facilitate and accelerate government investment. Carbon tax is a means adopted by many countries to receive revenue in terms of tax from greenhouse gas emitters and use it to invest in climate change mitigation and adaptation. Besides, if climate adaptation investments can be included as a part of the carbon credit scheme, or if we can establish a separate scheme similar to it, the private sector will be able to contribute to climate adaptation in the transportation sector.

The private sector can also play a vital role in climate adaptation investment, especially when the government provides incentives to expedite private investment, which can be in terms of financial incentives or tax exemptions. Sustainable banking, sustainable financing, and sustainability-linked bonds can further facilitate the investment. Furthermore, private sector can join hands with government to invest on climate adaptation via Public-Private Partnership (PPP) scheme. Another option that would support government green investment is international funds. However, it should be noted that recent funding concentrates on low-income economies while Thailand is categorized as an upper-middle income economy.

In short, this assessment identified target roads and rails classified into tiers as well as climate adaptation countermeasures. It pointed out the possible required investments and their flows, involved stakeholders and the way they interact, and the policy options to enable and facilitate the investment. The next step would be to motivate the stakeholders to actually invest on climate adaptation. Meetings or workshops to urge other indirect stakeholders' awareness on the importance of climate adaptation investment and the necessity of timely implementation of the countermeasures are needed. Hands-on activities to deepen the understanding on the countermeasures, the ways to facilitate the investment, and the ways to successfully implement the countermeasures and sustain the resulting infrastructure are also required. In addition, studies to thoroughly explore domestic funding entities and mechanisms that can contribute to climate-proofing investments, as well as to identify external funding that can be obtained from private sector or international funds should be conducted. Further meetings or workshops to discuss the plausible climate-proofing investment model that suit the economic, political, and societal contexts of Thailand, along with discussion on how to actually acquire the funds for climate-proofing investment is also recommended. Finally, a pilot project to explore the practicalities of different climate adaptation countermeasures and their applicability to selected target roads or rails and estimate the actual expenditure on those countermeasures needs to be carried out to validate the results of this investment and financial flows assessment.

1 Introduction

1.1 Background and Objectives

Climate change has emerged as an important threat to the world since the industrial revolution until the modern world today. Countries have been discussing on the ways to implement countermeasures to mitigate the changes of the global climate and to adapt to these changes. Most climate-proofing countermeasures require significant amount of initial investment and a financing mechanism to sustain their ability in addressing climate change. Cost-benefit analysis is an important tool to assess economic feasibility of climate-proofing investment, in terms of net present value, cost-benefit ratio, payback period, or other financial parameters. However, it is generally performed as a case study, and hence, it calls for an alternative tool to deliver a bigger picture of the climate-proofing investment of a country.

Investment and financial flows (I&FF) assessments provide the information on required changes and increases in investments in physical assets and in programmatic measures needed to mitigate greenhouse gas (GHG) emissions and adapt to climate change in key sectors[1]. It can help a country figure out the incremental investment needed in climate-proofing investment, capture the stakeholders involving in the investment, identify sources of funding including both domestic and international funds, and formulate and evaluate policy options to address climate change. The goal of this study is to perform an I&FF assessment of investment on climate adaptation of the transportation sector in Thailand in order to contribute to the strengthening of the national capacity of developing countries to assess and develop policy options for addressing climate change. The specific objectives of this report are to define the scope of this I&FF assessment, specify reference scenarios and plausible adaptation measures, describe the calculation procedure along with the I&FF results, which has gone through consultation with relevant parties, and identify available policy options to promote climate-proofing investment.

1.2 Expected Deliverables

(1) The scope for the assessment of I&FF, from the point of view of adaptation
(2) The reference and target scenarios for adaptation for the transport sector
(3) The political and technical viability of the identified adaptation measures
(4) Procedures of calculation that are consistent and suitable with the objectives and procedures for the I&FF in the selected sector
(5) I&FF assessment results and documentation used and generated in the process of assessing I&FF
(6) Policy options to promote decisions of investment directed to facilitate adaptation for the transport sector

[1] UNDP (2020) UNDP methodology for assessing investment and financial flows. Available at: https://www.ndcs.undp.org/content/ndc-support-programme/en/home/our-work/focal/ndc-finance-and-investment/investment-and-financial-flows--iff--assessments/domestic-finance-assessments-iff-methodology.html

1.3 Scope of Investment and Financial Flows Assessment

Climate mitigation and climate adaptation are the two main goals of all past United Nations Climate Change Conferences (COP), including COP26 in Glasgow, United Kingdom[2]. Climate adaptation aims to ensure that people can live along with the change of climate while climate mitigation focuses on reducing greenhouse gas emission into the environment. Alike many countries in the world, Thailand's goal and action plans for climate mitigation in key sectors are relatively well-established, starting from the updated Nationally Determined Contribution (NDC) at COP26 where the Prime Minister pledged to reduce GHG emission by 40% by 2030, achieve carbon neutrality by 2050, and pursue net zero emission by or before 2065[3]. On the other hand, according to the National Adaptation Plan (NAP) issued in 2019, only few countermeasures are explicitly listed as actions needed for climate adaptation[4].

The transportation sector is the vein of almost every sector, and it can be severely affected by climate change[5,6]. Generally, transportation is classified into four different modes, namely road, rail, marine and aviation[7]. Each mode has its own advantages and constrains depending on specific needs of the users. For instance, marine transport is an economical choice of carrying heavy objects in a long distance though it consumes time. Aviation is the most suitable candidate for rapid transportation with a much higher price. Justification is required to identify the transportation means to be included in this I&FF assessment based on geographical location and preferred mode of transportation.

Rail and road are the major modes of transportation in Thailand[8]. It not only serves for the mobilization of passengers from one place to another but also delivers goods from the places of origin to markets in city areas. Therefore, the present study focuses on these two modes of transportation. The scope of the assessment is illustrated in Figure 1. Since the two sectors are looked after by both private and government entities depending on the usage and the location where the infrastructure is situated, the scope in further narrowed down to specify the main stakeholders of the two selected modes. This study considers roads that are under the purview of

[2] UN Climate Change Conference UK (2021) COP26 goals. Available at: https://ukcop26.org/cop26-goals/

[3] Ministry of Foreign Affairs Thailand (2021) The Prime Minister Speech at UNFCCC COP26. Available at: https://www.mfa.go.th/en/content/cop26-glasgow?page=5d5bd3cb15e39c306002a9ac&menu=5d5bd3cb15e39c306002a9ad

[4] Office of Natural Resources and Environmental Policy and Planning (2019) Thailand's National Adaptation Plan (NAP). Available at: https://climate.onep.go.th/wp-content/uploads/2019/07/NAP.pdf

[5] Bangkok Post (2021) Samut Prakan's Bangpoo Industrial Estate Flooded. Available at: https://www.bangkokpost.com/thailand/general/2173031/samut-prakans-bangpoo-industrial-estate-flooded

[6] Reliefweb (2021) Malaysia: Flash Floods - Emergency Plan of Action (EPoA), DREF Operation MDRMY008. Available at: https://reliefweb.int/report/malaysia/malaysia-flash-floods-emergency-plan-action-epoa-dref-operation-mdrmy008

[7] Ivanov, D., Tsipoulanidis, A., & Schönberger, J. (2017). Distribution and transportation network design. In *Global Supply Chain and Operations Management: A Decision-Oriented Introduction to the Creation of Value* (pp. 189-232). Springer International Publishing. https://doi.org/10.1007/978-3-319-24217-0_8

[8] Surachet Pravinvongvuth (2017) Transportation infrastructure development in Thailand: go green or go grey? Available at: https://www.uncrd.or.jp/content/documents/5602Presentation%205%20-%20Module%202%20-%20Mr.%20Surachet%20Pravinvongvuth.pdf

Department of Highways (DOH) or Department of Rural Roads (DRR) and the railways under State Railway of Thailand (SRT).

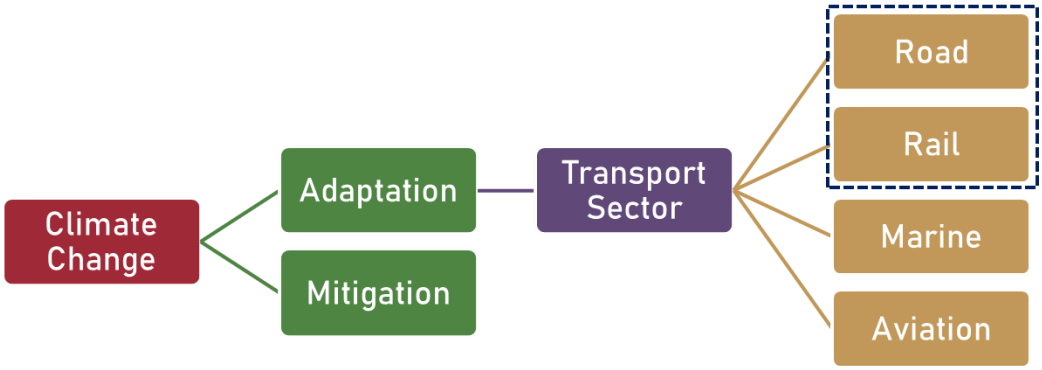

Figure 1 Scope of the I&FF assessment

1.4 Flow of the Report

This report comprises of eight chapters namely, Introduction, Literature Review, Reference and Target Scenarios, Technical Viability and Political Viability, Calculation Procedure, Investment and Financial Flows Results, Policy Options to Facilitate Climate Adaptation in Transport Sector, Recommendations and Way Forward, and five Appendices. Individual chapters were produced based on data and assumptions gathered from multiple available secondary resources. However, primary data obtained from organizations in charge are crucial in ensuring validity and reliability of data and assumptions in the report. Several consultation meetings with direct stakeholders were conducted to receive useful feedback towards the study including facts, realistic assumptions, opinions, and any other essential information for the assessment.

Since OTP is the project overseer responsible for project overseeing, project direction determination, and cooperation with relevant stakeholders, it is important to begin a series of stakeholder consultation with OTP. Additionally, since the focuses of the study are roads under the responsibility of DOH and DRR and rails under the responsibility of SRT in transport sector, direct stakeholders, included OTP, DOH, DRR, and SRT. The consultation meeting aimed for further inputs and realistic assumptions to enhance the accuracy of the data and the assumptions in order to improvement of report. This will lead to a more realistic figure of total investment and a more reasonable framework of investment and financial flows of probable climate-proofing activities in transport sector.

Hence, Chapter 4, 5 and 6 were revisited and changes were made according to the information and opinions from direct stakeholders. However, initial data and assumptions remain in each chapter in order to show how information, assumptions, and results evolved during the study. To ease the comprehension of the readers and offer a clear flow of the report, a section to elucidate the additional inputs from the stakeholders and present updated results corresponding to the stakeholders' inputs were added to each abovementioned chapter.

2 Literature Review

2.1 Motivation of the Study

Climate change is a central challenge to the achievement of sustainable development. Numerous developing countries around the world, specifically those in Asia, are among the most vulnerable countries to the inevitable impacts of climate change. These countries have put a lot of effort to revitalize detrimental economy and to boost adaptive capacities against climate change in order to pave way towards sustainable development. They adopted the United Nations' Sustainable Development Goals (SDG) as a conjunctive solution to address threats against worldwide sustainable development[9]. In line with SDGs, climate change mitigation and adaptation are considered means to support such development, leading to great capabilities to address climate issues and enhance the standard of living to the level of developed countries. Many mitigation measures have led to significant greenhouse gas emission reductions and contributed to the achievement of SDGs in several regions. However, a number of countries are still facing climate risks with limited adaptive capacities. Since the risks along with vulnerability against climate events in various areas pose challenges to the attainment of sustainable development, a wide range of stakeholders including scientists, engineers, economists, and policymakers are joining hands to strategize climate-proofing activities to be able to cope with more intense climate impacts in the future. As a 2°C increase in global average temperature essentially leads to more extreme natural events, it will become much harder for a developing country to manage consequences, secure living standard, and foster the development path at their best[10]. That said, countries need to adopt various approaches and measures in order to cope with climate change. Climate adaptation covers development of climate proofing infrastructure and enhancement of resilience to climate risks accounting for uncertainties of climate predictions. Based on a report of ADB, many economic sectors have invested in new physical assets of which the investment comes from four reliable sources: household, government, financial cooperation, and non-financial cooperation. This reflects how climate change impacts spread out globally and how the stakeholders attempted to address unpredictable consequences. Until now, transport, storage, and communications sector accounts for 15 percent of the total global investment funded by loans from commercial banks. Yet the climate proofing investment on roads and rails should still be highlighted since the interruption of these infrastructures by climate change can still be observed around the world.

Generally, investments on critical infrastructure, economic feasibility and benefits of the investment must be ensured. This calls for the use of cost-benefit analysis to confirm that climate-proofing countermeasures have positive net present value in order to efficiently generate benefits to stakeholders and public. A UNDP report on climate change adaptation in transport sector in Thailand has explored the ways to ensure the feasibility of climate adaptation countermeasures through cost-benefit analysis (CBA). The study focused on two transportation modes: roads and

[9] UNFCCC (2022) Action on Climate and SDGs. Available at: https://unfccc.int/topics/action-on-climate-and-sdgs/action-on-climate-and-sdgs

[10] IPCC (2018) Summary for Policymakers. In: Global Warming of 1.5°C. Available at: https://www.ipcc.ch/site/assets/uploads/sites/2/2019/05/SR15_SPM_version_report_LR.pdf

rails. A series of cost-benefit analysis were performed, and social aspects were taken into account in order to maximize the benefits of the countermeasures. The study concluded positive economic and social benefits over the cost and investment can receive payback within a certain period of time. However, the study focused on only two particular study areas and on assessing economic feasibility of the countermeasures. This report sets clear aim to extend CBA results in order to see a clearer and broader picture of investment scale of each climate adaptation countermeasure in the transport system of Thailand. The creation of climate adaptability requires a larger set of potential climate countermeasures, being implemented in vulnerable areas across the country. To realize national efforts towards climate adaptation and identify possible options to enhance climate adaptation capabilities in Thailand's transportation sector, a different approach that can widen the viewpoint, identify potential financial resources and flow of investment, and engage relevant stakeholders is needed. An Investment and financial flows (I&FF) assessment is developed upon a promising methodology, allowing policymakers and involved stakeholders to realize the broad picture of total flow of investment and construction of additional infrastructure required to meet the projected demand[11]. The assessment not only offers an opportunity to estimate mitigation or adaptation costs, but also to identify different domestic and international financing sources and their future potentials.

2.2 Thailand's Current Situation

Since Thailand is located in the tropical climate zone, the country is vulnerable to natural disasters including floods, storms, and drought[12,13,14]. Steep and hilly areas in the northern and southern regions frequently experience disasters, especially landslides and flash floods. Speaking of flooding, several massive and unique events occurred and caused many casualties in the past. For example, the Indian Ocean Tsunami in 2004, which was triggered by a strong earthquake in the Andaman Nicobar Island, caused over 5,000 causalities in six provinces on the coastline. Looking particularly at Thailand, the country is facing floods for several decades in almost all provinces, causing severe damage to human beings, assets, and the economy[12]. A well-recognized major flooding event in Thailand was during July to December 2011. It occurred in Chao Phraya and Mekong River Basins, which are considered big flooding plains in the country. Over 14 million people in 65 provinces suffered from the flood. Bangkok area was seriously affected as it took 680 lives and resulted in estimated economic loss of 46$ billion THB. The issue is that the country has a complex river system, relying on flood plains and the majority of people and critical infrastructure are located near water bodies, especially in the central region. In the past, flooding was considered a seasonal event in an annual cycle. However,

[11] UNFCCC (2007) Investment and financial flows to address climate change. Available at: https://unfccc.int/resource/docs/publications/financial_flows.pdf
[12] UNFCCC (2020) Thailand third biennial update report. Available at: https://unfccc.int/sites/default/files/resource/BUR3_Thailand_251220%20.pdf
[13] UNDP (2022) Thailand climate change adaptation. Available at: https://www.adaptation-undp.org/explore/south-eastern-asia/thailand
[14] ADPC, UNDRR (2020) Disaster risk reduction in Thailand. Available at: https://reliefweb.int/sites/reliefweb.int/files/resources/Disaster%20Risk%20Reduction%20in%20Thailand%20Status%20Report%202020.pdf

settlement expansion and human activities reduced absorbing capability in regions, preventing the flow of water, and resulted in increase of flood risk.

Climate change is an important issue in Thailand as it exacerbates natural hazards, particularly heavy rainfalls, and flash floods[15]. Moreover, sea level rise impacts local fishing communities, seaports, and industrial estates along the country's coastline of the Gulf of Thailand and Andaman Sea. The country has also faced challenges in increased temperature and precipitation since the middle of the 20th century. It has been observed that between 1955 and 2009, the average annual temperature in Thailand has increased by 0.95°C which is significantly higher than the global average of 0.69°C during the same period. The annual increase of sea levels in the Gulf of Thailand, approximately 3-5 millimeters, is by far above global average level of 0.7 millimeters per year between 1993 and 2008. Precipitation has slightly changed between 1955 and 2014, resulting in heavier rainfalls in the capital city of Bangkok, northeastern provinces, and the Gulf of Thailand.

The World Bank predicts that Thailand will face more intense climatic conditions in the future. Multiple analyses performed by the bank have shown an expected increase in average temperature by 1.4-1.8°C by 2060 and an increase of 3.0-3.8°C by 2090[15]. Climate change has led to climatic changes in several regions in the country. The northern region has a more rapid pace in temperature rise compared to the southern and coastal regions. With regard to sea level rise, it will bring about impactful consequences to the country and exacerbate floods and storms. Bangkok, the capital city which stands only 1.5 m above sea level, is within the province that is expected to be most affected by climate change. Over the past decade, there were a dozen severe flooding events documented by the Center for Excellence in Disaster Management & Humanitarian Assistance (CFE-DM). Starting from the most recent event, heavy rain in December 2021 caused flash floods, leading to overflow in nine provinces in the south of Thailand. Over 43,000 locals were affected. In August 2021, a monsoon from Vietnam with a typhoon in the Andaman Sea caused heavy rain for three consecutive days, resulting in flash floods that affected 65,000 people in ten provinces. There were four flooding events in the second half of 2020 mainly taking place in south and central Thailand. The events impacted over 600,000 households in total, leaving people suffering. Back in December 2018, heavy rain caused a severe flood and led to school closure and evacuation in Nakhon Si Thammarat Province. In 2017, there were ten casualties in 23 provinces as a result from a tropical depression, causing discharge from Chao Phraya Dam which affected 120,000 houses. Furthermore, three flooding events documented in June, October, and December 2016, killed 11 locals in central north of Thailand. The event in June broke the 25-year record of highest flooding level. The rainfall caused 200 mm-high floods in Bangkok Metropolitan. As mentioned above, the major flood in 2011 affected 14 million people and resulted in a great economic loss[15].

To address the issue, Thailand called for international cooperation and participated as a member state in the United Nations Framework Convention on Climate Change (UNFCCC) in 1991 and ratified Kyoto Protocol in 2002. Participation to the international treaties encouraged the country to have a national strategy to cope

[15] CFE-DM (2022) Thailand disaster management reference handbook. Available at: https://reliefweb.int/sites/reliefweb.int/files/resources/CFE-DM-DMRH-Thailand2022.pdf

with climate issues[16]. Later, Thailand formulated a National Strategic Plan on Climate Change B.E. 2551-2555 (2008-2013) which ordered all government departments and agencies to give priority to the issues. Later, a Climate Change Master Plan B.E. 2558-2593 (2015-2050) was developed utilizing a Driving Force-Pressure-State-Impact-Response (DPSIR) framework in a long-term perspective to reinforce the national strategic plan in tackling climate change in important areas. The Master Plan has four main purposes including 1) to provide a long-term national framework for climate change adaptation and low carbon growth promotion according to sustainable development principles, 2) to provide a policy framework for the development of mechanisms and tools, at sectoral and national level, to achieve effective resolutions for climate change, 3) to provide government agencies and relevant organizations with a framework for detailed action plans; and to facilitate awareness and mutual understanding by means of a common framework of reference points, thereby increasing integration and reducing redundant processes, and 4) to provide budgeting agencies with a clear framework for budget allocation, thus enabling the mobilization of concrete climate change resolutions. The plan ensures continuity of state actions, promotes establishment of practical indicators and evaluation systems, and allows Thailand to progress further in harmony with other related domestic plans and action plans in other countries.

As Thailand has submitted an ambitious Nationally Determined Contribution (NDC) target for reducing its greenhouse has (GHG) emissions, climate mitigation goals set forth in the Master Plan can be progressed corresponding to the NDC. The country committed to reduce GHG mission by 40 percent compared to business-as-usual (BAU) levels by 2030 subject to global technical support from abroad and reach carbon neutrality in 2050 and subsequently net zero GHG emissions by or before 2065. To achieve the targets, the country also makes use of the opportunity and momentum created by Paris Agreement to carry on long-term, low-carbon and climate-resilient development. In order to deploy the targets committed in the NDC to respective sectors, Thailand developed the mid-century, long-term low greenhouse gas emission development strategy (LT-LEDS) through comprehensive process with various working group from all sectors and stakeholders. The LT-LEDS aims to align the mitigation goal with the IPCC reports, aiming to reduce GHG emissions in consistence with global 2-degree pathway. Thailand's LT-LEDS focuses on priority sectors including energy and transport sectors. While measures identified in the energy sector prioritize improvement of energy efficiency, deployment of renewable energy and adaption of carbon capture storage, measures identified in transport sector include modal shift, energy efficiency improvement and promotion of advanced vehicle fleets. Based on the plan, Thailand is encouraged to prioritize and develop its new infrastructure especially in energy and transport systems. To achieve such great goals, international cooperation and support, in terms of policy development, technology advancement, and capacity building should be put in place.

Following the global effort to mainstream climate adaptation in national climate planning, Thailand also adopted National Adaptation Plan (NAP) in 2018. The plan is built upon the Climate Change Master Plan B.E. 2558-2593 (2015-2050) aiming for resilience and adaptive capacity of the country towards impacts of climate change[4].

[16] ONEP (2015) Climate change master plan 2015-2050. Available at: https://climate.onep.go.th/wp-content/uploads/2019/07/CCMP_english.pdf

The plan aims to integrate sustainable development[4] in alignment with the late King Rama IX's Sufficiency Economy Principle (SEP) and local wisdom. To cooperate well with other strategic approaches, the objectives of the NAP were set to 1) mainstream adaptation into sectoral plans and strategies, 2) apply adaptation to government agencies' frameworks for budgeting and implementation, 3) raise awareness and understanding within relevant sectors, and 4) establish and develop resiliency measures and adaptation readiness for all stakeholders and levels[17]. It can be said that NAP integrates climate resilience into the country's sustainable development.

In the perspective of natural disasters, Thailand is exposed to several disasters including floods, landslides, droughts, earthquakes, tsunamis, forest fires, and epidemics. Flooding is a serious threat to communities and has brought about the most significant impacts on human life, livelihoods, and the national economy so far[15]. To cope with the issues, Thailand has evolved from civil defense posture and emergency management orientation to government-led disaster management system. The approach embraced government, network of NGO, charities, academic institutions, business and private enterprises, and community-citizen networks to support disaster management capabilities. Thailand's disaster management system is divided into two level including policy-level and operational-level, and operates under law, policies, and plans related to disaster management. The framework includes Disaster Prevention and Mitigation Act of 2007 (DPM Act 2007), National Disaster Risk Management Plan 2015-2020 (National DRM Plan), Provincial and District DRM Plans, and DRM Annual Action Plans. Essentially, it is important to note that the National DRM Plan should be reviewed, revised to and updated every five years to incorporate changes in disaster characteristics, related facts, or management practices[18].

DPM Act 2007 governs disaster management at national, provincial, district, sub-district, and local community level, aiming to streamline disaster management systems of Thailand throughout comprehensive process in clarifying stakeholders, roles, and coordination. The plan covers a wide range of man-made and natural disasters, disasters resulting from air raids during wars and disasters from sabotage or terrorist attack. National DRM Plan 2015-2020 has been developed based on DPM Act 2007 as a guideline for emergency management, disaster recovery, and creation of international cooperation on disaster management. The plan aims to promote a common understanding of key concepts and introduce national strategies towards disaster risk management. The strategies focus on disaster risk reduction, integrated management system, increase in efficiency of disaster recovery, and the creation of international cooperation on disaster management. Provincial and District DRM Plans are designed to synchronize with the National DRM Plan. A provincial and district level plan aims to adopt the national plan and allows provincial governance to implement measures using national budget allocated by central government. The plan is also expected to support relevant stakeholders in implementing prevention and mitigation actions. DRM Action Plans are annually updated and applied at the local level. The plans guide provincial disaster management centers (DMCs) to prepare specific multi-hazard action plans to encounter disasters in each district based on geographical

[17] NAP Global Network (2019) Thailand national adaptation plan (NAP) approach. Available at: https://napglobalnetwork.org/wp-content/uploads/2018/02/napgn-en-2019-thailand-nap-process-poster-2.pdf

[18] Department of Disaster Prevention and Mitigation (2015) National disaster management plan. Available at: https://www.disaster.go.th/upload/download/file_attach/584115d64fcee.pdf

conditions. The plans enable cooperation with provincial DRM plans and pave ways for local communities to foster implementation of disaster risk management.

2.3 Overview of I&FF

Parties of UNFCCC are aware of inadequateness of existing international financial resources from both public and private sectors to lead to a constructive transition and meaningful development to address climate change. UNFCCC Parties held a meeting in Nairobi in 2006 to entrust UN Climate Change Secretariat to make an assessment to guide investment direction towards 2030 in order to strengthen mitigation and adaptation capability worldwide[19]. In 2007, investment and financial flows (I&FF) were assessed globally and made a great contribution on realization of the investment flow to encounter climate change. Since it had received a great attention among scientific community, UNFCCC further developed the said assessment in 2009.

Investment and financial flows assessments include two distinct types of flows: investment flows and financial flows. In UNFCCC report, investment flows (IF) are defined as initial (capital) spendings for physical assets, while financial flows (FF) refer to ongoing expenditures related to climate change mitigation or adaptation that are not related to investment in physical assets. Later, UNDP has further developed the methodology and created a clear workplan guidance for such assessments[20]. UNDP made a slight modification to definitions of I&FF where investment flow refers to *capital cost of a new physical asset with a life of more than one year* and financial flow refers to *an ongoing expenditure on programmatic measures, encompassing expenditures other than those for expansion or installation of new physical asset.* As reported by UNDP[20], a key challenge of developing countries is to understand their own national requirements on how greenhouse gas emission is reduced (mitigation perspective) and how negative impact of climate change is reduced (adaptation perspective). Therefore, UNDP has developed the methodology to guide those countries to strengthen capacities towards climate change in both perspectives and evaluate or formulate policy options to address climate issues corresponding to national goals.

The methodology created by UNDP describes the essential steps for a sectoral assessment. I&FF assessment of UNDP comprises eight steps; 1. establishing key parameters of the assessment, 2. compiling historical cost data and other input data for scenarios, 3. defining the baseline scenario, 4. Identifying I&FF for the baseline scenario, 5. defining (mitigation or adaptation) target scenario, 6. Identifying I&FF for the mitigation or adaptation scenario, 7. calculating changes in I&FF needed to implement the target scenario, and 8. evaluating policy implications[20]. Since 2008, I&FF assessment have been carried out to assess mitigation and adaptation actions in many countries[21], including Bangladesh, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Gambia, Haiti, Honduras, Liberia, Morocco, Namibia,

[19] UNFCCC (2022) Financing climate change action investment and financial flows for a strengthened response to climate change. Available at: https://unfccc.int/topics/climate-finance/resources/financing-climate-change-action-investment-and-financial-flows-for-a-strengthened-response-to

[20] UNDP (2009) Methodology Guidebook for the Assessment of Investment and Financial Flows to Address Climate Change. Available at: https://www.ndcs.undp.org/content/dam/LECB/docs/iff/iff%20methodology/iff%20methodology%20english/undp-iff-chapter-1-2-methodology-en.pdf

[21] The World Bank (2022) Upper middle income. Available at: https://data.worldbank.org/country/XT

Niger, Nigeria, Paraguay, Peru, Togo, Turkmenistan, Uruguay, and Uzbekistan; and now in Thailand. As mentioned above, I&FF assessments are specifically designed to assist countries to address climate change, and Thailand is among those developing countries and is one of the upper-middle income countries that volunteered to carry out this assessment. For the I&FF assessment of climate adaptation investment in transportation sector in this study, good practices exist in Colombia, Dominican Republic, Ecuador, Paraguay, and Peru, which have similar conditions to Thailand and have conducted assessment for climate adaptation, which can be referred to. I&FF assessments conducted in those countries applied to many sectors, for example, agriculture, energy, water, tourism, transport, forestry, food security, health, and fisheries. However, the assessment on climate adaptation investment in transport sector has never been conducted. This becomes a great opportunity for Thailand to conduct this first-of-a-kind assessment using UNDP investment and financial flow methodology to enhance and strengthen adaptive capability of the country's transport sector.

3 Baseline and Adaptation Scenarios

3.1 Baseline Scenario

As stated in the scope of the study, this study focuses on major transportation infrastructures, including roads and rails. Since the investment to enhance climate adaptability of the infrastructure typically does not affect the composition of vehicle fleet, fuel use, or driver or passenger behaviors, investments and cash flows in the baseline scenario will only include those directly related to the infrastructures themselves. The baseline scenario will include investment and financial flows of construction and retrofitting of roads and rails, operation and maintenance of the existing infrastructures, and other activities to facilitate or promote the usage of the infrastructures. These investments are generally made by government since they contribute to public benefits. Department of Highways (DOH) and Department of Rural Roads (DRR) are responsible for investments on national road infrastructure, and State Railway of Thailand (SRT) looks after the investment on national rail infrastructure. Several projects have been funded under the public private partnership (PPP), or by foreign loans or aids. Investments through these channels will be included in the baseline scenario.

Unfortunately, climate related investment in transportation sector have not been distinguished from other investments. Therefore, government investment and financial flows in the baseline scenario are forecasted based on average total budget in the past of DOH, DRR, and SRT. Past road and rail projects that utilized PPP scheme, and past international loans and aids for transport infrastructure are also used to estimate the baseline investment and financial flows. Since Thailand's updated NDC aims to reduce GHG emission by 40% by 2030, reach carbon neutrality by 2050, and achieve net zero emission by or before 2065[22], it is advisable to align the timeframe of climate adaptation actions with the milestones in the NDC. Hence, the baseline scenario will adopt two different timeframes: 2022 – 2030 and 2022 – 2050.

Since the investments are basically in terms of construction projects, they can vary significantly according to the national direction on infrastructure development and economic situation. To simplify the assessment, investments and cashflows of past five years are gathered and averaged, then the average values are used throughout the timeframe using the GDP growth to discount to the year 2022.

[22] Ministry of Foreign Affairs Thailand (2021) The Prime Minister Speech at UNFCCC COP26. Available at: https://www.mfa.go.th/en/content/cop26-glasgow?page=5d5bd3cb15e39c306002a9ac&menu=5d5bd3cb15e39c306002a9ad

3.2 Adaptation Scenario

In 2014, Thailand submitted its National Appropriate Mitigation Action (NAMA) plan, which aimed to lower greenhouse gas emissions in the range of 7 to 20 percent below business-as-usual (BAU) scenario by 2020 by mainly reducing the emission from energy and transportation sectors[23]. The goal is subjected to the international financial aids, capacity-building, and innovation technology. The report specified many countermeasures for the two sectors, such as:

- Development of renewable and alternative energy sources
- Energy efficiency improvement in industries
- Building, transport, and power generation
- Biofuels in transportation
- Environmentally sustainable transportation system.

Later in 2015, the Office of Natural Resources and Environmental Policy and Planning (ONEP) submitted a new report to the United Nations Framework Convention on Climate Change (UNFCCC) on Thailand's Intended Nationally Determined Contribution (INDC). The new document set out a more specific plan on how and how much emissions should be reduced compared to the BAU projection using 2005 as the reference year. The estimated greenhouse gas emissions in BAU scenario in 2030 was around 555 $MtCO_2e$[24]. Thailand aimed to cut this off by 20%[24]. With better access to technology development and transfer, financial resources and capacity-building helps, the contribution can be boosted up to 25%[24]. Although Thailand submitted the updated national determined contribution (NDC)[25] in 2020, the greenhouse gas emission goal remained the same as originally stated in the INDC. However, the country's goal was slightly modified during the world leaders' summit of COP26 in October 2021. Based on the Prime Minister's speech at the summit, Thailand aims to reduce greenhouse gas emission by 40% by 2030 subject to technical and financial support from international community and reach carbon neutral by 2050 and consequently net-zero greenhouse gas emissions by or before 2065[26]. According to the aforementioned evidence, it is highly likely that all climate mitigation measures will be in place. However, the National Adaptation Plan (NAP)[4] includes climate adaptation plans only for some key sectors. So far, there has not been a structured study to define the adaptation scenario for road and rail transportation in Thailand. Therefore, it is essential to define a reasonable scenario to use as a starting point.

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[23] Ministry of Natural Resources and Environment (2014) Communication on Thailand's nationally appropriate mitigation actions (NAMAs). Available at: https://unfccc.int/files/meetings/cop_15/copenhagen_accord/application/pdf/thailandcphaccord_app2.pdf

[24] Office of Natural Resources and Environmental Policy and Planning (2015) Thailand's Intended Determined Contribution (INDC). Available at: https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Thailand%20First/Thailand_INDC.pdf

[25] Office of Natural Resources and Environmental Policy and Planning (2020) Thailand's Updated Nationally Determined Contribution. Available at: https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Thailand%20First/Thailand%20Updated%20NDC.pdf

[26] Ministry of Foreign Affairs Thailand (2021) The Prime Minister Speech at UNFCCC COP26. Available at: https://www.mfa.go.th/en/content/cop26-glasgow?page=5d5bd3cb15e39c306002a9ac&menu=5d5bd3cb15e39c306002a9ad

However, since climate adaptation involves a number of stakeholders whose interests are different, it is highly unlikely that we can reach a single scenario that is sensible for all stakeholders. However, it does not seem reasonable to include all available options in this report. Justification of countermeasure selection is required. Considering the scope of the report which only focuses on rails and roads, only countermeasures suitable for these modes of transport will be discussed. Only countermeasures that have been implemented in the past by DOH, DRR or SRT (even if the countermeasures did not intend to increase climate change resistance of the infrastructures or the countermeasures were implemented after the infrastructure were damaged by a climate event), and countermeasures that were proved capable for enhancement of climate adaptability in other countries. Improving the road drainage system, pumping water from one side to another, installing a box culvert for water passage, ditch lining, an underground tunnel to avoid floods, laying the road higher, resurfacing and mechanically stabilized wall are the possible road countermeasures to survive floods. Sleeper replacement, an underground tunnel, and water passage (either box culvert or bridge construction) are selected countermeasures for rail transport. However, the suitability of these countermeasures needs to be justified according to the actual geographical conditions in Thailand to ensure that they are capable for addressing climate change. Upon consultation with experts and responsible organizations in the previous cost-benefit analysis study on specific cases of roads and rails, laying the road higher, cape seal treatment and mechanically stabilized earthwall were the chosen climate-proofing countermeasures for roads. Ensuring water passage by reconstructing the bridge was the only countermeasure selected for rails.

Figure 2 shows the schematic representation of climate adaptation scenarios in this study. Even though climate-proofing countermeasures were selected in the previous cost-benefit analysis, the selection was based on criteria specific to the target sites. In this I&FF assessment, countermeasures will be divided into categories according to their functions and reconsidered upon consultation with responsible organizations based on their technical and political viability. Since the budget available for climate-proofing countermeasures is limited, the roads and rails to undergo countermeasures also should be classified according to their importance (which could be represented by several parameters, e.g., number of vehicles or passengers, number of lanes). This will provide a clear picture to the stakeholders and the related entities for a better understanding of how each countermeasure benefits rail and road infrastructures. What is more, it provides an understanding of the available choices of climate-proofing countermeasures for the selected road/rail infrastructures. Following information can be obtained from this matrix. For example, if the mechanically stabilized wall is applied to the entire road network (from tier 1 to tier 3) in Thailand, what is the output from this action. Of course, the road will be more resilient to climate change, especially floods. However, investing in this type of technology may require tremendous amount of investment which could be problematic for the government.

Tier	Category A			Category B			Category C		
	Countermeasure A-1	Countermeasure A-2	Countermeasure A-3	Countermeasure B-1	Countermeasure B-2	Countermeasure B-3	Countermeasure C-1	Countermeasure C-2	Countermeasure C-3
1									
2									
3									

Figure 2 Matrix of climate adaptation scenarios

For the development of the investment and financial flows for the adaptation scenarios, the investments and associated costs of selected countermeasures will be added to the general expenditures of the baseline scenario. To align with the timeframe of the NDC, the timeframes are set to 2022 – 2030 for the progressive adaptation case, and to 2022 – 2050 for the moderate adaptation case. Note that the total investments on climate-proofing countermeasures of both cases are the same, and the only difference is the timeframe. In order to illustrate the effects of the countermeasures, the emergency expenditures are assumed to decrease by half by the end of the timeframe of both cases.

4 Technical and Political Viability

4.1 Technical Viability

4.1.1 Definition

Viability analysis aims to identify potential constraints and related solutions concerning technical, economic, regulatory, and managerial aspects of the project[27]. The technical viability evaluation is considered as one of the good instrumentations for analyzing and identifying suitable technical solution(s) for long-term planning. The definition of "technical viability" can vary according to the scope of the evaluation since it has been used in many types of investigation, ranging from social, political, to engineering studies. This study employs the definition of UNDP where technical viability is defined as the employment of the suggested countermeasure action to the real-world under the viable skills, equipment, and certain other local elements such as geography, government, climate, and infrastructure system[28]. All the proposed road and rail countermeasures requisitely undergo the investigation of technical viability under the aforementioned definition to ensure its suitability and applicability.

4.1.2 Countermeasures for Roads

Countermeasures covered in this study include those undergone cost-benefit analyses in the former phase of the project, including laying the road surface higher, cape seal treatment and mechanically stabilized earthwall, and other countermeasures that have been implemented elsewhere and could potentially be implemented in Thailand.

4.1.2.1 Laying the Road Surface Higher

Laying the road surface higher is relatively simple to do and does not require heavy construction equipment compared to other methods. The construction cost mainly depends on the road dimensions and the types of gravel and soil that are used. In addition, the road is still able to operate while it undergoes half-width construction though it consumes much time than full road closure[29]. This is a good option for the road network with high traffic volume.

a) Procedure

The modified procedure[30] of this method can be divided into four essential steps. First, the spoiled soil is dug out. Then, the base course layer is prepared. Next, the new soil is placed over the base layer and rolled over and over to ensure the soil compaction is accomplished. Lastly, the finishing works are done as a final step.

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[27] Sartori, D., Catalano, G., Genco, M., Pancotti, C., Sirtori, E., Vignetti, S., & Bo, C. (2014). *Guide to cost-benefit analysis of investment projects. Economic appraisal tool for cohesion policy 2014-2020*. Available at: https://ec.europa.eu/regional_policy/sources/docgener/studies/pdf/cba_guide.pdf

[28] UNDP Public Website UNDP Social and Environmental Standards - Standard 2. Available at: https://info.undp.org/sites/bpps/SES_Toolkit/SitePages/Standard%202.aspx

[29] https://ops.fhwa.dot.gov/wz/resources/publications/fullclosure/crosscutting/its.htm

[30] Zaiton (2019) Finished surface road construction process. Available at: https://zaitoon.com.pk/road-construction-process/

b) Materials and equipment

The raw materials commonly used in this method are aggregates, sand, and high-quality soil. Only small and medium construction equipment is required, for instance, bulldozer excavators, loader, grader, compactor, dump truck, water tanker, low-loader trailers[31].

c) Unit price

At least five different middle prices for construction ranging from the year 2015 to the most recent one in 2020 were used to estimate the price of this countermeasure. Information extracted from the documents were the width and length of the road, the construction area, the total amount of landfilling in cubic meters, and the material cost. The unit price of each year was calculated by multiplying the material cost with the F-factor. Since there were at least five raw data set is available, the unit price is calculated one by one and then average them out to the final value which is 136.10 THB/m^3.

4.1.2.2 Cape seal treatment (resurfacing)

Cape seal is a good preservation treatment for roads with light to medium traffic, and they have also performed well on higher-volume roadways. Cape seal is generally placed on existing asphalt pavement[32].

a) Procedure

Road resurfacing with the cape seal treatment is multi-layered pavement preservation. The incorporated treatment is divided into two consecutive processes[33]. Initially, the chip seal is done where the liquid asphalt binder fills the open crack and provides a new restorative interlayer. Then, the chip seal is later covered with the micro-surfacing. The micro surface is applied to provide a final wearing surface with a smooth and uniform texture.

b) Materials and equipment

Since the task consists of two separate steps, it would be convenient to divide the construction materials into two distinct groups. The materials that are regularly found in the first step are polymer-modified emulsion and rejuvenating emulsion. The slurry surfacing in the second step mostly uses emulsion RS1, RS2, CR1, and CRS2[34].

c) Unit price

The raw data used to calculate the unit price for resurfacing with cape seal was also extracted from the announcement of the local administrative organization and the summary of cost estimation released by the construction company. For this case, seven sets of data from the completed construction sites located in Sukhothai (2), Nakhon Ratchasima (2), Chumphon (1), Udon Thani (1), and Trang (1) were used. The total budget and the total area of each site were used to calculate the unit price. In both

[31] Siddig, O., Eltybe, Z., Mohyeldin, O., Elybe, Z., & Omer, O. (2018). *Gravel road construction principles of practical information*. https://doi.org/10.13140/RG.2.2.24669.92648
[32] Mineta (2019) Transportation institute manual for cape seals. Available at: https://transweb.sjsu.edu/sites/default/files/1845C-Cheng-Cape-Seal-Manual.pdf
[33] Indusinc (2021) Cape seal. Available at: https://indusinc.com/roads/cape-seal/
[34] Mcasphalt (2019) Cape seals. Available at: https://mcasphalt.com/processes/slurry-micro-systems/cape-seals/

cases, the unit price was inflated to the fiscal year 2019. The final unit price of resurfacing with cape seal after the inflation is 348.45 THB/m^2 for the road that has width of 12 m.

4.1.2.3 Mechanically stabilized earthwall (MSE)

The road that is built near the canal or river will require wall retaining to ensure that its structure will be able to handle the maximum load of the road. Wall retaining can also serve as the means to adapt to climate change. A mechanically stabilized earthwall (MSE) is one of the most well-known conventional alternatives to retain walls. This method is made up of alternating layers of compacted backfill and soil reinforcing components that are attached to a wall surface[35].

There are three essential elements to the construction of MSE: facing, soil reinforcement, and backfill[36]. Each of these components plays a different role to reinforce the road structure. For instance, the facing acts as a supporting system. The facing elements are regularly constructed using the precast concrete panel or wire mesh. Soil reinforcement is typically steel or geosynthetics, in the forms of strips or ladders. Furthermore, the backfill soil acts as a retaining structure which ensures the construction reliability and performance of the wall.

a) Procedure

Construction of MSE is relatively fast and straightforward. The construction sequence mainly consists of preparing the subgrade where the natural soil is compacted to ensure that it has the capacity to handle and support the total load, placing where the row of the panel is installed and braced, and compacting backfill in normal lift operations, laying the reinforcing layer into position, and installing the facing element (tensioning of the reinforcement may also be required)[37].

b) Materials and equipment

MSE needs not only special construction equipment, but also intensive local labor to ensure that the work is done within a proper timeframe. The material requirements depend on the construction steps. For instance, the facing elements are modular precast concrete panels or wire mesh, Soil reinforcement is typically steel or geosynthetics[38], Though a wide range of soil properties will meet the soil specifications, the ideal material for backfill is open-graded material with low plasticity and fine grains, such as sand or crushed stone.

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[35] Zumrawi, M. M., Barakat, A. B., Abdalla, I. M., & Altayeb, R. A. (2020). Mechanically stabilized earth with steel reinforcement. *FES Journal of Engineering Sciences*, *9*(3), 135-141.
[36] Reinforced Earth (2021) Mechanically stabilized earthwall. Available at: https://reinforcedearth.com/products/retaining-walls/mechanically-stabilized-earth-mse-retaining-walls/
[37] Vankavelaar, D., & Leshchinsky, D. (2002). Inspection guidelines for construction and post-construction of mechanically stabilized earth wall. *Delaware Center for Transportation, Newark, Delaware*. Available at: https://cpb-us-w2.wpmucdn.com/sites.udel.edu/dist/1/1139/files/2013/10/Rpt.-143-Mechanically-Stabilized-Earth-Wall-Final-Leshchinsky-yxyg38.pdf
[38] Gateway Structure SDN BHD (2021) What is geosynthetic. Available at: https://gssb.com.my/what-is-geosynthetic

c) Unit price

The raw data for the calculation of mechanically stabilized earthwall unit price was from the same source as cape seal treatment, though only three data sets could be gathered due to the limited number of construction sites. The raw data extracted from the local administrative organizations in Samut Prakan (2) and Nakhon Pathom (1), respectively. The construction cost per meter for this can be easily obtained by dividing the total cost by the total distance. Then, the unit cost similarly with other types of countermeasures were inflated to the year 2019. The unit price of this countermeasure is 39,289.28 THB/m.

4.1.2.4 Other additional approaches

Apart from the countermeasure mentioned above, there are a few more worth to be mentioned. These methods can provide alternative ideas in case the geographical conditions change. The detailed technical information about each method is described below.

a) Drainage system improvement

Road drainage is usually used to take out excess surface water from the road and it also prevents flood. This results in road stability and durability. A good drainage system can improve the longevity of roads and minimize maintenance costs. There are two types of road drainage, namely surface drainage, and sub-surface drainage[39]. As the name suggests the surface drainage is situated in the open area alongside the roadway and serves as the waterway for the surface water to flow out from the road, whereas the sub-surface drainage is commonly deployed underground to regulate the amount of moisture content of the road. The main reason to the necessity to regulate the moisture content is because the road's entire structure will be weak if the moisture content is high. The linear drainage and grated pit or pipe drainage are the two available approaches for surface water drainage[40]. The construction of pipe water drainage involves digging out the soil, placing and connecting the pipe, refilling the soil back in, and then filling it with the cement. High-Density Polyethylene (HDPE) type SN4 is employed in a construction site in Chonburi province[41]. According to this document, the middle price to construct the per meter is around 127,256 THB, which also includes the construction price of reinforced concrete of manhole for delivering the water from the road surface to the pipe underground.

b) Ditch lining

This countermeasure is not directly applied to the road, but is generally implemented on the river or canal that runs along the road. There are several ways to divert the excess water in order to avoid flooding on roads. Watergates can be installed at the junction of the river/canal to

[39] Constructionor (2021) Road drainage. Available at: https://constructionor.com/road-drainage/#Types_of_surface_drainage

[40] Acodrain (2021) Types of surface water drainage. Available at: https://www.acodrain.com.au/industry-solutions/types-of-drainage/#spoon

[41] Sanitary Technician Office (2020) Project to improve rainwater drainage pipes to prevent flooding, Yon Beach (Soi Phra Tamnak 5), Ban Lamung District, Chonburi Province. Available at: http://122.154.116.141/Lists/63/Attachments/301/ราคากลาง.pdf

regulate the water level to keep the road along the river/canal dry. Though the main purpose of most water gates is to secure water for agriculture, the operator can take into account the aspect of flood prevention during the operation. If there is a possibility to redesign the canal and road network, an additional branch of the canal to divert excess water to so-called monkey cheeks[42] can be constructed. The ditch and canal liner are the two options for taking out the water from the main channel and distributing it to somewhere else intending to prevent a specific area from the effect of the flood. The huge amount of water can be displaced due to the new waterway, which was created by digging of the new canal. However, a large investment is required, and it maybe not be politically viable in most situations. These two methods involve digging to create the ditch or canal, compacting, and putting the concrete pad on site except for the canal. In general, the concrete canal liners cost up to 30 times more than the normal canal[43]. According to a document about the summary of construction cost estimation released by the office of the official information commission in 2019[44], there are two related projects that are built related to the reinforced concrete canal. The thickness, height, bottom, and top width of the canal are 0.1 m, 2.0 m, 1.0 m, and 3.0 m, respectively. The first investment project is 1,795,099 THB with the total distance of 548 m. And the second investment is 358,644 THB with the total distance of 106 m. By using the data of these projects, the average unit price is 3,329.58 THB per meter.

c) Pumping water from one road side to another

Some road infrastructure was built across the natural waterway. Therefore, the road is highly prone to floods, especially if a huge volume of water goes through the waterway. The instantaneous solution for the scenario would be to pump water out from the upstream to the downstream to ensure the water does not pass the road. This method should never be the option for long-term climate adaptation planning because the investment would be tremendous. The sewer pipe crossing the road can serve as a better option. The cost of transferring water from one side to another is varied according to the type of size of the water pump engine. Hence, the calculation of unit price will relate to the water pump size and the fuel price. For the water pump using diesel engine is quite hard to estimate the price per cubic meter since the fuel consumption will be varied according to many parameters. Thai government procurement has just announced the central price of the centrifugal pump with diesel engine 40 hp, flow rate 500m^3/h at 12m suction lift, and the tube diameter is more than 8 in[45]cost approximately 650,000 THB per unit. The estimate of the price can be derived by taking the

[42] Office of the Royal Development Projects Board (2021) Development of water sources. Available at: http://www.rdpb.go.th/en/Projects/project-categories-c54/development-of-water-sources-v60
[43] https://www.westernliner.com/cxanal-liners.html
[44] Office of the Official Information Commission (2018) Summary of construction cost of reinforcement concrete canal at Kanchanaburi province. Available at: http://www.oic.go.th/FILEWEB/CABINFOCENTER30/DRAWER017/GENERAL/DATA0000/00000052.PDF
[45] Thai Government Procurement (2021) Procurement announcements search (Project ID: 64127298603). Available at: http://process.gprocurement.go.th/

water pump machine that has similar specification from the catalogs provided by the distribution company. For instance, the water pump size 12 inches stainless tube 6 meter was distributed by Kelenor Company Limited[46], the summary specification of this machine is provided in Table 1.

Table 1 Specifications of water pump (12 inches)

Pump type	**Naga water pump**
Engine type	Diesel engine
Dimension pipe	Inlet and outlet 12 inches Thickness 6 mm
Deliverable flow rate	1,250 m^3/h
Fuel consumption at 75% (1500 RPM)	15.38 l/h[47]
Price	475,000 THB

According to the PTT oil price board, Premium Diesel, Diesel B7, Diesel, Diesel B20 is charged around 35.06, 29.04, 29.04, 29.04 THB[48], respectively. The fuel consumption price is based on the price of Diesel B7 since it is commonly used for this purpose. If the machine can pump water out at 1250m^3/h and consume fuel 15.38 l/h, the diesel price is 29.04 THB/l. The estimated price to move one cubic meter of water will cost 0.35 THB excluding the operational and maintenance cost. Assume that the water pump has a coverage range of 15 meters in radius from the location where it is located. The price to employ the method is approximately 15,833 THB/meter.

d) Water passage (box culvert)

The general purpose of the bridge is to simultaneously provide the way for water to flow freely and the vehicle to pass through regularly. The bridge water passage capacity plays an essential role to regulate the amount the water upstream and downstream. A bridge provides a similar function to sewer pipes crossing the road but at a higher volume. But the construction cost of the bridge is higher, and the project demands a longer timeframe. There are many types of bridges available base on the specific need and geography condition. In this case, precast box culverts type is considered due to its advantage on the investment price, ease of installation on the existing road. The process is straightforward and requires only small construction equipment. The summary of construction cost estimation of 2-channel reinforced concrete square pipes in Phachit province based on the

[46] Product catalogues of Auger Kelenor (2019) Water pump stainless steel 12inch 9.4m. Available at: https://auger.kelenor.co.th/index.php?route=product/product&product_id=471

[47] Ricardo R6105AZLP Engine specification. Available at: https://e-katalog.lkpp.go.id/jcommon.blob.filedownloader/download?id=65c9e3f6b1fb04481c8692ad4991d42890f941fce5aec6eb71c2067bfa2a1386ddc542523db68ff4e0345f962803a1eaf59403eeb7f296939c4edc3ff7d91df859fdec4cf42599867b260f6cf49a9208fc1bfad59ed4e69e29c3e23c1d877fbe

[48] PPT Station (2022) Oil price board. Available at: https://www.pttor.com/th/oil_price_board?lang=en [Accessed Jan 07, 2022]

data provided by Huayruam subdistrict administrative organization[49]. The dimension of the box culvert span, height, and width distance is 1.8 m, 1.8 m, and 6 m, respectively. The total investment cost of this project is 285,010 THB. If we assume that there will be an average of four box culverts per kilometer, the unit price of the countermeasure is 1,140 THB per meter.

e) Underground tunnel

This countermeasure is more relevant to rail network and will be discussed in detail in the following subsection. Plus, the unit cost will be quite similar to the case for rail. However, its total cost should be cheaper since the surface road construction in the tunnel will be simple and require less raw material to get the job done. According to the large diameter (twin bores) highway tunnel project that was built the under Shanghai River[50] which has a total length of 7,403 m and diameter of 15.4 m, sand, clay, and rubble is the soil composition in that region cost 562,199 THB per meter with the conversion rate from US Dollar to Thai Baht of 33.51.

4.1.3 Countermeasures for Rails

Alike the previous subsection, this section discusses the technical viability of water passage which underwent cost-benefit analysis in the former phase of the project and other countermeasures that have been implemented elsewhere and could potentially be implemented in Thailand.

4.1.3.1 Water Passage (Bridge Construction)

Bridge construction water facilitates the flow of water from upstream to downstream regions. The region around this area is unlikely to undergo a flood. Even though this method dramatically increases the climate adaptive capacity of the rail, the initial investment cost is considerably expensive and with a very long payback period. The raw materials for the bridge are generally masonry, concrete, and steel. And these raw materials are assembled using hinged or pinned joints, rivets and bolts, and welding. It is difficult to estimate the unit price per meter since the length of the bridge may not be the suitable unit and the construction substantially varies from one location to another. For instance, the bridge is generally required to have a stable foundation and column at a particular distance and supporting structure in the middle which needs diverse raw materials to complete the task. Hence, the cost will make more sense in the actual world scenarios.

The unit price of bridge construction for water passage is estimated in terms of investment per spot based on the budget allocated to the northern branch of State Railway of Thailand (SRT) in the past decade. The documented raw data indicated that about 36 million THB was allocated to four different spots in 2011. Then in 2014, 117.5 million THB was distributed to nine spots starting from km 517/1-2 to 520/9-10 of the northern line. Most budget was spent on railway construction near mountain areas. Afterward,

[49] Huayruam Subdistrict Administrative Organization (2021) Summary of construction cost estimation items to determine the middle price for the construction for reinforced concrete culvert in Phichit province. Available at: https://www.huayruam.go.th/files/com_networknews/2021-03_9ab8765085545c5.pdf

[50] TunnelTalk (2015) Cost benefits of large-diameter bored tunnels. Available at: https://tunneltalk.com/TunnelTECH-Apr2015-Arup-large-diameter-soft-ground-bored-tunnel-review.php

around 90 million THB was allocated to nine spots in the nearby area in 2015. The budget was for the reconstruction of railway which was damaged by the large flash flood in Denchai district in 2012[51]. Besides, approximate 15 million THB was apportioned for railway development at km 519/3-4. The summary of budget allocation is illustrated in Figure 3. Essentially, all aforementioned budget is mainly for railway in Phrae and Uttaradit which implies that the areas are prone to flash floods. The total cost was inflated to the year 2019 with an inflation rate of 1.59%[52]. The total investment cost in constructing water passages was estimated to be 279.6 million THB.

The estimated price of the bridge per construction spot can be determined by dividing the total budget by the number of the construction spots: the average cost per construction spot was about 12.5 million THB.

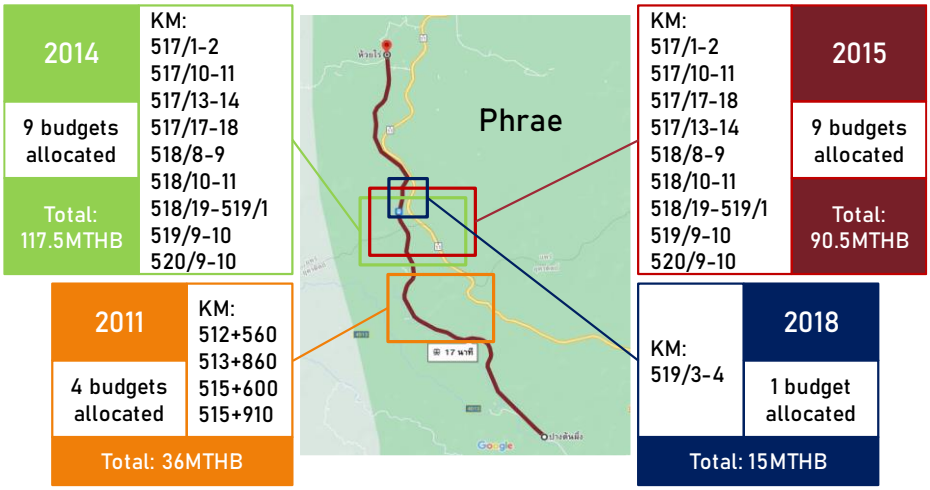

Figure 3 Previous adaptation investment in SRT Northern Line

4.1.3.2 Other alternative methods

a) Water passage (box culvert)

Although the water passage (box culvert) has an identical name of the road countermeasure, the construction procedure along with the railway network and the requirement of the construction material will be slightly different from the road. The box culvert can normally be found at the intersection between the canal and the rail route. Due to the similar reason with the bridge construction, the price of this method should be expressed in terms of spot. The selected location can have multiple spots where it perpendicular or close to the mountain. The unit price that using for this countermeasure is taken from the TOR e-bidding provide by the procurement of Thai railway. The investment cost per spot for the box culver is 8,300,000 THB for the rail that has the dimension of 2x2 meters and can support an axial load up to standard U.20 which can support load up to 20 tons. In addition, five box culverts are assumed to be the requirement for the

[51] Post Today (2012) Flooding floods Den Chai - the railroad is broken (Translated from Thai). Available at: https://www.posttoday.com/social/general/158564

[52] Bank of Thailand (2015) Thailand's macroeconomic indicator – Inflation rate. Available at: https://www.bot.or.th/App/BTWS_STAT/statistics/ReportPage.aspx?reportID=409&language=th

purpose of climate adaptation for the rail line that operates near the mountain or perpendicular to the river.

b) Sleeper replacement

The sleeper replacement has been commonly done in many places especially developing countries to retrofit railway lines. The countermeasure usually involves changing wooden sleepers into concrete sleepers. Concrete sleepers are better in terms of reliability, durability, and availability. In the climate adaptation context, concrete sleeper is a preferable option unless there is a specific need for wooden or other types of sleepers. The sleeper replacement generally involves sweeping the wooden with concrete sleeper because it is suitable to use in almost every soil condition except the bridge.

For the commercial employment of sleepers, the institution should consider consulting with a private company to produce a large quantity so that the government can easily control the quality and customize the design based on the need standard of the final product. Moreover, the unit price of a single sleeper can be slightly cheaper compared with the price if it was directly bought from an industrial. One local company located in Rayon named BJC Heavy Industries Public Company Limited is capable of manufacturing the precast railway sleeper concrete according to the customer's distinct design required.

Replacing the sleeper is a time-consuming task if it was done by hand. Currently railway sleeper replacement most of the time is achieved by employing the heavy construction machine. This type of machine comes with the new technology and is able to save the labor cost, move faster, and therefore save time. However, the cost of the machine is quite expensive. Human labor is required in a critical location where the big machinery is not allowed or impossible to enter and do the job though. If the budget is constrained, the excavator can be modified to accomplish the same with the cheaper price, because only a sleeper changer excavator attachment is needed. The whole set of machines, including special track crawler excavator and railway sleepers' replacement equipment, cost approximately 1.9 million THB.

The monoblock sleeper is worth 1,381 THB/piece. The lift and putting down the piece to the truck will cost around 76.8 THB/piece. And the transportation will cost 199.51 THB/piece. The replacement cost of change from the sleeper timber to precast concrete is around 321.58 THB/piece and the change from the old to new concrete sleeper cost 481.68 THB/piece. The total price is 1,979 THB/piece on the condition that the wood sleeper is changed with the concrete and 2,139 THB/piece if the former concrete is replaced with the new one. The price is significantly difference compared to the year 2013, the monoblock railway sleeper cost only 540 THB per unit. As stated in the training document of the permanent way, the distance from the center of the one and second sleeper is about 83.9 centimeters. The price per meter for first and second case scenarios is 2,358 THB/meter and 2,549 THB/meter, respectively.

Table 2 Price of necessary activities for sleeper replacement

List of activities	Cost
Monoblock sleeper	1,381 THB/piece
Lift and put down the piece to the truck	76.8 THB/piece
Transportation	199.51 THB/piece
Change from timber to precast concrete	321.58 THB/piece
Change from the old to new concrete sleeper	481.68 THB/piece

c) Underground tunnel

Unlike other types of transportation, rail has a significant drawback which is the inflexibility of the routes. The entire route will need to be closed if the damage is detected at a particular spot due to some incidents, e.g., flash floods, while vehicles on the road can switch to an alternative route if the road ahead is not available. Underground tunnel reinforces the overall railway structure and operation and prevent or mitigate the consequences from flash floods and other flooding events. The level of reliability of rail will tremendously increase if the underground tunnel is built, especially in the areas prone to floods. The underground tunnel is considered the most expensive for any country to build unless area constraints or special geolocation are faced. This is one of the reasons that underground tunnels are only located in wealthy countries and densely populated cities. And the unit cost is also varied according to the condition of each country in which it was built. For instance, the price per kilometer of underground tunnels will significantly increase due to the price of the raw material and labor. As the result, the unit price will be cheaper if the site is located in China or India. In the blog post of *tunnelingonline*[53], four main categories of unit price based on the region are reported as follows; New York will cost around 31.23 – 52.06 million per meter while other parts of the United States and Australia only cost 12.49-18.74 million THB per meter. Moreover, the price in Europe, the Middle East is 5.20-10.41 million THB per mile. The construction price of India, China, Southeast Asia is only 4.16 million THB per meter which is categorized as the cheapest investment cost compared to other locations. The abovementioned price is converted from the US dollar with the conversion rate of 33.51 THB for 1 US dollar.

4.1.3.3 List of capable local construction companies

Climate-proofing countermeasures in the transportation sector tend to be large-scale projects that require contractors that are equipped with technical capability, financial capacity, and have experience in such construction work. Local companies with the highest budget record for some of the companies are listed in Table 3. These companies have considerable experience in handling and delivering construction projects corresponding to each aforementioned countermeasure within the expected timeframe. The

[53] Tunnelingonline (2020) Why tunnels in the US cost much more than anywhere else in the world. Available at: https://tunnelingonline.com/why-tunnels-in-the-us-cost-much-more-than-anywhere-else-in-the-world/

listed budget record of each company is the highest budget that was recorded on the company website or the Thai government procurement website. Most companies are involved in large governmental and private projects to construct backbone infrastructure in Thailand, including expressways, airports, mass rapid transit systems, processing plants, and petrochemical plants.

Table 3 List of selected qualified companies

Company	Highest budget record (Million THB)
Company A	6,757[54]
Company B	1,724[55]
Company C	1,544[56]
Company D	905[57]
Company E	573.22[58]
Company F	534.6[59]
Company G	59.8[60]
Company H	50[61]

4.1.4 Economic Feasibility

All countermeasures can enhance the climate adaptive capacity of road and rail infrastructure. The potential contribution to the said capacity is used to classify the countermeasures into three tiers. Nevertheless, if the initial investment is very large without a promising cost-benefit ratio, it can be challenging for the responsible authority to finance the investment. There are many types of countermeasures available for road and rail. Each countermeasure would respond to climate events differently according to the tier to which they belong. Thus, choosing the right method for the particular zone from an economic perspective is essential for a large-scale investment. Based on the previous study on cost-benefit analysis, there are three chosen

[54] Prachachat (2018) The connecting road connecting Ratchaphruek-Kanchanaphisek is finished more than 50% (Translated from Thai). Available at: https://www.prachachat.net/property/news-105267
[55] CH. Kamchang Public Limited Company (2020) Highway Route no. 3256 Ladkrabang-Bang Pli Highway. Available at: www.ch-karnchang.co.th/en/#/project/detail/57
[56] Sino-Thai Engineering & Construction Public Company Limited (2020) Contract agreement. Available at: https://weblink.settrade.com/simsImg/news/histri/202008/20100729.pdf
[57] Christiani & Nielsen (Thai) Public Company Limited (2016) Annual report – Focus on the future. Available at: http://cnt-th.listedcompany.com/misc/AR/20170324-cnt-ar2016-03.pdf
[58] TRC Construction (2009) Construction contract of Highway Route No. 35. Available at: https://www.trc-con.com/en/projects/civil-and-infrastructure/192/construction-contract-of-highway-route-no-35-samutsakorn-pakto-part-4-82-km-distance-with-lighting-works-and-traffic-signal
[59] Italian-Thai Development (2018) Contract agreement. Available at: https://www.itd.co.th/document-file/ir/CSD002_2018E_th.pdf
[60] Thai Government Procurement, Procurement announcements search (Project ID: 64107208496). Available at: http://process.gprocurement.go.th/
[61] Thai Government Procurement, Procurement announcements search (Project ID: 64117028648). Available at: http://process.gprocurement.go.th/

countermeasures namely laying the road 0.5 m higher, resurfacing with cape seal with the assumption that the road width and length are 12 m and 600 m, respectively. Data for the estimation of unit price of each countermeasure was mostly obtained from the e-bidding documents that were made available online by the construction company themselves or other relevant entities.

In the railway sector, there are several practices adopted in order to respond to the climate events. Potential countermeasures involve sleeper replacement, underground tunnel, and construction of water passage of both box culvert and bridge construction. Among abovementioned countermeasures, building bridge for water passage is considered technically feasible to minimize consequences from frequent natural disaster to rail routes such as flash flood. Nevertheless, the initial investment cost will be a little bit higher compared to the other countermeasure. The unit price of entire proposed methods is recapped in Table 4.

Table 4 Unit price of the selected countermeasures after inflation to fiscal year 2019

Countermeasure		Unit price
Road	Laying the road 0.5 m higher	136 THB/m^3
	Resurfacing with cape seal (width = 12 m and length = 600 m)	348 THB/m^2
	Mechanically stabilized earth wall	39,289 THB/m
	Drainage system improvement	127,256 THB/m
	Ditch lining	3,330 THB/m
	Pumping water from one side to another	15,833 THB/m
	Water passage (box culvert)	1,140 THB/m
	underground tunnel	562,199 THB/m
Rail	water passage (bridge construction)	12,500,000 THB/spot
	water passage (box culvert)	8,300,000 THB/spot
	sleeper replacement	2,549 THB/m
	underground tunnel	4,164,440 THB/m

4.2 Political Viability

4.2.1 Involved Stakeholders

Climate adaptation investment is gaining attention globally as the means to address the climate crisis. It requires policy decisions, implementing organizations, governmental budgeting, and private investment to materialize. Climate adaptation investment requires the cooperation of a wide range of involved stakeholders. A key organization is the Office of Natural Resources and Environmental Policy and Planning (ONEP) who is responsible for the determination and monitoring of the fulfillment of the Nationally Determined Contribution (NDC). ONEP cooperates with other entities whose look after each key sector to drive and support operation of climate-related actions,

leading to effective implementation to fulfill the targets stated in the NDC. However, particularly the adaptation portion of the climate investment in transportation sector is inattentive compared to other sectors. To create strong awareness and encourage climate adaptation investment in transportation sector, Office of Transport and Traffic Policy and Planning (OTP), who supports transport and traffic policy, mass transit planning, transport safety measure, and standard for national sustainable development, is a promising organization to driving the investment and supporting the operation of climate-related actions. OTP is responsible for providing viable solutions to land traffic issues in consideration of quality of environment and perform continuous assessment of infrastructure performance in accordance with plan and budget constraints. Besides, OTP plays a significant role in climate matters especially in transport sector. The office has put efforts into national action plan for transport in comprehensive mitigation process with several national and international stakeholders whose interest is development and expansion of public transport. Therefore, OTP is a key organization that can further climate-related initiatives in transport sector.

Towards climate change, policy formulation and direction are developed by ONEP and OTP taking into account extensive data on weather and disaster including facts, statistics, and evidence provided by a number of national and international organizational entities. For instance, Thai Meteorological Department (TMD) and Department of Disaster Prevention and Mitigation (DDPM), which contribute to national safety against natural disaster, supply informative weather and disaster forecasts and information to government institutions. The governmental organizations have their roles on supporting guideline and measures in disaster prevention and mitigation and developing information technology for assessing disaster management and recovery.

Since the project targets on transportation sector, particularly road and rail, Department of Highways (DOH) and Department of Rural Roads (DRR), which are responsible for national highways and rural highways, both oversight by Ministry of Transport, are direct stakeholders. While construction, expansion, maintenance, and repairing of national highways are carried out by DOH, those activities on rural highway are covered by DRR[62]. State Railway of Thailand (SRT), also under Ministry of Transport, operates all national rail lines. SRT infrastructure investment involved track duplication, extension of elevated railway, construction of bridges and fences, and track improvement[63]. Apart from three key transport stakeholders, local administrative organizations (LAO) in target areas are also key players in cooperating with public, and integrating, monitoring, and evaluating implementation of local development plans. During the development of transport infrastructure, LAO facilitates construction through traffic volume redirection and road closure. Hence, traffic issues and local difficulties are alleviated. Royal Irrigation Department (RID) is entailed

[62] Wikipedia (2021) Thai highway network.
Available at: https://en.wikipedia.org/wiki/Thai_highway_network

[63] Wikipedia (2021) State Railway of Thailand.
Available at: https://en.wikipedia.org/wiki/State_Railway_of_Thailand

when the construction takes place next to areas under RID's purview, such as river and irrigation canals. Within the scope of this study where study areas aim for routes laid along river or canals, RID becomes another important stakeholder. As Land Acts, B.E. 2518 (1975) defined state properties as all types of real assets belonging to the country used by citizen or reserved for benefits of the public, such as waterways and public highways, it is necessary to also include Treasury Department (TD), under Ministry of Finance, which is governing, overseeing, and maintaining state properties. Speaking of infrastructure construction, Department of Public Works and Town & Country Planning (DPT) becomes one of the key stakeholders when a project scale is large and involves infrastructure design and development planning. DPT is responsible for urban development, especially in assurance of public safety against natural disasters, establishment of flood-proofing system in the communities, riverbank construction, critical infrastructure, and land development. The department is working in accordance with Building Control and Town Planning Acts, and also provides technical and engineering advisory in relation to abovementioned issues and policy.

Adaptation is generating direct and indirect benefits both in economic and social perspectives. However, the benefits are not fully recognized by the majority of stakeholders. In order to receive finance at a necessary scale, large cash outlay should be mobilized from multilaterally involved institutions. The Budget Bureau (BB) is the central unit responsible for budgeting and proposing to the Prime Minister's Office for approval. BB also manages budget expenditure in accordance with Annual Budget Expenditure Act, ensuring that spending on state activities is economically feasible and the national usage shall be optimized for the country's benefits. BB can offer beneficial advice on budgeting and managing for utmost results and cost effectiveness of the proposed investment. Comptroller General's Department (CGD), which manages national revenues and expenditures, can potentially assist in ensuring lawful use of national budget in compliance with the country's ultimate targets and benefits. The department looks after national accounting according to the acts and also has responsibility to maintain the accounts of royal assets, optimize national budgets and facilitate international investments. Since road and rail infrastructures are mostly considered royal assets, CGD plays a critical role in decision making of climate-proofing projects. Thailand Greenhouse Gas Management Organization (TGO) provides technical support to facilitate and accelerate the reduction of greenhouse gas emissions and also promote carbon tax to generate country revenue for national budget. On the other hand, TGO offers carbon credit mechanism to raise the awareness of climate change and private participation in the country.

Collaboration with the private sector is also recognized as another way to promote climate-proofing investments. Since the transport infrastructure investment often requires large financial resources and private stakeholders have capabilities in financing the project as well as up-front services, public-private partnerships (PPP) are an important mechanism to realize climate adaptation. However, the government needs to ensure a smooth procurement process for infrastructure investment and the delivery of infrastructure assets and minimize the magnitude of various risks: political risks, business risks, and

technical risks, their probability of occurrence, and exposure of properties to those risks. The approach attracts high-quality private participation from both local and international players and offers monitoring and supervising procedure to ensure the operation results and planning for resolution. Private Investments in State Undertakings (PISU) Act B.E. 2562 (2019) was enacted in order to explicitly remark that Thailand is in need of infrastructure construction and allow PPPs to be conducted in Thailand. PISU has evolved over time to meet the needs of the stakeholders and reflect international standards. There are a number of existing PPP projects conducted by several agencies in Thailand. In transportation/logistics sector, tollways, mass transit trains, ports, depots, and cargos involved. To conduct such a project, key players and experts from several organizations must involve, including project agency, responsible ministers, State Enterprise Policy Office (SEPO) representatives, BB, Office of the National Economic and Social Development Council (NESDB), Attorney General, and other relevant agencies. The procedure of PPP involves project appraisal, approval of responsible key players, revisions of project proposal, project implementation, private entity selection, and committee selection.

To facilitate private investment in climate adaptation, there should be key stakeholders who foster investment and develop guideline in public-private and domestic-foreign interactions. The Bank of Thailand (BOT), which is recognized as an organization driving the financial sector in Thailand, promotes sustainable banking for climate-proofing investment and acts as a financial intermediary to key sectors including transportation. With the support and guidance of BOT, financial instability in a project can be prevented. As the Office of Board of Investment (BOI) has a role to promote investments both in Thailand and Thai overseas, the Office can facilitate Thai investors in climate-related PPP projects. In the perspective of foreign investment, BOI also provides useful information, services, and incentives to foreign investment, for example, sustainable investment program. Securities and Exchange Commission (SEC) is another organization that can trigger private investment on climate change countermeasures. It has been supporting Thai firms in issuing Green Bond, Social Bond, and Sustainability Bond. It proposed new regulations related to issuance of Sustainability-linked Bond (SLB) to further develop the capital market's role in contributing to solving social and environmental issues and promoting sustainable development of businesses in various sectors[64].

In order to ensure political viability of climate-proofing investment in the transportation sector, coordination among the aforementioned stakeholders is inevitable. Once the main responsible organization is identified, it should lead the coordination in order to ensure continuous financing for the project(s).

[64] Securities and Exchange Commission (2020) SEC public hearing on proposed regulations related to issuance and offer for sale of Sustainability-linked Bond. Available at: https://www.sec.or.th/EN/Pages/News_Detail.aspx?SECID=8610

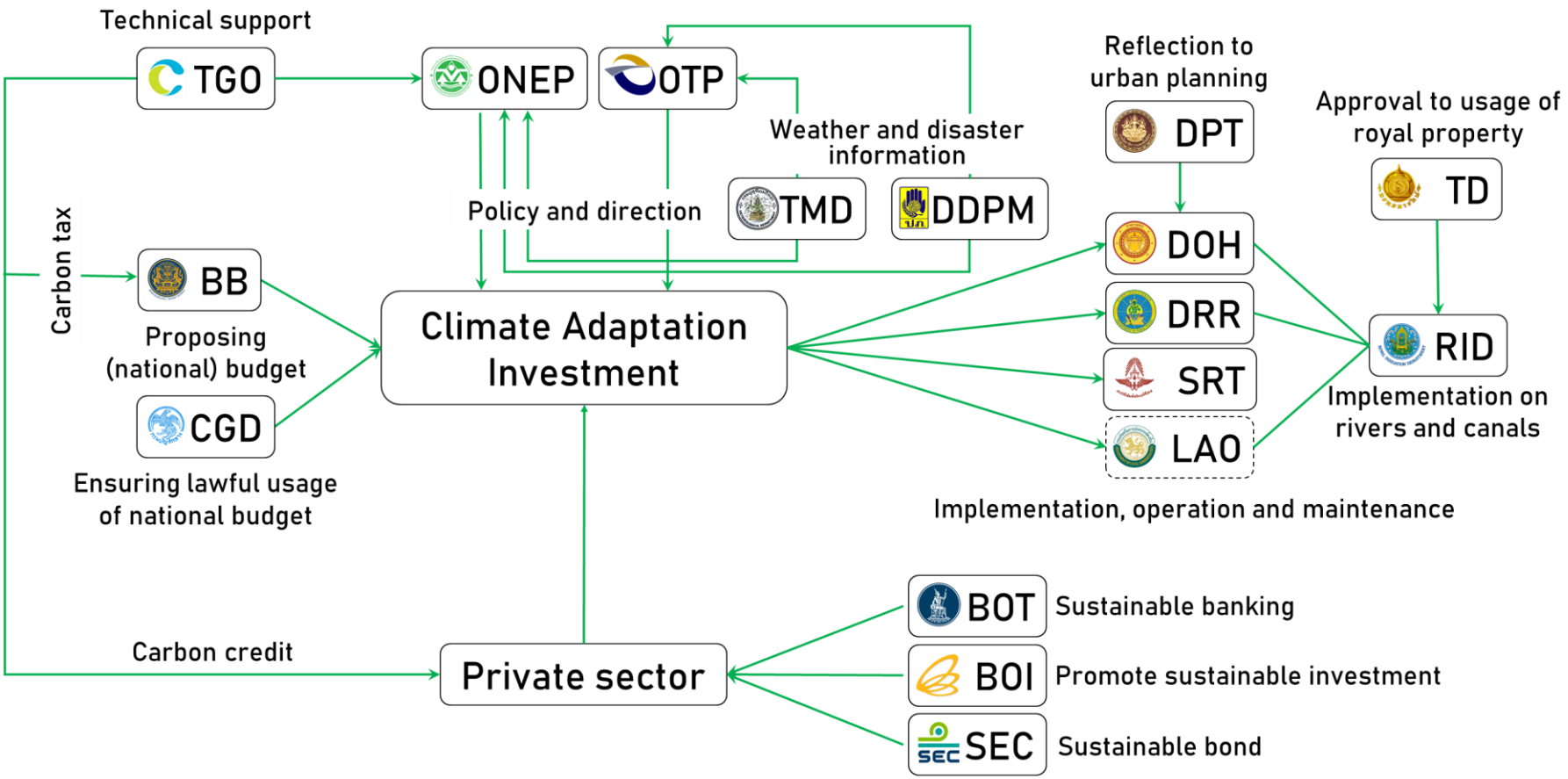

Figure 4 Involved stakeholders

4.2.2 Constraints

Political constraints in this study may involve construction right and ownership of targeted sites. Since the Ministry of Finance is the owner of State Property, according to Section 5 on Administration and Maintenance of the Ratchaphatsadu Land Act, B.E. 2518 (1975), any constructions related to State Property must be permitted and approved by Treasury Department. Requests must be summited through the department's procedures where decision regarding permission will be made based on necessity and appropriateness of the requests. If the state property is in use by another governmental unit, requesting unit must make an agreement with the other unit and enclose the consent letter in its submission. In this study, any construction in relation to areas under RID purview, DOH or DRR has to cooperate with RID in order to proceed for the construction. When infrastructure is completely constructed, requesting unit shall inform the Treasury Department and register the infrastructure with the department or authorized local government agencies.

Speaking of abovementioned constraints, political and regulatory risks involve and can rise in accordance with several factors, for example environmental review, contract and stakeholder negotiation, cancellation of construction permit, enforcement of contract, decommission of infrastructure and change in taxation. These issues have a wide range in the degree of possibility from low to high and are linked to all phases of infrastructure lifecycle, including development phase, construction phase, operation phase, and termination phase. Furthermore, during the construction phase, there may be necessity to cooperate with local administrative organizations in facilitating traffic, detouring, or route closure strategy in order to minimize disturbance to road users.

4.2.3 Social Perspectives

Theoretically, rivalry is referred to when individual's utilization of resources intrudes resource available to others[65]. In the transportation sector, roads are not classified as rival nor non-rival as does not comply to the definition above. However, in some circumstances, for example, when differences in the level of maintenance, road quality, or use of vehicles exist, rivalry becomes possible. Road rivalry can exhibit when users perceive high congestion and presence of additional vehicles. At a particular point where new-built infrastructures offer climate-proofing capabilities and prosperity to the community, they attract a higher volume of vehicle and public use. Rivalry causes include slower travel time, poor traffic flow during peak time, changes in road use patterns, displacing some road users. In this sense, the road may produce benefits to a large group of people and contribute to climate-proofing advantages, but in turn, it may negatively influence a small group of local road users where the new-built infrastructure is taking place.

Public acceptance and benefits cannot be neglected and are considered important risks for the implementation of climate-proofing countermeasures. According to social-psychological theory of public acceptance, benefits and

[65] Wales, J., & Wild, L. (2012). The political economy of roads: An overview and analysis of existing literature. *London: Overseas Development Institute*.

trust perceptions are crucial[66] when an infrastructure construction is taking place where local beneficiaries involved. The process of achieving public acceptance should start at planning and development phases to understand public attitudes and their views toward the project. Environment Impact Assessment (EIA) has been used as a panacea against public opposition. Thai Constitution B.E. 2550 (2007) additionally required that a health impact assessment should also be conducted as a part of EIA of mega projects. Environmental and Health Impact Assessment (EHIA) then becomes essential for the acquisition of the project approval by Ministry of Natural Resources and Environment. Yet, public opposition continues to slow the development of new infrastructure projects[67]. Construction will be more difficult when public opinion is diverse and consensual agreement cannot be made. To ensure that public opinions are carefully taken into consideration in decision making related to environmental and prejudicial issues, combination of activities, such as transparent public hearing, public participation mechanism, public forums[68], distribution and offers of employments opportunities during project construction, should be conducted and put in place. This can bridge the gap between political will and public expectations.

Political issues not only involve regulatory constraints and multi-stakeholder cooperation barriers, but also relationship between politicians and citizens. Development of a road network is likely to be socially suboptimal if patronage or clientelistic relations exist. This issue occurs in climate-proofing projects in different ways: benefits for a particular group of people, inappropriate resource allocation for personal gain, political actor influence on decision, and short termism[65], where short-term beneficial gains is given priority over long-term advantages and far-seeing profits. These approaches can affect social benefits, and equality in utilization of climate-proofing infrastructure cannot be met for all individuals.

Apart from all aspects mentioned above, there are risks of project agencies lacking technical expertise, or other external factors that can significantly delay the project. As for the former, there are possible options to prevent or alleviate the risks. For instance, the expected finish date and the quality of the construction can be guaranteed if the project is handed over to a private professional contractor with a good reputation and relevant experience. As for the latter, governmental procedures and regulations can become a barrier to the implementation of the project. One way to address this issue is to create a sandbox to test the operation of the project and use the reflection from the sandbox project to optimize the procedures and regulations.

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[66] Ge, Y., Cui, C., Zhang, C., Ke, Y., & Liu, Y. (2020). Testing a social-psychological model of public acceptance towards highway infrastructure projects: a case study from China. *Engineering, Construction and Architectural Management*.

[67] Cohen, J. J., Reichl, J., & Schmidthaler, M. (2014). Re-focussing research efforts on the public acceptance of energy infrastructure: A critical review. *Energy*, *76*, 4-9. https://doi.org/https://doi.org/10.1016/j.energy.2013.12.056

[68] Wang, Y., Shen, C., Zuo, J., & Rameezdeen, R. (2021). Same tune, different songs? Understanding public acceptance of mega construction projects: A comparative case study. *Habitat International*, *118*, 102461. https://doi.org/https://doi.org/10.1016/j.habitatint.2021.102461

4.3 Revisiting Technical and Political Viability

4.3.1 Countermeasures for Roads

DOH made valuable suggestions on many points related to countermeasures, such as the classification, the validity of countermeasures, and the unit prices. DOH suggested that the road width should be modified to take into account the actual situation since most roads running along a canal or a river will have a narrow shoulder. And the number of lanes of tier one and tier two roads should be changed to match the actual number. Based on the data provided by DOH, the number of lanes for tier one and tier two roads were both averaged and rounded to be four. The mechanically stabilized earthwall gathered the most attention since it has already been used in many places in Thailand regardless of its high price. Pumping water from one side to another and underground tunnel were deemed impractical and were proposed to be excluded. In addition, DOH also made an observation that box culverts are generally designed before the road construction, and water gates can be used as the better alternative to the box culvert. Finally, DOH noted that cape seal treatment is not suitable for national highways since such roads will not be able to withstand the loads from a large traffic volume, and suggested double-layered asphalt resurfacing instead.

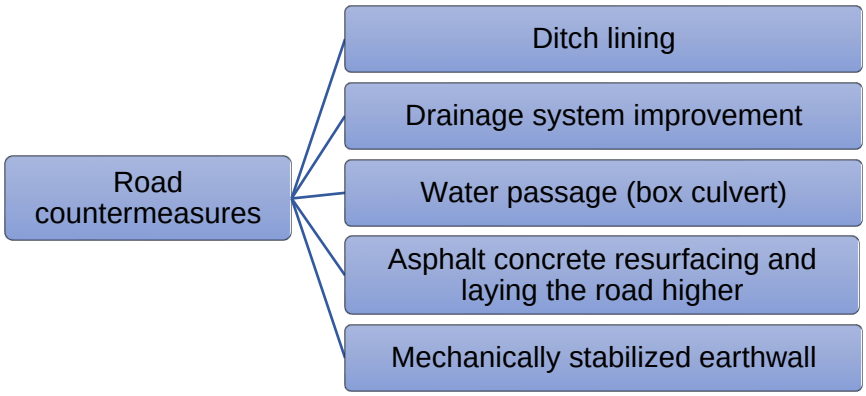

Figure 5 Selected road countermeasures

4.3.1.1 Asphalt concrete resurfacing

Cape seal treatment was initially proposed in one of the road countermeasures. As mentioned above, this countermeasure may not be suitable for roads under the purview of Department of Highways (DOH) especially roads in the first and second tiers. Asphalt concrete surface is commonly applied to roads that are required to support heavy road traffic. It is assumed to be the same as the double layer asphalt resurfacing considering the process: using the asphalt-concrete mixture as the foundation and then add an asphalt layer on top. The unit price of asphalt concrete resurfacing, 1,809 THB, is estimated based on the average of the five previous construction sites of DOH. Two sets of data were extracted

from the 2020 annual report of DOH[69] while the rest was obtained from the press release of DOH[70,71,72].

4.3.2 Countermeasures for Rails

SRT provided very useful feedback on the countermeasures for rails. Most selected countermeasures, including box culvert and bridge construction, are currently used in many construction sites in Thailand. Nonetheless, the underground tunnel was deemed not feasible due to its high initial investment cost. This countermeasure is often implemented in high-income countries. Furthermore, the term price per spot was suggested to be modified to price per location to avoid confusion. SRT also recommended to include ballast refill as a countermeasure for fast recovery after floods and add construction of steel bridges which are more common than concrete bridges. These two countermeasures will be explained in detail below.

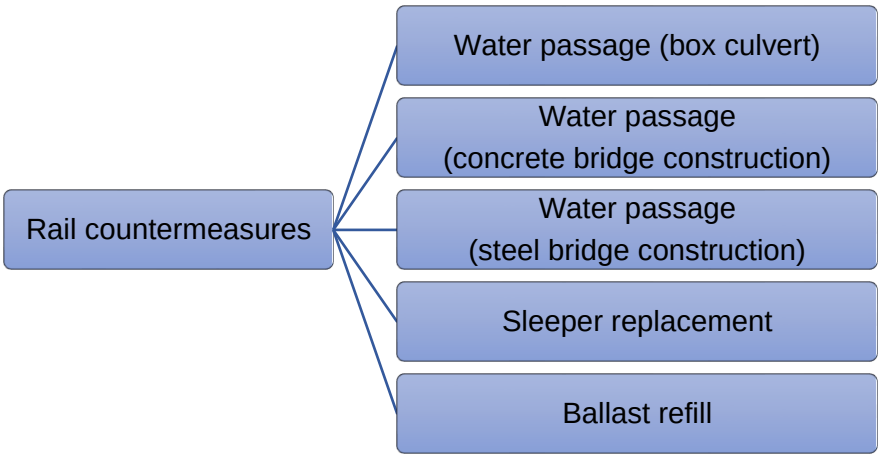

Figure 6 Selected rail countermeasures

4.3.2.1 Ballast Refill

Price for ballast refill varies according to the conditions of the construction site and the load it will support. For instance, if the rail is built for freight transportation, the number of ballasts over the distance will be increased. The detail of construction procedure and the cost required for each activity were originally discussed with the assumption that ballasts are totally washed out. The discussion meeting with the SRT brought in a new perspective about this countermeasure which will illustrate the actual scenario of this countermeasure. The officer from SRT noted that, recently, rail routes that run through flat terrain has higher possibility to experience floods (this will be discussed in detail in subsection 5.8.1). During this period,

[69] DOH (2020) Annual report of fiscal year 2020. Available at: http://www.doh.go.th/content/page/journals/140182#page/51
[70] DOH (2021) Expand traffic lanes - Highway No 332 and 3. Available at: http://www.doh.go.th/content/page/news/174608
[71] DOH (2021) The Royal Thai air force has expedited the expansion of route 226. Available at: http://www.doh.go.th/content/page/news/173933
[72] DOH (2021) Department of Highways expands Buriram-Surin route. Available at: http://www.doh.go.th/content/page/news/132866

the railway level must be raised up to ensure that the train can operate even if the water is still in place. Therefore, SRT should prepare annual budget for ballast refill which should then be included in the financial flow. However, since the identification of lowlands that has high possibility of being flooded is not straight forward, qualitative evaluation will not be conducted.

4.3.2.2 Water Passage (steel bridge construction)

Bridges commonly used in the railway are made of steel or concrete. However, steel bridge is generally adopted by SRT in most locations that the rail runs perpendicular to the river, canal, or water passage. The concrete bridge will only be considered if the organization aims to finish the project in a short period of time. Moreover, a steel bridge has a longer lifespan when comparing with a concrete bridge.

In this subsection, only the unit of the steel bridge will be estimated since the unit price of concrete bridge construction have already been discussed earlier. According to the two projects listed down in the SRT procurement website, the average unit price is approximately 1.3 million THB per meter. However, the details of each project were quite difference. The first project started from kilometer number 852/16 until 853/1 with the total distance of 91.5 meters and the cost of around 184,755,500 THB[73]. The construction of reinforced concrete piers, assembly, and installation of the steel bridge itself were covered. Apart from these activities, digging and facilitating the drainage canal and construction of bypass route for the train to continue the operation during the construction were also included. The total distance of the second project was 210 meters and the cost of 122,212,000 THB[74]. The project only aimed to modify the supporting piers and remove the deteriorated steel out and then replace with the new one.

During the consultation meeting, the representative from SRT stated that the length of a steel bridge is approximately 50 meters to 100 meters. The average figure, 75 meters, will be used to calculate the total price of the countermeasure which turns out to be 97.5 million THB.

[73] Procurement SRT (2014) Construction contract price calculation and the middle price disclosure of the budget amount allocation in the construction work. Available at: https://procurement.railway.co.th/auction/system/download/2557/N201412313179.pdf

[74] Procurement SRT (2014) Construction contract price calculation and the middle price disclosure of the budget amount allocation in the construction work. Available at: https://procurement.railway.co.th/auction/system/download/2014/N201411302267.pdf

5 Calculation Procedure

5.1 Overview of the Procedure

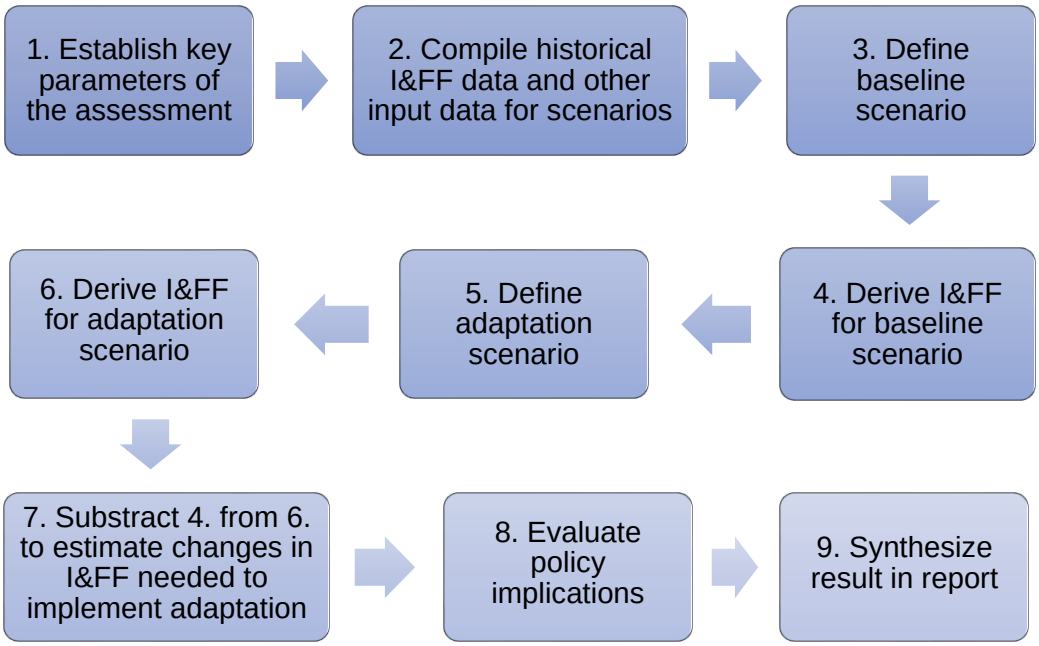

Figure 7 Steps in I&FF assessment to address climate change[75]

UNDP's I&FF assessment methodology guidebook[75] suggests nine steps for the assessment for both mitigation and adaptation scenarios. The workflows of these two scenarios are similar. Figure 7 shows the assessment steps for climate adaptation investment adopted from the guidebook. Though the assessment performed in this study followed the flow shown in the figure, the structure of this report was designed to ease the comprehension of the involved stakeholders by providing the big picture first, and then dig deep in to details afterward. Therefore, coordinating each chapter to each item in Figure 7 will facilitate the understanding of the reader who is already familiar with the existing structure. Items 1, 3, and 5 in Figure 7 which are related to the scope of the assessment and the scenario development were explained in chapter 3 of this report. The baseline scenario was determined by the investment cost from government effort to address climate change. Though corporation and household sectors are crucial in the country's development, it is difficult to access publicly reliable resources. Item 2 which associates with assumptions and input data was placed in chapter 4. Item 6 which is about deriving I&FF for adaptation scenario is slightly modified since it does not seem reasonable to have a single adaptation scenario as mentioned in chapter 3. Timeframes were set according to the two milestones in 2030 and 2050 in the NDC. Item 6 will discuss about the combinations of possible countermeasures and targeted roads and railways classified into tiers. I&FF for the adaptation scenario will be accomplished by following the workflow in Figure 8. Note that the plausible total

[75] UNDP (2019) Methodology Guidebook for the Assessment of Investment and Financial Flows to Address Climate Change

climate adaptation investment that will be used for the derivation of I&FF will be obtained through consultation with key stakeholders (See appendices 1 - 5 for reference). As for item 7, incremental annual climate adaptation investment (section 6.4) will be derived by subtracting I&FF and O&M of baseline scenarios (section 6.1) from those of adaptation scenarios (section 6.3). This will be shown in chapter 6. Lastly, items 8 and 9 are located in chapter 7 of this report.

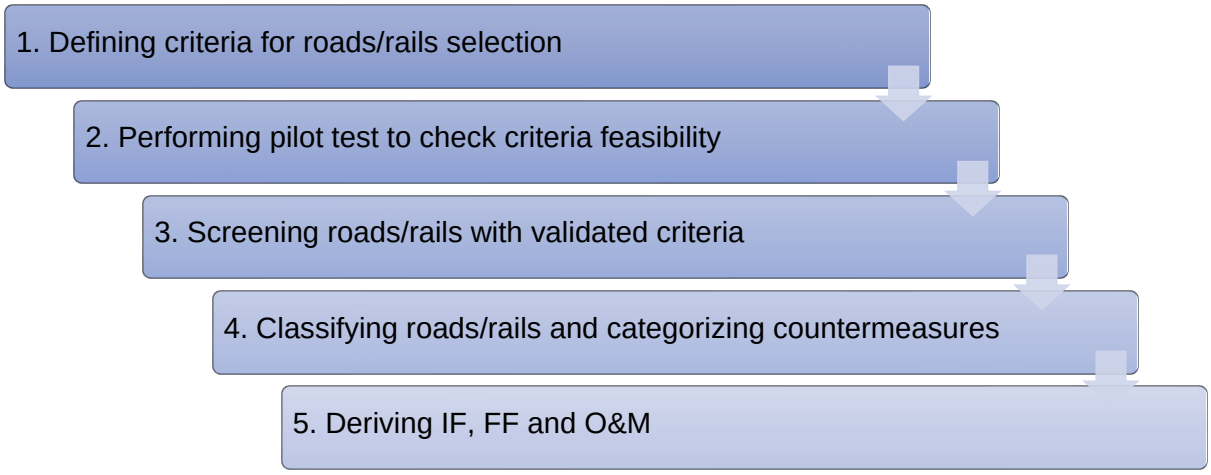

Figure 8 Workflow for estimation of climate adaptation investment and the resulting investment and financial flow

5.2 Defining Criteria for Target Selection

5.2.1 Target Selection Criteria for Roads

Thailand consists of many regions that are likely to have different geographical conditions. Mountain ranges can be found in the northern part of the country while the central area has a complicated water distribution network spreading the water from Chao Phraya River. As the terrain significantly varies a lot from one region to another, the road construction needs to take into account this aspect. This makes the selection process of the target roads for climate adaptation investment rather complicated. It is essential to set criteria to scope down and select roads that are vulnerable to floods and require enhancement of climate adaptability. The criteria should also be set in a manner that the assessment can be done within the expected timeframe. The first criterion is that the road must be under the purview of Department of Highway (DOH) or Department of Rural Roads (DRR). With these criteria, the main stakeholders that will be responsible for the implementation of the countermeasures will be reduced to two organizations which seems to be appropriate for a pilot I&FF assessment. Second, the road must be located near a canal or a river which will make it more vulnerable to floods. These criteria will be applied for the selection of target roads for this study. The simplified diagram of the selection criteria for roads is illustrated in Figure 9.

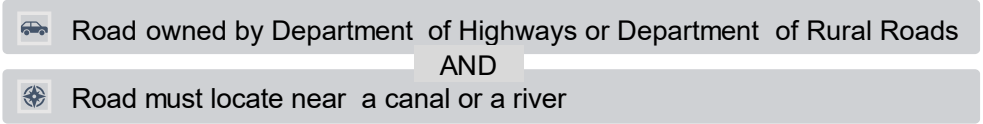

Figure 9 Target selection criteria for roads

5.2.2 Target Selection Criteria for Rails

The major five rail routes under the responsibility of State Railway of Thailand (SRT) are located at many different geographical locations. The criteria are required to identify the locations that can possibly undergo floods. Like the case of roads, criteria should be set to select rails that are vulnerable to floods. The two criteria include, being adjacent to a mountain or running perpendicular to a river or a waterway. The simplified diagram of the selection criteria for rail is illustrated in Figure 10.

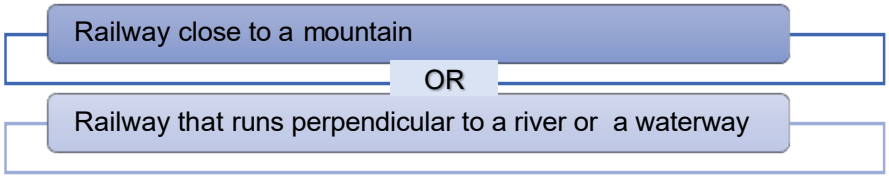

Figure 10 Target selection criteria for rails

5.3 Pilot Test

There are quite a number of roads and rails in Thailand. There are over 6,000 routes in total for highways and rural roads, and the railway consists of five lengthy lines. It is therefore necessary to perform a pilot test to check whether the abovementioned criteria for roads and rails can functionally select the target roads and rails.

Highway route 4 and all associated highways (i.e., all highways that start with 4), rural roads in Pathum Thani zones which contain 157 routes, and the northern railway line were selected for pilot test. During the pilot test, the procedure of each mode of transportation was optimized and the process was accelerated. In addition to that, the procedures are also customized for national highways, rural roads, and railways based on the challenges faced during the pilot test. The overview of the pilot test is illustrated in Figure 11.

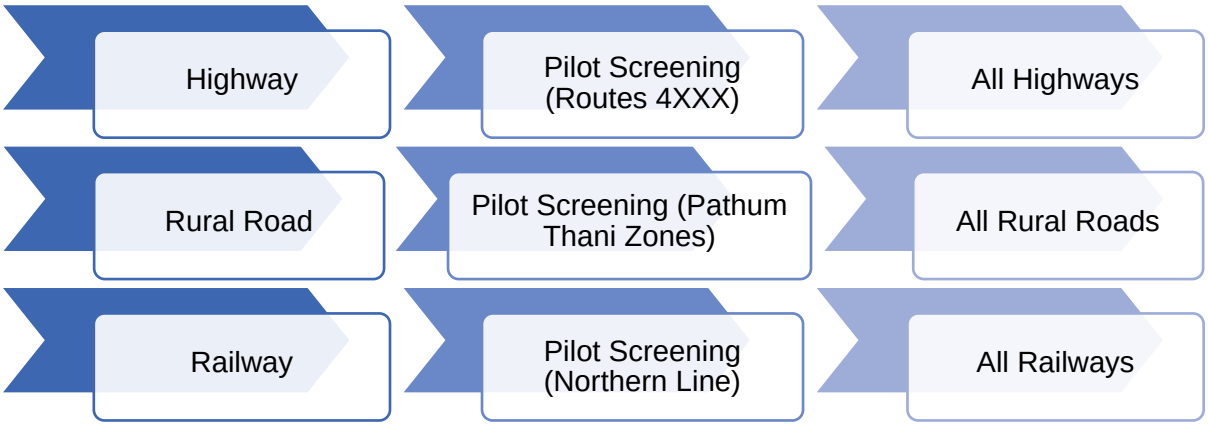

Figure 11 Highway, rural road, and railway pilot tests

5.4 Road and Rail Screening

5.4.1 Screening Procedure

5.4.1.1 Screening procedure for national highways

The procedure for national highway screening is shown in Figure 12. It starts from copying the highway route number and its description from Wikipedia[76] and pasting onto a Microsoft Excel sheet. Also paste the highway route number onto the Roadnet[77] website. Starting and ending coordinates of the highway are then extracted from the Roadnet website. Next, manually specify the route between the two coordinates in Google Maps. Once the route is specified, manually check whether the route entirely or partially fulfills the abovementioned criteria. Finally, copy both starting and ending coordinates, total distance, and the Google Maps link, and paste them onto the Microsoft Excel sheet along with the information on the fulfillment of the criteria. Follow this procedure for all highway routes.

5.4.1.2 Screening procedure for rural roads

The screening procedure for rural roads can be found in Figure 13. The procedure for rural road screening is quite different from national highways since the rural road list grouped into zones with the details of each route is provided in the DRR annual report. At the beginning of the procedure, copy starting and ending coordinates from the DRR Report[78] paste onto Google Maps and match the total distance of the suggested route in Google Maps and the report. Then, manually specify the route if the route suggested by Google Maps does not match with the actual route. If the road cannot be found in Google Maps, use Longdo Traffic[79] to double-check the information. Once the route is specified, the following steps are the same as national highways.

5.4.1.3 Screening procedure for rails

The procedure for national highway screening is shown in Figure 14. The procedure for the railway is rather simple compared to highways and rural roads. It starts from finding the railway that runs near a hill/mountain or perpendicular to a river/canal using Google Maps. Then, locate the starting and ending coordinates, and specify the transit option in Google Maps. Finally, copy the Google Maps link, district, province, and region then paste them into the Excel sheet. Follow this procedure for all railway lines.

[76] Wikipedia Thai highway network (2021). Available at: https://en.wikipedia.org/wiki/Thai_highway_network
[77] Department of Highways (2021) Roadnet central road database. Available at: https://roadnet2.doh.go.th/
[78] Department of Rural Roads (2022) Rural road network accounts for fiscal year. Available at: https://maintenance.drr.go.th/?page_id=5911
[79] Thai Intelligent Traffic Information Center (2021) Longdo traffic. Available at: https://traffic.longdo.com/

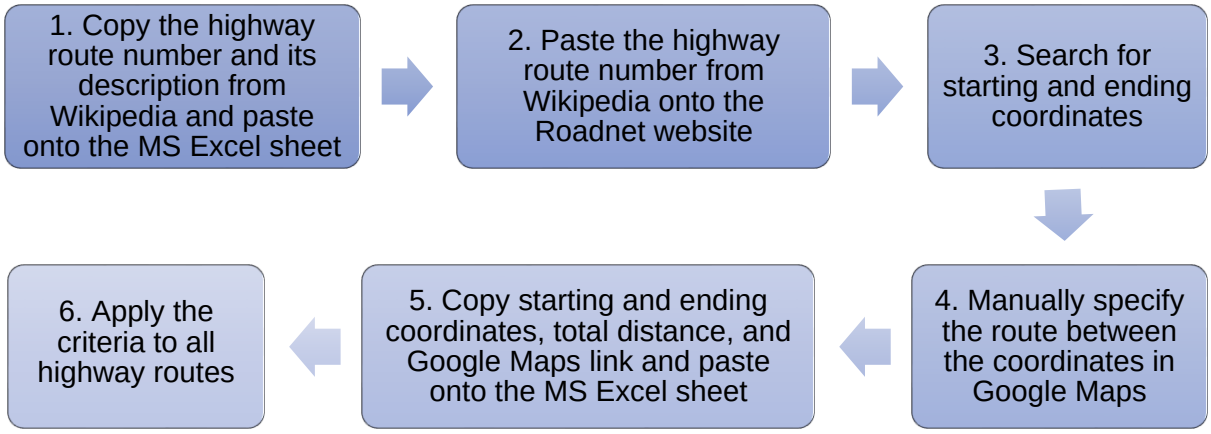

Figure 12 Screening procedure for national highways

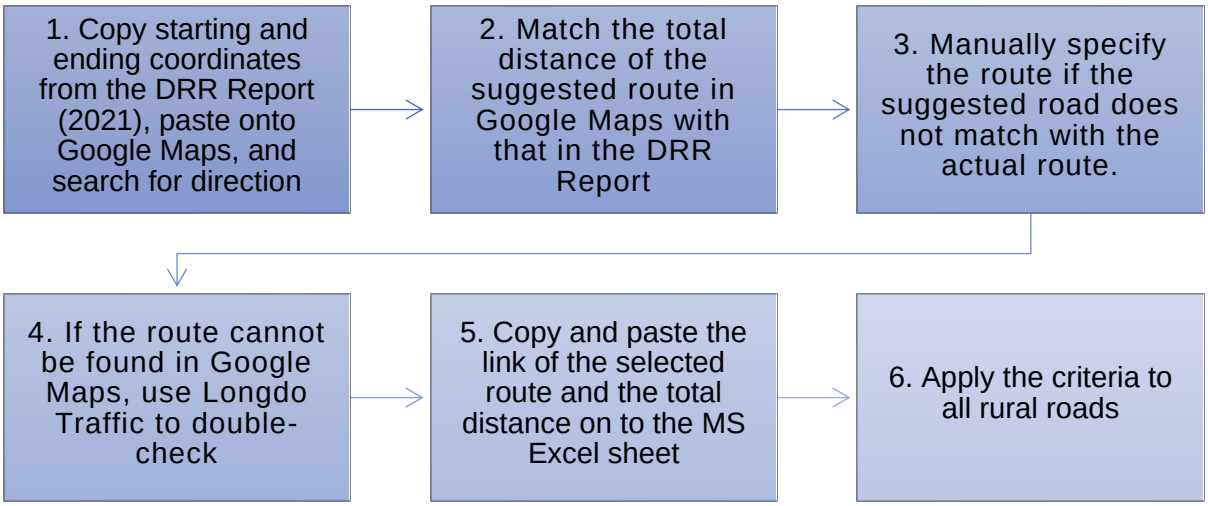

Figure 13 Screening procedure for rural roads

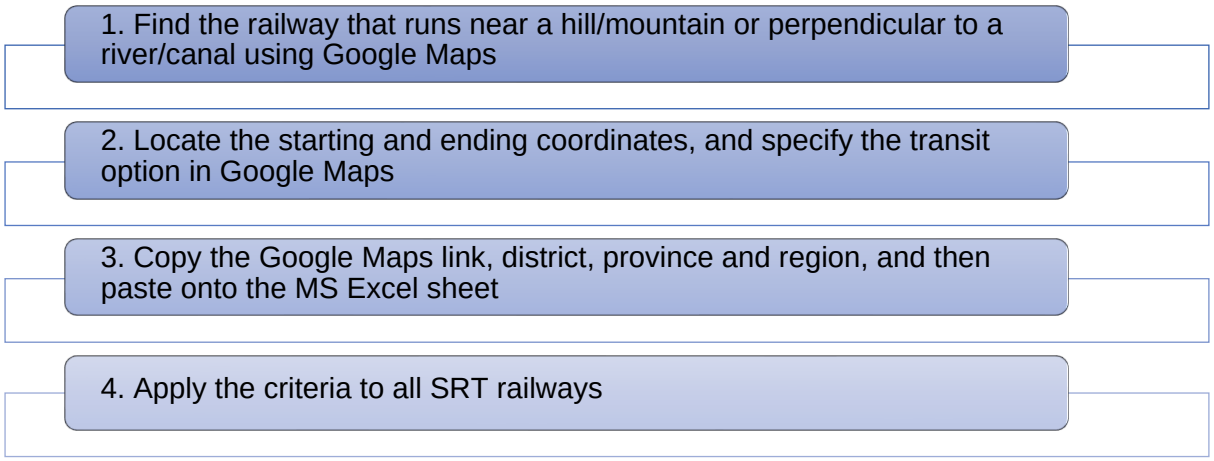

Figure 14 Screening procedure for rails

5.5 Classification of Target Roads and Rails

5.5.1 Classification of Target Roads

Highways and rural roads are the two important road types in the road network of Thailand. Highways are inter-city roads and rural roads are intra-city roads. The Department of Highway (DOH) and Department of Rural Roads (DRR) under the Ministry of Transportation of Thailand are the two authorities that look after highways and rural roads, respectively. This report focuses only on national highways. Express ways, motorways, or concession highways are not included in the scope of the study even if they are under the purview of DOH. National highways start with one-digit highways which are the four major roads running to four regions of Thailand. Routes 1, 2, 3, and 4, head to the north, northeast, east, and south of Thailand. Overall, the route network connects Bangkok to outlying regions. Two-digit highways are those branched from one-digit highways which indicate a principal highway within a region, for example Route 22 connecting Udon Thani and Nakhon Phanom. The three-digit highways are divided from two-digit highways and was mainly used in the regional secondary highway. Last, the four-digit highways are separated from three-digit highways which was used to travel intra-province highway connecting a provincial capital to its districts, or between important sites.

Numbering of the roads managed by DRR generally starts with two Thai letters that are the abbreviation of the name of the province where road is located and followed by three- or four-digit numbers. The number after the abbreviation describe the connection conditions of each road. For instance, the rural roads that start with 1, 2, 3, or 4 connect to single-digit, two-digit, three-digit, and four-digit national highways, respectively. If the road number starts with 5 the rural road connects to another rural road. If it starts with 6, the rural road starts from a place such as school, temple, sub-district office or district office. Finally, if only 3-digit number appears after the abbreviation, it represents a bridge or a connecting road.

Target roads are divided into three tiers according to the road usage and the traffic capacity. The first tier will include both one- and two-digit national highways, the three-digit national highways is in the second tier, and the four-digit highway and all rural roads are classified into third tier. The road tiers in this study can be found in Figure 15.

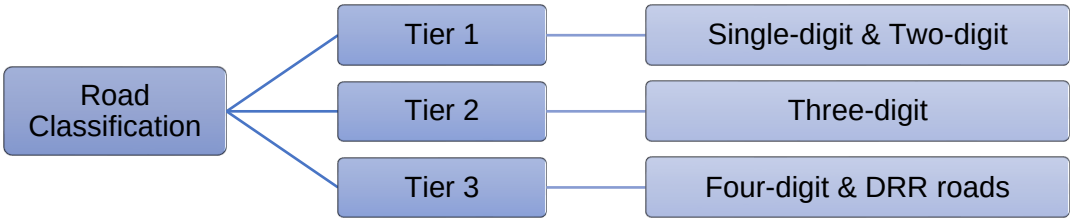

Figure 15 Target road classification

5.5.2 Classification of Target Rails

There are five railway lines under SRT, namely Southern, Northern, Eastern, Northeastern, and Maeklong line[80]. The Southern Line connects Hua Lamphong Station in Bangkok to Sungai Kolok Station in Narathiwat Province which is the longest railway line in Thailand. The Northern Line runs from Bangkok to Chiang Mai with a total distance of 751 km[80]. The Eastern Line has three branches. The first branch connects between Ban Phlu Ta Luang (Pattaya) to Bangkok while the second branch links Bangkok to the Aranyaprathet close to the border of Cambodia. The third branch which is solely used for freight transportation runs from Map Ta Phut station near the seaport back to Bangkok. There are multiple main lines in the northeastern region. The initial line starts from Bangkok station and ends at Ubon Ratchathani province. This line has a total distance of 575 km[80] and runs across many provinces, such as Ayutthaya, Saraburi, Nakhon Ratchasima, Buriram, Surin, and Sisaket. Another line runs up to Nong Khai and has a total distance of 624 km. Lastly, Maeklong railway consists of two separate lines. The first line departs from Wong Wian Yai Station to Mahachai in Samut Songkhram Province with a total distance of 33 km. The second line starts from Ban Laem Station, Samut Sakhon Province and runs until Mae Klong Station, Samut Songkhram Province. The total distance of this line is 31 km. All railway lines begin in Bangkok and goes to five distinctive regions. Therefore, the railway cannot be classified in the same way as the highways or rural roads. The railways are categorized only according to the passenger volume and the distance that the trains carry those passengers. This is such an important parameter since it will not capture the number of people who use the train service but also the total distance how far the passenger will go starting from the departure station. However, the categorization will be enhanced if the data of the freight is available.

According to the statistical data of SRT in the year 2017, the ability of each line to mobilize passengers in terms of passenger-kilometer of the Southern, Northern, Eastern, Northeastern, and Maeklong lines were 2.9 billion, 1.3 billion, 283 million, 1.9 billion, and 78 million, respectively. Rail routes are divided into two tiers according to these numbers. In the first tier, the total passenger number is more than one billion passenger-kilometer. The rest belongs to the second tier. Figure 16 provides the layout for easy understanding the rail classification.

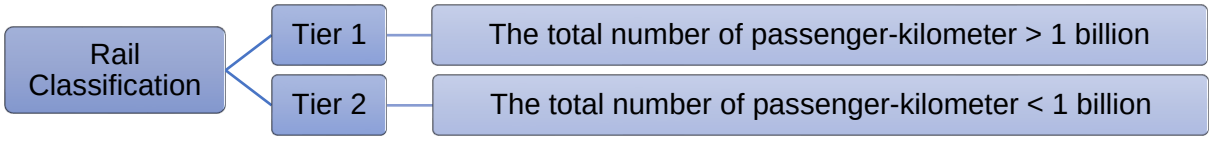

Figure 16 Target rail classification

[80] State Railway of Thailand (n.d.) Train route map. [Accessed Jan 19, 2022] Available at: https://www.railway.co.th/More/Knowledge_Detail_แผนที่เส้นทางรถไฟ

5.6 Categorization of Road and Rail Countermeasures

It seems appropriate to categorize the countermeasures proposed in chapter 4 in order to make it easier to find a suitable solution for target roads and rails with different geographical conditions. Categorization can be based on various factors, for instance, technical procedure, the longevity of the technique, and the function of the countermeasures. The factor that would likely be the best option for the categorization of roads and rails is the function or the usage of the countermeasures against climate adaptation, since this will assist the selection of countermeasures that deserve investment during the consultation with key stakeholders. Countermeasures are categorized into three groups, namely flow management, flood avoidance, and structure reinforcement.

Road and rail countermeasures are grouped together according to their functions. A matrix can be developed by matching the categorized countermeasures with the classified roads and rails. The schematic representation of the matrix is shown in Figure 17. The tier ranges from the most important to the least important while the countermeasures are grouped together if they serve the same purpose. During the estimation of the investment associated with roads and rails countermeasures, the total investment corresponding to each cell can be inputted to complete the matrix. This matrix will be an essential tool to analyze the appropriate scope of target roads and rails, suitable countermeasures. It will facilitate derivation of recommendations for climate adaptation investment in the transportation sector corresponding to the size of the budget and the significance of the roads and rails.

Tier	Category A			Category B			Category C		
	Countermeasure A-1	Countermeasure A-2	Countermeasure A-3	Countermeasure B-1	Countermeasure B-2	Countermeasure B-3	Countermeasure C-1	Countermeasure C-2	Countermeasure C-3
1									
2									
3									

Figure 17 Schematic representation of a matrix of classified roads/rails and categorized countermeasures

5.6.1 Categorization of Road Countermeasures

As mentioned in the previous section, the countermeasures will be categorized according to their function. There are three functions, including flood management, flood avoidance and structure reinforcement. Figure 18 demonstrates the categories of road countermeasures and the countermeasures under each category. Mechanical stabilized earthwall is the only element under structure reinforcement while flood management and flood avoidance consist of three items.

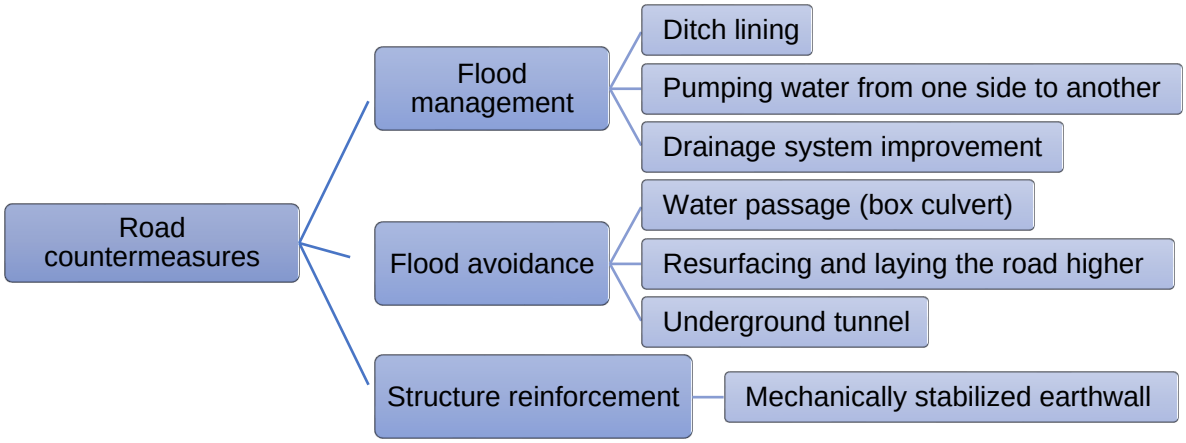

Figure 18 Categorization of road countermeasures

5.6.2 Categorization of Rail Countermeasures

Categories of the rail countermeasures are identical to those of roads: flood management, flood avoidance and structure reinforcement. Water passage (box culvert) and water passage (bridge construction) belong to flood management. The two countermeasures are interchangeable. Water passage (bridge construction) should be applied to the railway that operates near a mountain while water passage (box culvert) is suitable for rails running perpendicular to a waterway. Underground tunnel and sleeper replacement are countermeasures for flood avoidance and structure reinforcement, respectively.

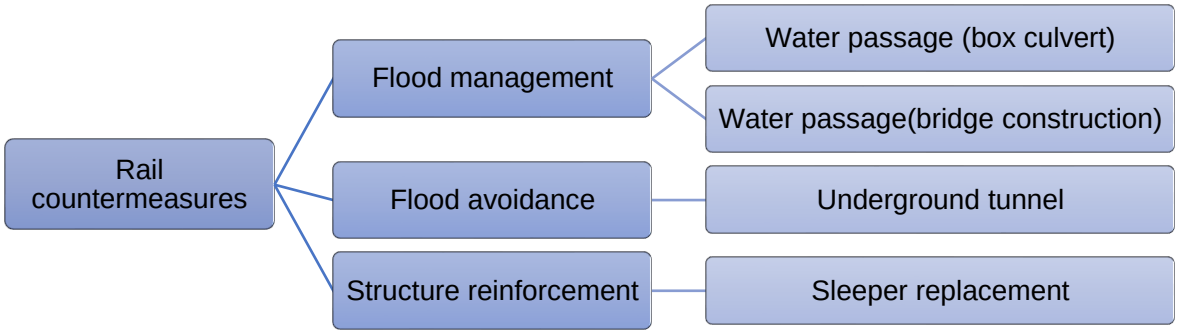

Figure 19 Categorization of rail countermeasures

5.7 IF FF O&M Subsidy

Countermeasures for roads and rails in the current analysis are basically based on construction. Therefore, financial flow and subsidy will not be taken into consideration. The crucial element is the investment for construction in a suitable location. The total investment on all selected countermeasures to any tiers of target roads and rails is too enormous to be paid just in a fiscal year, and in reality, it is not practical to do so. It is commonly divided into several years make it feasible to request national budget for the implementation or to make it sufficiently attractive to private investors. In this case, annual expense accounts for annual total investment pluses the cost of operation and maintenance of the infrastructure.

In sections 5.2 - 5.6, the adaptation scenario was first introduced followed by a detailed step-by-step procedure to derive the total investment for climate adaptation in transportation sector. The final outputs from section 5.6 are the matrices of total investments on each category of climate-proofing countermeasures being implemented on each tier of target roads and rails. However, among all countermeasures, only a few of them will be selected based on the discussion with key stakeholders including DOH, DRR, and SRT.

The total investment is a function of the total distance of target roads or rails in each tier and the unit price of the countermeasures determined in chapter 4.

$$TC_{In} = TD \times UPC$$

where TC_{In} [million THB] is the total investment, TD [m] is the total distance of rails or roads in each tier, and UPC [million THB] is the unit price of the selected countermeasure.

However, this equation is impractical when the countermeasure is applied to several spots that cannot be turned into distance. Water passage (box culvert) and water passage (bridge construction) under flood management for rails will exclusively use the following equation.

$$TC_{In} = TNS \times TNCS_{Req} \times UPC$$

where TNS is the total number of locations that exist in the target rails in each tier and $TNCS_{Req}$ is the total spots in respective locations that require the countermeasure. The $TNCS_{Req}$ of the water passage (box culvert), and water passage (bridge construction) are assumed to be five and four, respectively.

The estimated annual expense is obtained based on several assumptions. The operational and maintenance (O&M) cost, as the name suggested, occurs during the operation, and normally shares some percentages of the project's total investment. The O&M cost commonly covers the cost of the rental, repair, and insurance[81]. Second, the annual inflation rate is adapted from the average of the country's GDP growth rate from the fiscal year 2001 to 2021. These assumptions are used for both roads and rails. The simplified form of the equation to estimate annual investment and O&M cost are:

$$AC_{In} = \frac{TC_{In}}{(Y_n - Y_0)}(1 + \overline{GR})^{(Y_x - Y_0)}$$

[81] Investopedia (2022) Operating expense vs. capital expense: what's the difference? Available at: https://www.investopedia.com/ask/answers/042415/what-difference-between-operating-expense-and-capital-expense.asp

$$AC_{O\&M} = \frac{TC_{O\&M}}{(Y_n - Y_0)}(1 + \overline{GR})^{(Y_x - Y_0)}$$

where AC_{In} [million THB] is the annual investment, $AC_{O\&M}$ [million THB] is the annual operation and maintenance cost, Y_n is the last year of investment, Y_x is the year of investment, Y_0 is the reference year, $\overline{GR}$ is the average annual inflation rate, and $TC_{O\&M}$ [million THB] is the total cost of operation and maintenance. It is normally estimated in terms of percentage of total investment. The percentage differs from one project to another. This parameter can be estimated by

$$TC_{O\&M} = N_P \times TC_{In}$$

where N_P is the percentage of the total investment.

5.8 Revisiting Classification of Target Roads and Rails

5.8.1 Classification of Target Roads

According to the stakeholder meetings, DRR representatives recommended using passenger car unit (PCU)[82], which is widely used in Asian countries[83], to classify roads. It represents number of vehicles in terms of passenger car, which could indirectly represent both traffic volume and road width. It is not only used by DRR, but also DOH. This study employed road classification by determining tiers with highway route numbers where tier 1 is single-digit highways, tier 2 is two- and three-digit highways, and tier 3 is four-digit highways and all rural roads as mentioned above. Each tier represents different level of traffic volume and width of road. Comparing the road classification employed in this study with the PCU approach, the two methods shared similarities as they represent traffic volume and road width which are both associated to traffic flow rate. However, it is important to note that some lower-tier roads may have a higher volume than major roads due to passenger behaviors and current conditions of road usage. Considering the similarities among the two methods, the study will continue to use current approach for road classification. However, it is noted that PCU approach which can reflect the road usage more accurately may need to be adopted if a detailed study is going to be conducted in the future.

5.8.2 Classification of Target Rails

As proposed in this study, two criteria: railway that is close to a mountain or running perpendicular to a river or a waterway were used to locate the target railways. According to the consultation meeting with SRT, an officer suggested another criterion to include rails in lowland area as another target group. Based on the officer's experience, lowland areas have rarely confronted with flash floods. Nonetheless, lowlands are now increasingly facing floods, essentially in Sawi, Chumphon and Bamnet Narong, Chaiyaphum. In 2021, several areas in Chumphon were flooded due to 300 millimeters of rainfall, blocking several routes to the South of Thailand. Long detour was advised for all vehicles adding

[82] JICA (2017) Ex-post evaluation of Japanese ODA load project – Chao Phraya River crossing bridge at Nonthaburi 1 road. Available at: https://www2.jica.go.jp/en/evaluation/pdf/2017_TXXXII-2_4_f.pdf

[83] UNESCAP (2001) Asian highway classification and design standards. Available at: https://www.unescap.org/sites/default/files/pub_2173_ah_annexes.pdf

approximately 200 kilometers to the journey to the south[84]. Additionally, railway tracks were damaged and blocked by high water level for a full day. Inundated tracks required repair and maintenance[85]. In the same year, Chaiyaphum was hit by the worst flooding in 50 years. Out of 16 districts, flooding particularly impacted Bamnet Narong, causing over 3,000 houses being sunk in the water[86]. Eight round-trip rail services were suspended and resumed after the water was drained and the rail was repaired[87]. These events proved that lowland is becoming a risky area in which floods can occur, and importantly, it was left out from the criteria. The SRT representative advised to implement temporary countermeasures: ballast refill and sleeper replacement to bear with the impact, allowing services to continue. However, due to the variety in geographical conditions in Thailand and the uncertainty of natural events, it seems difficult to identify the exact conditions for this criterion. Further studies should be conducted to understand the conditions and to be able to include an additional criterion for lowland in the future.

[84] Neill Fronde (2021) Chumphon flood makes main North-South highway impassable. Available at: https://thethaiger.com/news/south/chumphon-flood-makes-main-north-south-highway-impassable
[85] Bangkok Post (2021) Road to South reopens, train services resume after flooding. Available at: https://www.bangkokpost.com/thailand/general/2215215/road-to-south-reopens-train-services-resume-after-flooding
[86] Prasit Tangprasert (2021) Most of Chaiyaphum flood disaster zone. Available at: https://www.bangkokpost.com/thailand/general/2188363/most-of-chaiyaphum-flood-disaster-zone
[87] Bangkok Post (2021) Flooding halts trains to Nong Khai. Available at: https://www.bangkokpost.com/thailand/general/2189675/flooding-halts-trains-to-nong-khai

6 Investment and Financial Flow Results

6.1 Investment and Financial Flows in Baseline Scenario

The baseline scenario includes general and planned emergency investments by government on roads through Department of Highways (DOH) and Department of Rural Roads (DRR), and on rails through State Railway of Thailand (SRT). It also includes funding under the public private partnership (PPP) scheme, and foreign loans and aids. For the development of investment and financial flows, two different timeframes are adopted based on the milestones in the NDC, namely 2022 – 2030 (progressive adaptation case) and 2022 – 2050 (moderate adaptation case). Historical data were gathered and averaged to annual investment, and the average GDP growth of the year 2001-2020 (1.59%) is used to take into account the inflation.

The cumulative discounted IF, FF, and O&M estimates by investment type, investment entity, and funding source of the baseline scenarios are shown in Table 5 and Table 6. Table 5 shows the progressive adaptation case while Table 6 shows the moderate adaptation case. Annual IF, FF, and O&M estimates by investment type are shown in Table 7 and Table 8. The cumulative and annual estimates are also illustrated using bar graphs and line stacks in Figure 20 to Figure 23 in order to visualize the size of investment.

Table 5 Baseline scenario: cumulative discounted IF, FF, and O&M estimates by investment type, investment entity, and funding source (progressive adaptation case)

Category of Investment Entity	**Source of I&FF Funds [million THB]**		**General Budget [million THB]**			**Emergency Budget [million THB]**		
			IF	**FF**	**O&M**	**IF**	**FF**	**O&M**
Government	Domestic	Domestic funds DOH	985,936	18,028	53,923	0	2,163	0
		Domestic funds DRR	442,023	0	55,240	0	975	0
		Domestic funds SRT	41,312	75,701	186,439	0	0	0
	Total Domestic Sources	**1,861,739**						
	Foreign	Foreign borrowing (loans)	48,462	0	0	0	0	0
		Bilateral foreign aid (bilateral ODA)	266,736	0	0	0	0	0
		Multilateral foreign aid (multilateral ODA)	4,009	0	0	0	0	0
		Private donor	4	0	0	0	0	0
	Total Foreign Sources	**319,211**						
	Total Government Funds	**2,180,950**						
Corporations	Domestic	PPP (public–private partnership)	254,210	0	0	0	0	0
	Total Corporation Funds	**254,210**						
Total			**2,042,692**	**93,729**	**295,602**	**0**	**3,138**	**0**

Table 6 Baseline scenario: cumulative discounted IF, FF, and O&M estimates by investment type, investment entity, and funding source (moderate adaptation case)

Category of Investment Entity	Source of I&FF Funds [million THB]		General Budget [million THB]			Emergency Budget [million THB]		
			IF	FF	O&M	IF	FF	O&M
Government	Domestic	Domestic funds DOH	3,749,122	62,173	185,966	0	7,661	0
		Domestic funds DRR	1,680,837	0	210,056	0	3,706	0
		Domestic funds SRT	157,094	287,863	642,985	0	0	0
	Total Domestic Sources	**6,987,462**						
	Foreign	Foreign borrowing (loans)	184,282	0	0	0	0	0
		Bilateral foreign aid (bilateral ODA)	1,014,291	0	0	0	0	0
		Multilateral foreign aid (multilateral ODA)	15,246	0	0	0	0	0
		Private donor	14	0	0	0	0	0
	Total Foreign Sources	**1,213,832**						
	Total Government Funds	**8,201,294**						
Corporations	Domestic	PPP (public–private partnership)	966,661	0	0	0	0	0
	Total Corporation Funds	**966,661**						
Total			**7,767,545**	**350,035**	**1,039,007**	**0**	**11,367**	**0**

Table 7 Baseline scenario: annual IF, FF, and O&M estimates by investment type (progressive adaptation case)

Year	General Budget [million THB]			Emergency Budget [million THB]		
	IF	FF	O&M	IF	FF	O&M
2022	212,910	9,595	28,479	0	306	0
2023	216,295	9,747	28,932	0	311	0
2024	219,735	9,902	29,392	0	316	0
2025	223,228	10,060	29,860	0	321	0
2026	226,778	10,219	30,334	0	326	0
2027	230,383	10,382	30,817	0	331	0
2028	234,046	10,547	31,307	0	336	0
2029	237,768	10,715	31,804	0	342	0
2030	241,548	10,885	32,310	0	347	0

Table 8 Baseline scenario: annual IF, FF, and O&M estimates by investment type (moderate adaptation case)

Year	General Budget [million THB]			Emergency Budget [million THB]		
	IF	FF	O&M	IF	FF	O&M
2022	212,910	9,595	28,479	0	306	0
2023	216,295	9,747	28,932	0	311	0
2024	219,735	9,902	29,392	0	316	0
2025	223,228	10,060	29,860	0	321	0
2026	226,778	10,219	30,334	0	326	0
2027	230,383	10,382	30,817	0	331	0
2028	234,046	10,547	31,307	0	336	0
2029	237,768	10,715	31,804	0	342	0
2030	241,548	10,885	32,310	0	347	0
2031	245,389	11,058	32,824	0	353	0
2032	249,291	11,234	33,346	0	358	0
2033	253,254	11,413	33,876	0	364	0
2034	257,281	11,594	34,415	0	370	0
2035	261,372	11,778	34,962	0	376	0
2036	265,528	11,966	35,518	0	382	0
2037	269,750	12,156	36,082	0	388	0
2038	274,039	12,349	36,656	0	394	0
2039	278,396	12,546	37,239	0	400	0
2040	282,822	12,745	37,831	0	407	0
2041	287,319	12,948	38,433	0	413	0
2042	291,888	13,154	39,044	0	420	0
2043	296,529	13,363	39,664	0	426	0
2044	301,243	13,575	40,295	0	433	0
2045	306,033	13,791	40,936	0	440	0
2046	310,899	14,010	41,587	0	447	0
2047	315,842	14,233	42,248	0	454	0
2048	320,864	14,459	42,920	0	461	0

Year	General Budget [million THB]			Emergency Budget [million THB]		
	IF	FF	O&M	IF	FF	O&M
2049	325,966	14,689	43,602	0	469	0
2050	331,149	14,923	44,295	0	476	0

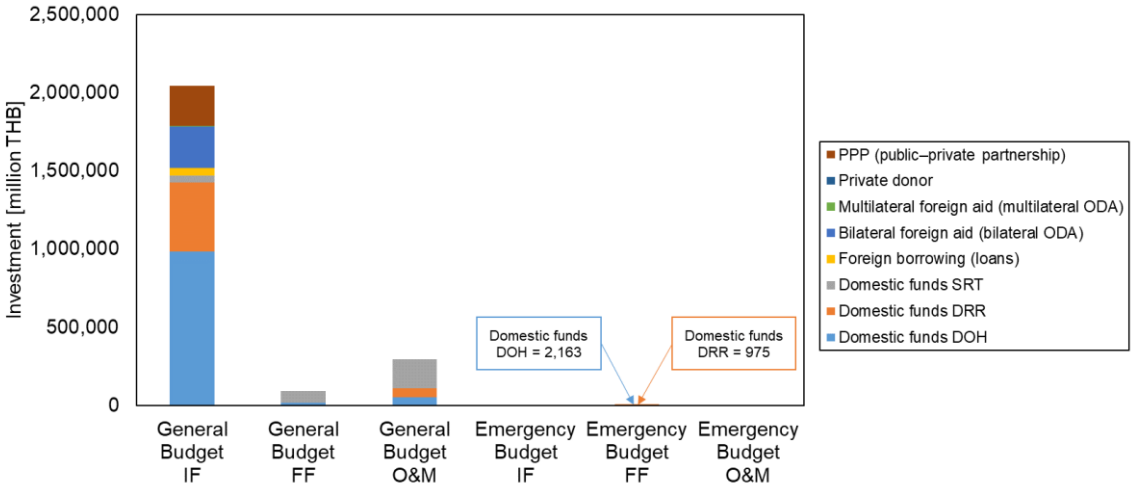

Figure 20 Baseline scenario: cumulative discounted IF, FF, and O&M estimates by investment type, investment entity, and funding source (progressive adaptation case)

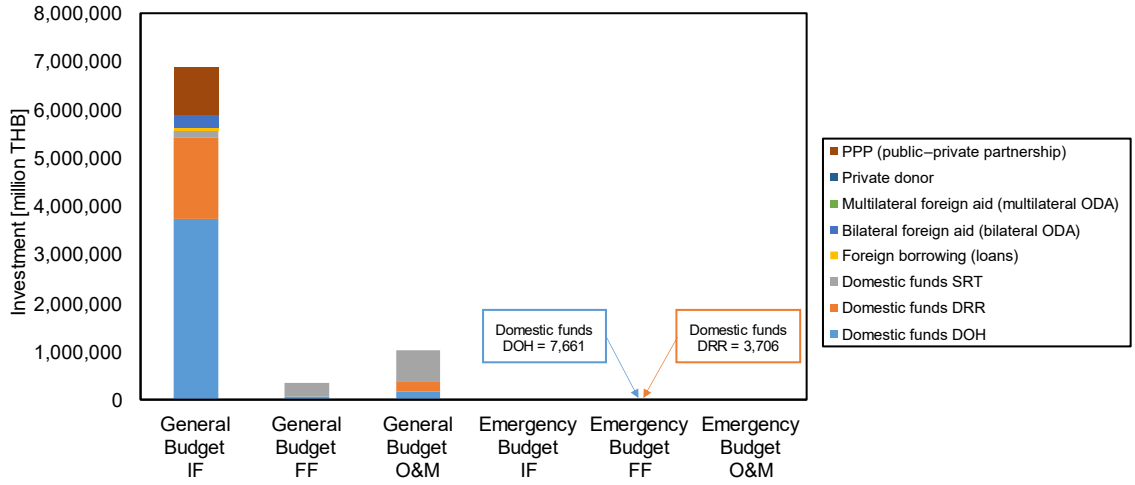

Figure 21 Baseline scenario: cumulative discounted IF, FF, and O&M estimates by investment type, investment entity, and funding source (moderate adaptation case)

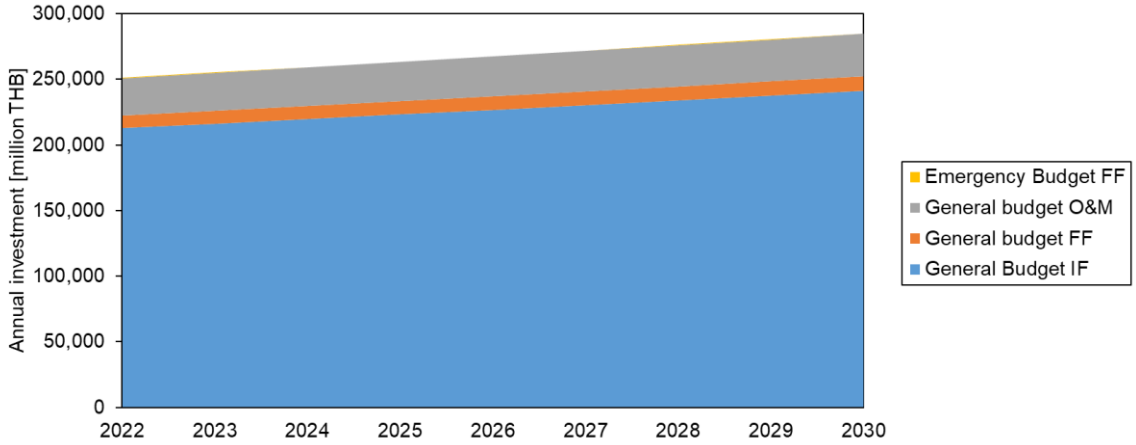

Figure 22 Baseline scenario: annual IF, FF, and O&M estimates by investment type (progressive adaptation case)

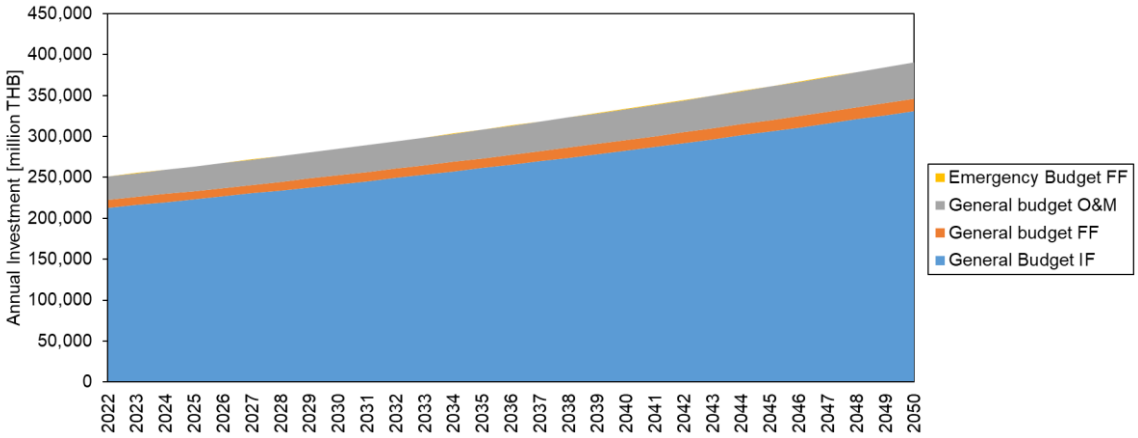

Figure 23 Baseline scenario: annual IF, FF, and O&M estimates by investment type (moderate adaptation case)

From Table 5 and Table 6, it can be seen that several items are left blank, e.g., O&M of foreign and private funds. This is due to the unavailability of the information. However, it can be recognized from domestic governmental investments that the portion of IF is by far larger than that of FF or O&M. Also note that there are some other investments in roads and rails that are not included in the scope of this study, such as express ways, electric trains, or roads owned by local administrative organizations. It is obvious from Figure 20 and Figure 21 that the investments from domestic governmental organizations, i.e., DOH, DRR, and SRT, are substantially larger than international loans/aids or investment from private corporations through public-private partnership (PPP). The international loans/aids are in the same order as the private investment. Since Thailand heavily relies on road transportation, cumulative IF, FF, and O&M estimates of DOH and DRR are significantly larger than those of SRT. Emergency budgets that DOH and DRR planned to use to cope with damages from unexpected climate events are several orders smaller than the total budget, and SRT has no distinct emergency budget. Yet the emergency budget can be hidden in other budget items which makes it impossible to distinguish it from the

total budget. In addition, in an event of a devastating disaster, such as the 2011 Thailand floods, a separate emergency budget is approved by the cabinet to be used for the aftermath. Therefore, the small amount of the emergency budget does not necessarily mean that the actual emergency expenses are small.

Looking at annual IF, FF, and O&M estimates in Table 7 and Table 8, and Figure 22 and Figure 23, the linear relations are attributed to the assumption where average historical data is used, taking into account the inflation. This assumption is due to the fact that the past historical data is available only for three to five years. It can be seen from Figure 22 and Figure 23 that the main portion of the investment are covered in the investment flows which represent the construction of road and rail infrastructure and their operation and maintenance expenses. Though the quantifiable annual emergency budget is very small, it is expected to significantly increase with the escalating severity of the consequences of climate change. However, with the limited information available, it is nearly impossible to accurately estimate the increment of this emergency budget.

Comparing Table 5 to Table 6 , and Figure 20 to Figure 21, the cumulative estimates of the moderate adaptation case are much larger than those of the progressive adaptation case. This is because the timeframe of the moderate adaptation case is longer by over three times. Comparing Table 7 to Table 8, and Figure 22 to Figure 23, it can be recognized that the baseline scenario of the moderate adaptation case is basically the extension of the progressive adaptation case. Note that the infrastructure naturally deteriorates over time which could result in higher emergency expenditure in the moderate adaptation scenario, though the expenses from this deterioration cannot be easily quantified.

6.2 Total Investment in Climate Adaptation Countermeasures

Total investment in adaptation scenarios will be present in terms of matrix of the target roads or rails classified into tiers and the countermeasures for roads and rails categorized into groups based on their functions. The matrix can provide a clear picture to the stakeholders and the related entities for a better understanding of how each countermeasure benefits rail and road infrastructures. In addition, it assists readers' recognition of the available choices of climate-proofing countermeasures for the selected road/rail infrastructures. Development of this matrix requires unit price of each countermeasure using the same unit and total distance/spots of target roads and rails being classified into tiers.

6.2.1 Unit Price of Countermeasures

As already mentioned in chapter 5, road and rail countermeasures could be categorized based on their functions. Both road and rail countermeasures were divided into three groups: flood management, flood avoidance, and structure reinforcement. Categorized roads and rails countermeasures described in detail in chapter 5 are reposted as Figure 24 and Figure 25, respectively, to facilitate the comprehension of the results.

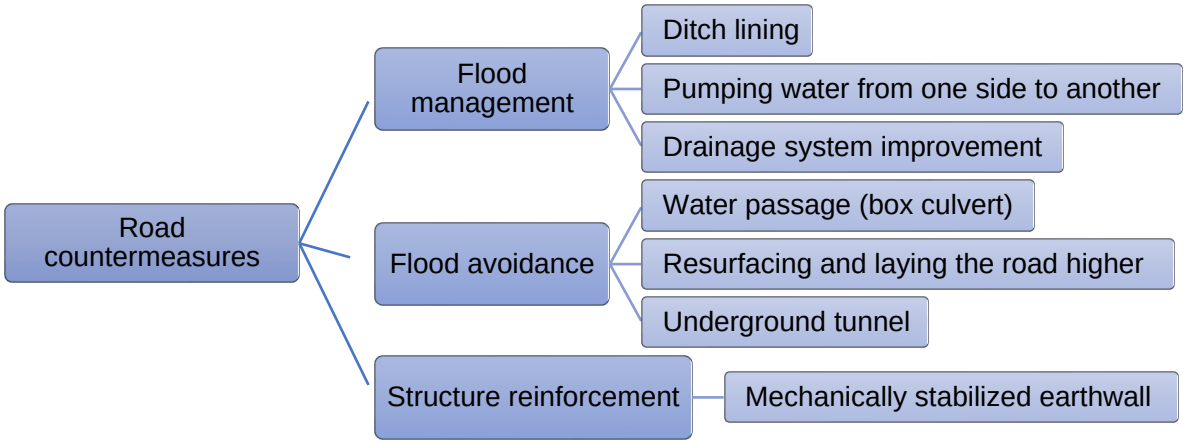

Figure 24 Road countermeasures and their categorization

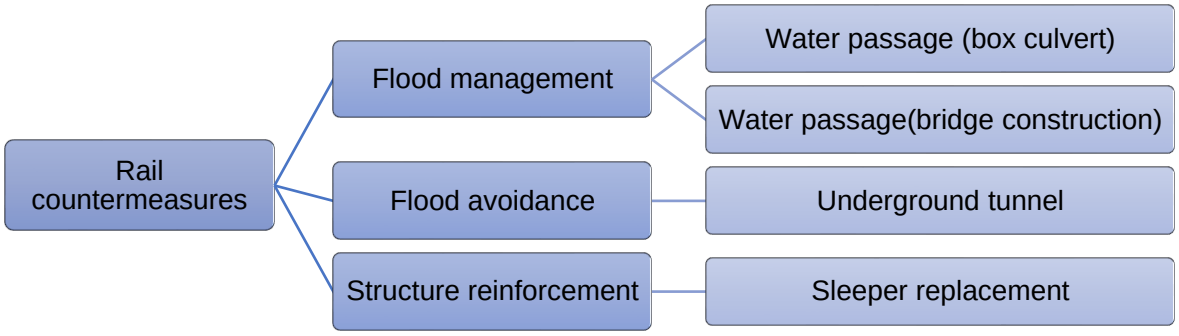

Figure 25 Rail countermeasures and their categorization

In order to obtain the matrix, the unit price of each countermeasure in Figure 24 and Figure 25 has to be estimated. Though the unit prices of these countermeasures have already been discussed in chapter 4 under the evaluation of technical feasibility, some countermeasures were combined, and some unit prices have different unit for others. For instance, laying the road higher and resurfacing were combined, and the unit price needs to be recalculated. In addition, resurfacing the road with concrete is assumed to be applied to all target roads in tiers 1 and 2 while tier 3 roads still adopt the cape seal treatment. It was assumed that roads in tiers 1, 2, and 3 have a width of 48 m (8 lanes), 24 m (4 lanes), and 12 m (2 lanes), respectively. The superscripts (1) and (2) in Table 9 indicate the unit prices of the concrete resurfacing and laying the road higher for tier 1 and tier 2 roads while superscript (3) is for the cape seal resurfacing with laying the road higher for tier 3 roads. The unit prices of the remaining countermeasures follow those introduced in chapter 4.

Table 9 Unit price of selected road countermeasures

Categorization	Road countermeasure	Unit price [THB/m]
Flood management	Ditch lining	3,330
	Drainage system improvement	127,256
	Pumping water from one side to another	15,833
Flood avoidance	Water passage (box culvert)	1,140
	Resurfacing and leveling	32,024(1), 16,012(2) and 5,066(3)
	Underground tunnel	562,199
Structure reinforcement	Mechanically stabilized earthwall	36,735

Table 10 Unit price of selected rail countermeasures

Categorization	Rail countermeasure	Unit price [THB/spot]	Unit price [THB/m]
Flood management	Water passage (box culvert)	8,300,000	
	Water passage (bridge construction)	12,500,000	
Flood avoidance	Underground tunnel		4,164,440
Structure reinforcement	Sleeper replacement		2,549

6.2.2 Total Distance and Total Spots

Once the unit prices were all determined, the total distance and total spots of the target roads and rails have to be estimated. Roads and rails were screened according to the screening criteria and classified into three tiers for road and two tiers for rails according to the conditions specified in chapter 5. Total distance of target roads is summarized in Table 11. The table also categorizes the waterways with which the roads align into river, diversion canal, and other canal. Total distance and spots of target rails are summarized in

Table 12. Number of spots are needed for the calculation of investment on water passage (box culvert) and water passage (bridge construction).

Table 11 Total distance of target roads

Target roads	River [km]	Diversion canal [km]	Other canal [km]	Total distance [km]
Tier 1 roads	0	49	17	66
Tier 2 roads	0	9	215	224
Tier 3 roads	179	809	3,857	4,845

Table 12 Total distance and spots of target rails

Railway lines	Total distance [km]	Total usage [passenger-kilometer]	Count of applicable spots
Maeklong	64	78,403,262	0
Eastern	255	282,633,965	0
Northern	751	1,347,807,947	4
Northeastern	621	1,912,828,990	1
Southern	990	2,945,635,807	5

6.2.3 Matrix for Climate Adaptation Investment in Transportation Sector

The unit prices of climate adaptation countermeasures were multiplied by the total distance or total applicable spots depending on the countermeasures and to obtain the matrix for climate adaptation investment. Matrices for roads and rails are shown in Table 13 and Table 14, respectively.

Table 13 Matrix for climate adaptation investment on road infrastructures (million THB)

Tier	Flood Management			Flood Avoidance			Structure Reinforcement
	Ditch Lining	Drainage System Improvement	Pumping Water from One Side to Another	Water Passage (box culvert)	Resurfacing and Laying the road higher	Underground Tunnel	Mechanically Stabilized Earthwall
1	220	8,405	1,046	75	2,097	37,133	2,426
2	747	28,537	3,551	256	3,560	126,073	8,238
3	16,131	616,543	76,711	5,523	24,215	2,723,796	177,977

It can be seen from Table 13 that there are many countermeasures for flood management and flood avoidance and can be selectively applied based on the geographic location or conditions at the construction site. Indeed, it is not realistic to apply all countermeasures to all target roads and rails. Through consultation with main stakeholders, including DOH, DRR, it seems more reasonable to select a countermeasure from each category and apply only to tiers 1 and 2 roads. In this study, pumping water from one side to another, resurfacing and laying the road higher, and mechanically stabilized earthwall, were selected as the suitable candidates for flood management, flood avoidance, and structure reinforcement, respectively. Note that this selection was not made based on the mutual agreement of all parties but is merely made to continue to the next step of the calculation to be able to illustrate the investment and financial flow of possible climate adaptation investment in transportation sector in Thailand. The total investment cost is estimated based on the combination of these selected countermeasures. Combination of countermeasures is necessary because climate change can affect many

aspects in the transportation sector. For instance, pumping the water from one side to another will only benefit flood level adjustment. It cannot reinforce the road structure to withstand the force created by the floods which can only be addressed by installing mechanically stabilized earthwall. The total distances of the road under tier 1 and tier 2 are 66.1 and 224.3 kilometers, respectively. By applying the combination of the countermeasure to these roads, the total costs of tiers 1 and 2 roads are 5.75 billion THB and 15.95 billion THB, respectively. Although roads under tier 2 are assumed to be smaller than those in tier 1, the total investment cost of tier 2 is much higher. Though the tier 1 roads are among the most significant to the transportation sector of the country, there are not many roads under this tier that run along a river or a canal.

Table 14 Matrix for climate adaptation investment on rail infrastructures (million THB)

Tier	Flood Management		Flood Avoidance	Structure Reinforcement
	Water Passage (box culvert)	Water passage (bridge construction)	Underground Tunnel	Sleeper Replacement
1	83	400	41,644	301
2	N/A	N/A	N/A	41

Alike the countermeasure selection in roads, rail countermeasures are selected based on consultation with the key organization, SRT. As for flood management, water passage (box culvert) and water passage (bridge construction) will be adopted for the railways that run perpendicular to the river and close by the mountain, respectively. The total cost of each countermeasure in tiers 1 and 2 could be estimated by getting the total number of applicable spots that exist on the rails. In the first tier, there are only two locations where the rail will run perpendicular to the river. The railway will travel nearby the mountain for the rest of the spots. There is no spot to be found under the second tier according to the rail screening criteria stated in the previous section. Thus, the total cost of both water passage box culvert and bridge construction. Underground tunnel will not be applied to any of the target rails due to its large investment. Most of Thailand's railways are using concrete sleepers. only some specific locations where concrete sleepers cannot be used that are still using wooden sleepers. With this in mind, only five percent of the sleepers are assumed necessary to be replaced by the reinforced concrete sleepers. Finally, the total investments of tiers 1 and 2 rails become 784 million THB and 41 million THB, respectively.

6.2.4 Discussion

For both roads and rails, it can be clearly seen that the investment on underground tunnel is the highest. It seems not to be economically feasible and was also deemed impractical according to the discussion with DOH and DRR. Note that water passage (box culvert) is the cheapest countermeasure for both roads and rails. Its construction procedure is simple and requires only light construction equipment which means the construction period will be short. However, the route will be temporarily closed during the construction. For roads, drainage system improvement is the second most expensive countermeasure followed by the mechanically stabilized earthwall, pumping water from one side to another, resurfacing and laying the road higher, and ditch lining. The sleeper replacement is the second most expensive countermeasure for rails, followed by water passage (bridge construction).

The total investment is quite huge for the responsible entities, namely DOH, DRR, and SRT. It is equivalent to significant portion of the annual budget provided by the government which means it would be difficult for these organizations to request budget for the total amount of the climate adaptation investment. Therefore, I&FF assessment which will help design the investment flow is needed and will be discussed in detail in the next section.

6.3 Investment and Financial Flows in Adaptation Scenario

Climate-proofing investments in road and rail infrastructure and the associated operation and maintenance costs concluded in section 6.2 are added to the general expenditures in baseline scenario in order to develop the IF, FF, and O&M estimates of the adaptation scenarios. The timeframes are set to 2022 – 2030 for the progressive adaptation case, and to 2022 – 2050 for the moderate adaptation case. In order to account for the effectiveness of the climate-proofing countermeasures, the emergency expenditures are assumed to decrease by half by the end of the timeframe of both cases.

The cumulative discounted IF, FF, and O&M estimates by investment type, investment entity, and funding source of the adaptation scenarios are shown in Table 15 Adaptation scenario: cumulative discounted IF, FF, and O&M estimates by investment type, investment entity, and funding source (progressive adaptation case) and Table 16. Table 15 shows the progressive adaptation case while Table 16 shows the moderate adaptation case. Annual IF, FF, and O&M estimates by investment type are shown in Table 17 and Table 18. The cumulative and annual estimates are also illustrated using bar graphs and line stacks in Figure 26 to Figure 29 in order to visualize the size of investment.

Table 15 Adaptation scenario: cumulative discounted IF, FF, and O&M estimates by investment type, investment entity, and funding source (progressive adaptation case)

Category of Investment Entity	Source of I&FF Funds [million THB]		General Budget [million THB]									Emergency Budget [million THB]		
			IF	FF	O&M	Climate adaptation for roads			Climate adaptation for rails			IF	FF	O&M
						IF	FF	O&M	IF	FF	O&M			
Government	Domestic	Domestic funds DOH	985,936	18,028	53,923	27,147	0	1,357	0	0	0	0	1,458	0
		Domestic funds DRR	442,023	0	55,240	0	0	0	0	0	0	0	725	0
		Domestic funds SRT	41,312	75,701	186,439	0	0	0	849	0	42	0	0	0
	Total Domestic Sources	**1,890,181**												
	Foreign	Foreign borrowing (loans)	48,462	0	0	0	0	0	0	0	0	0	0	0
		Bilateral foreign aid (bilateral ODA)	266,736	0	0	0	0	0	0	0	0	0	0	0
		Multilateral foreign aid (multilateral ODA)	4,009	0	0	0	0	0	0	0	0	0	0	0
		Private donor	4	0	0	0	0	0	0	0	0	0	0	0
	Total Foreign Sources	**319,211**												
	Total Government Funds	**2,209,392**												
Corporations	Domestic	PPP (public–private partnership)	254,210	0	0	0	0	0	0	0	0	0	0	0
	Total Corporation Funds	**254,210**												
Total			**2,042,692**	**93,729**	**295,602**	**27,147**	**0**	**1,357**	**849**	**0**	**42**	**0**	**2,183**	**0**

Table 16 Adaptation scenario: cumulative discounted IF, FF, and O&M estimates by investment type, investment entity, and funding source (moderate adaptation case)

Category of Investment Entity	Source of I&FF Funds [million THB]		General Budget [million THB]									Emergency Budget [million THB]		
			IF	FF	O&M	Climate adaptation for roads			Climate adaptation for rails			IF	FF	O&M
						IF	FF	O&M	IF	FF	O&M			
Government	Domestic	Domestic funds DOH	3,749,122	62,173	185,966	32,037	0	1,602	0	0	0	0	5,448	0
		Domestic funds DRR	1,680,837	0	210,056	0	0	0	0	0	0	0	2,707	0
		Domestic funds SRT	157,094	287,863	642,985	0	0	0	1,002	0	50	0	0	0
	Total Domestic Sources	**7,018,941**												
	Foreign	Foreign borrowing (loans)	184,282	0	0	0	0	0	0	0	0	0	0	0
		Bilateral foreign aid (bilateral ODA)	1,014,291	0	0	0	0	0	0	0	0	0	0	0
		Multilateral foreign aid (multilateral ODA)	15,246	0	0	0	0	0	0	0	0	0	0	0
		Private donor	14	0	0	0	0	0	0	0	0	0	0	0
	Total Foreign Sources	**1,213,832**												
	Total Government Funds	**8,232,773**												
Corporations	Domestic	PPP (public–private partnership)	966,661	0	0	0	0	0	0	0	0	0	0	0
	Total Corporation Funds	**966,661**												
Total			**7,767,545**	**350,035**	**1,039,007**	**32,037**	**0**	**1,602**	**1,002**	**0**	**50**	**0**	**8,155**	**0**

Table 17 Adaptation scenario: annual IF, FF, and O&M estimates by investment type (progressive adaptation case)

Year	General Budget [million THB]									Emergency Budget [million THB]		
	IF	FF	O&M	Climate adaptation for roads			Climate adaptation for rails			IF	FF	O&M
				IF	FF	O&M	IF	FF	O&M			
2022	212,910	9,595	28,479	2,830	0	141	88	0	4	0	306	0
2023	216,295	9,747	28,932	2,875	0	144	90	0	4	0	291	0
2024	219,735	9,902	29,392	2,920	0	146	91	0	5	0	276	0
2025	223,228	10,060	29,860	2,967	0	148	93	0	5	0	261	0
2026	226,778	10,219	30,334	3,014	0	151	94	0	5	0	244	0
2027	230,383	10,382	30,817	3,062	0	153	96	0	5	0	228	0
2028	234,046	10,547	31,307	3,110	0	156	97	0	5	0	210	0
2029	237,768	10,715	31,804	3,160	0	158	99	0	5	0	192	0
2030	241,548	10,885	32,310	3,210	0	161	100	0	5	0	174	0

Table 18 Adaptation scenario: annual IF, FF, and O&M estimates by investment type (moderate adaptation case)

Year	General Budget [million THB]									Emergency Budget [million THB]		
	IF	FF	O&M	Climate adaptation for roads			Climate adaptation for rails			IF	FF	O&M
				IF	FF	O&M	IF	FF	O&M			
2022	212,910	9,595	28,479	878	0	44	27	0	1	0	306	0
2023	216,295	9,747	28,932	892	0	45	28	0	1	0	305	0
2024	219,735	9,902	29,392	906	0	45	28	0	1	0	305	0
2025	223,228	10,060	29,860	921	0	46	29	0	1	0	304	0
2026	226,778	10,219	30,334	935	0	47	29	0	1	0	303	0
2027	230,383	10,382	30,817	950	0	48	30	0	1	0	302	0
2028	234,046	10,547	31,307	965	0	48	30	0	2	0	300	0
2029	237,768	10,715	31,804	981	0	49	31	0	2	0	299	0
2030	241,548	10,885	32,310	996	0	50	31	0	2	0	298	0
2031	245,389	11,058	32,824	1,012	0	51	32	0	2	0	296	0
2032	249,291	11,234	33,346	1,028	0	51	32	0	2	0	294	0
2033	253,254	11,413	33,876	1,045	0	52	33	0	2	0	293	0
2034	257,281	11,594	34,415	1,061	0	53	33	0	2	0	291	0
2035	261,372	11,778	34,962	1,078	0	54	34	0	2	0	288	0
2036	265,528	11,966	35,518	1,095	0	55	34	0	2	0	286	0
2037	269,750	12,156	36,082	1,113	0	56	35	0	2	0	284	0
2038	274,039	12,349	36,656	1,130	0	57	35	0	2	0	281	0
2039	278,396	12,546	37,239	1,148	0	57	36	0	2	0	279	0
2040	282,822	12,745	37,831	1,166	0	58	36	0	2	0	276	0

Year	General Budget [million THB]									Emergency Budget [million THB]		
	IF	FF	O&M	Climate adaptation for roads			Climate adaptation for rails			IF	FF	O&M
				IF	FF	O&M	IF	FF	O&M			
2041	287,319	12,948	38,433	1,185	0	59	37	0	2	0	273	0
2042	291,888	13,154	39,044	1,204	0	60	38	0	2	0	270	0
2043	296,529	13,363	39,664	1,223	0	61	38	0	2	0	266	0
2044	301,243	13,575	40,295	1,242	0	62	39	0	2	0	263	0
2045	306,033	13,791	40,936	1,262	0	63	39	0	2	0	259	0
2046	310,899	14,010	41,587	1,282	0	64	40	0	2	0	255	0
2047	315,842	14,233	42,248	1,303	0	65	41	0	2	0	251	0
2048	320,864	14,459	42,920	1,323	0	66	41	0	2	0	247	0
2049	325,966	14,689	43,602	1,344	0	67	42	0	2	0	243	0
2050	331,149	14,923	44,295	1,366	0	68	43	0	2	0	238	0

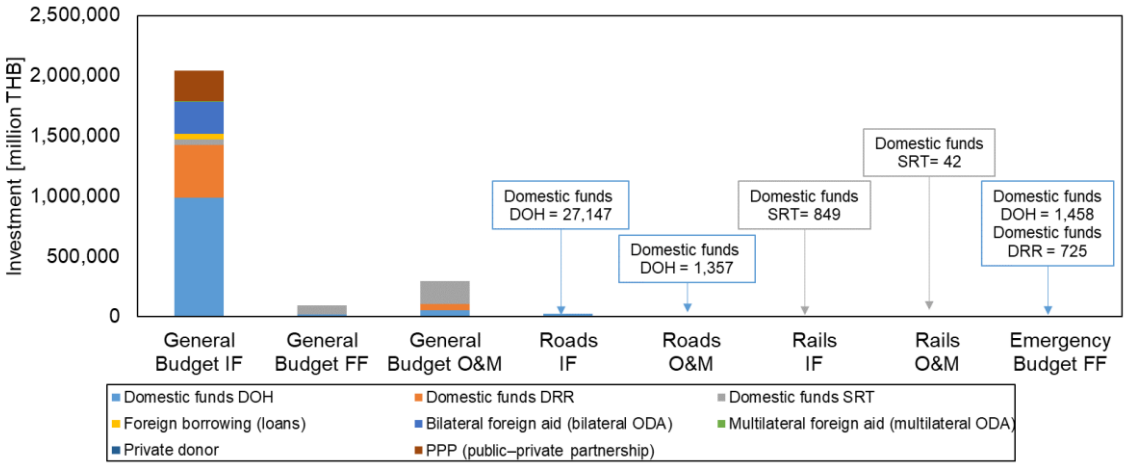

Figure 26 Adaptation scenario: cumulative discounted IF, FF, and O&M estimates by investment type, investment entity, and funding source (progressive adaptation case)

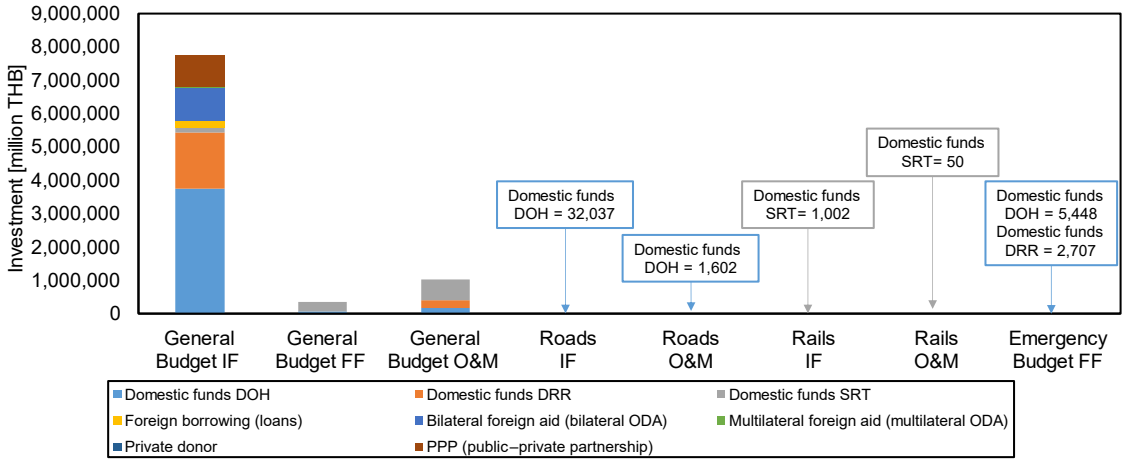

Figure 27 Adaptation scenario: cumulative discounted IF, FF, and O&M estimates by investment type, investment entity, and funding source (moderate adaptation case)

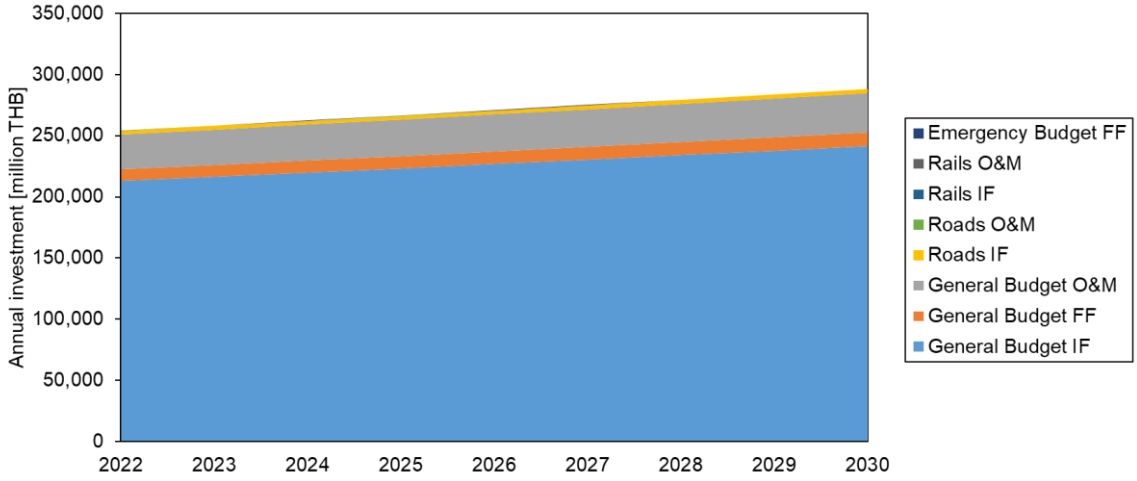

Figure 28 Adaptation scenario: annual IF, FF, and O&M estimates by investment type (progressive adaptation case)

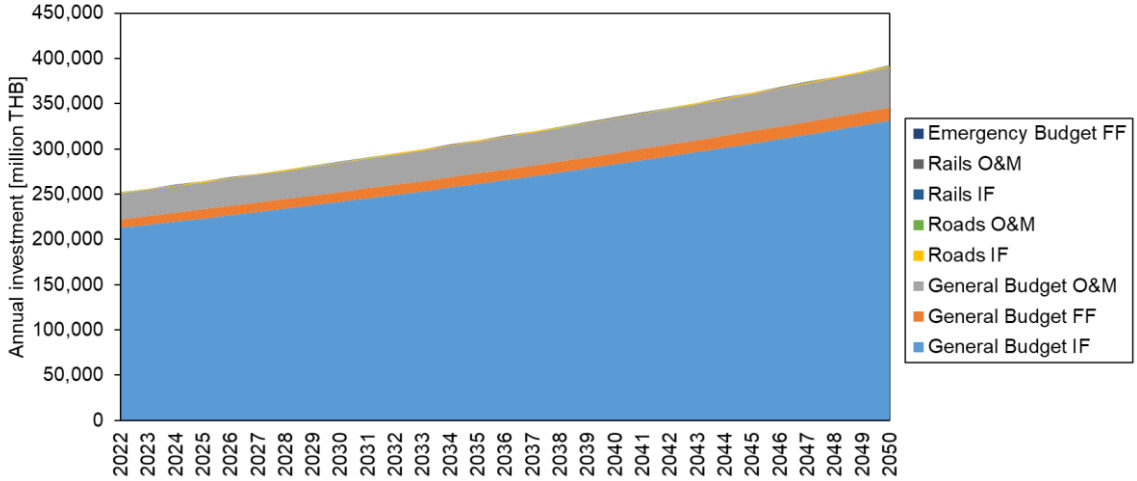

Figure 29 Adaptation scenario: annual IF, FF, and O&M estimates by investment type (moderate adaptation case)

It can be seen in Table 15 and Table 16 that the total investment on climate-proofing countermeasures is smaller than the general budget by one to two orders, and the emergency budget is smaller than the investments in countermeasures by an order. The differences in budget size can be clearly observed in Figure 26 and Figure 27. Alike the general budget, the climate-proofing investment on road infrastructure is significantly larger than that of rail infrastructure. Gradual decrease of the emergency budget is illustrated in Figure 28 and Figure 29. Note that the decrease in the moderate adaptation case is much slower than the progressive adaptation case. As stated earlier, the total investment on climate adaptation countermeasures is stretched to the period of 2022 – 2050 in the moderate adaptation case which is the reason to the smaller annual IF, FF and O&M estimates when comparing Table 17 to Table 18. Instead of equally dividing the investment each year, the assumption can be made to start with a smaller investment on pilot projects and increase the amount of investment later when the economic and political viabilities are clearly

demonstrated. This approach imitates the situation where pilot projects are first launched to demonstrate the feasibility of the investment and attracts larger amount of investment in future years. Assumptions can also be further tailored based on actual experience of direct stakeholders on similar types of investments.

6.4 Incremental Investment on Climate Adaptation in Transportation Sector

The incremental investment that is needed to be prepared for the climate-proofing investment in transport sector can be obtained by subtracting annual IF, FF, and O&M estimates of the baseline scenario from the adaptation scenario. Incremental annual IF, FF, and O&M estimates by investment type of progressive adaptation case and moderate adaptation case are shown in Table 19 and Table 20. The incremental annual estimates are also illustrated using line stacks in Figure 30 and Figure 31 in order to visualize the size of investment.

Table 19 Incremental annual IF, FF, and O&M estimates by investment type (progressive adaptation case)

Year	General Budget [million THB]									Emergency Budget [million THB]		
	IF	FF	O&M	Climate adaptation for roads			Climate adaptation for rails			IF	FF	O&M
				IF	FF	O&M	IF	FF	O&M			
2022	0	0	0	2,830	0	141	88	0	4	0	0	0
2023	0	0	0	2,875	0	144	90	0	4	0	-19	0
2024	0	0	0	2,920	0	146	91	0	5	0	-39	0
2025	0	0	0	2,967	0	148	93	0	5	0	-60	0
2026	0	0	0	3,014	0	151	94	0	5	0	-81	0
2027	0	0	0	3,062	0	153	96	0	5	0	-103	0
2028	0	0	0	3,110	0	156	97	0	5	0	-126	0
2029	0	0	0	3,160	0	158	99	0	5	0	-150	0
2030	0	0	0	3,210	0	161	100	0	5	0	-174	0

Table 20 Incremental annual IF, FF, and O&M estimates by investment type (moderate adaptation case)

Year	General Budget [million THB]									Emergency Budget [million THB]		
	IF	FF	O&M	Climate adaptation for roads			Climate adaptation for rails			IF	FF	O&M
				IF	FF	O&M	IF	FF	O&M			
2022	0	0	0	878	0	44	27	0	1	0	0	0
2023	0	0	0	892	0	45	28	0	1	0	-6	0
2024	0	0	0	906	0	45	28	0	1	0	-11	0
2025	0	0	0	921	0	46	29	0	1	0	-17	0

Year	General Budget [million THB]									Emergency Budget [million THB]		
	IF	FF	O&M	Climate adaptation for roads			Climate adaptation for rails			IF	FF	O&M
				IF	FF	O&M	IF	FF	O&M			
2026	0	0	0	935	0	47	29	0	1	0	-23	0
2027	0	0	0	950	0	48	30	0	1	0	-30	0
2028	0	0	0	965	0	48	30	0	2	0	-36	0
2029	0	0	0	981	0	49	31	0	2	0	-43	0
2030	0	0	0	996	0	50	31	0	2	0	-50	0
2031	0	0	0	1,012	0	51	32	0	2	0	-57	0
2032	0	0	0	1,028	0	51	32	0	2	0	-64	0
2033	0	0	0	1,045	0	52	33	0	2	0	-72	0
2034	0	0	0	1,061	0	53	33	0	2	0	-79	0
2035	0	0	0	1,078	0	54	34	0	2	0	-87	0
2036	0	0	0	1,095	0	55	34	0	2	0	-95	0
2037	0	0	0	1,113	0	56	35	0	2	0	-104	0
2038	0	0	0	1,130	0	57	35	0	2	0	-113	0
2039	0	0	0	1,148	0	57	36	0	2	0	-121	0
2040	0	0	0	1,166	0	58	36	0	2	0	-131	0
2041	0	0	0	1,185	0	59	37	0	2	0	-140	0
2042	0	0	0	1,204	0	60	38	0	2	0	-150	0
2043	0	0	0	1,223	0	61	38	0	2	0	-160	0
2044	0	0	0	1,242	0	62	39	0	2	0	-170	0
2045	0	0	0	1,262	0	63	39	0	2	0	-181	0
2046	0	0	0	1,282	0	64	40	0	2	0	-192	0
2047	0	0	0	1,303	0	65	41	0	2	0	-203	0
2048	0	0	0	1,323	0	66	41	0	2	0	-214	0
2049	0	0	0	1,344	0	67	42	0	2	0	-226	0
2050	0	0	0	1,366	0	68	43	0	2	0	-238	0

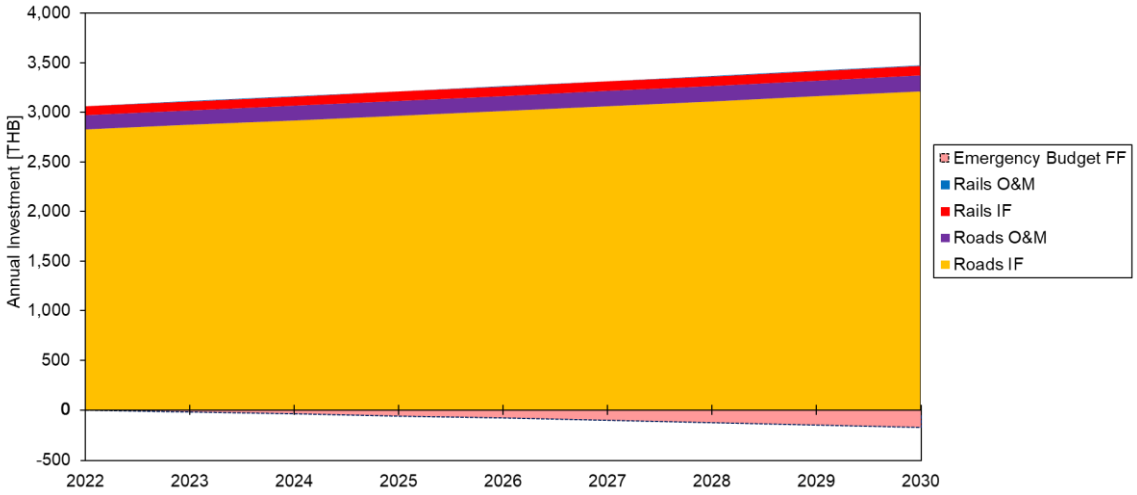

Figure 30 Incremental annual IF, FF, and O&M estimates by investment type (progressive adaptation case)

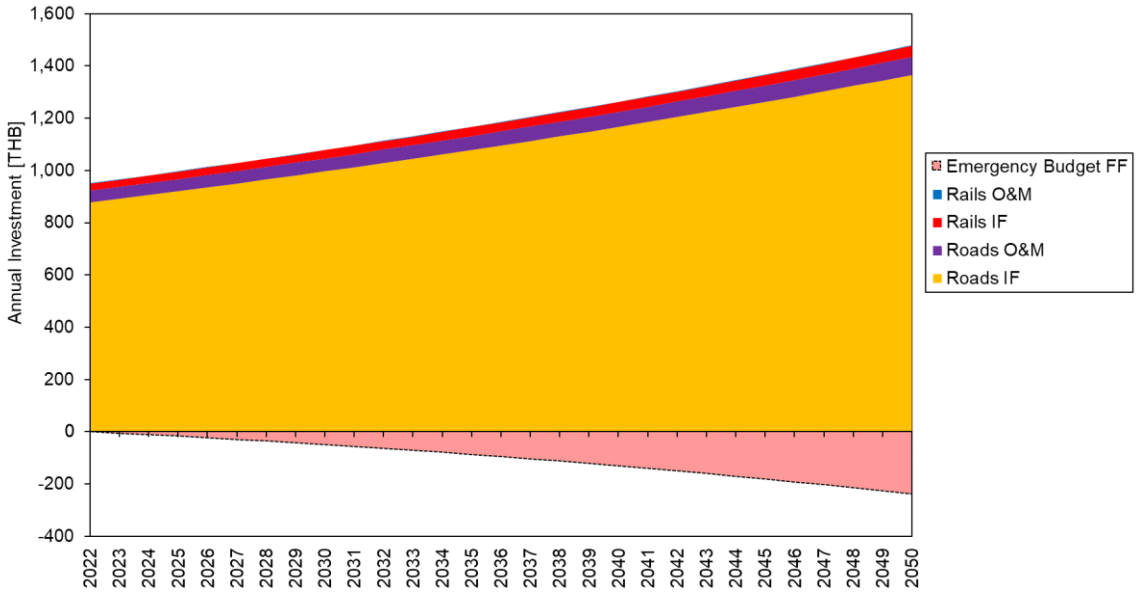

Figure 31 Incremental annual IF, FF, and O&M estimates by investment type (progressive adaptation case)

It can be seen from Table 19 and Table 20 and Figure 30 and Figure 31 that the general budgets are balanced out, the investments on climate-proofing countermeasures remain, and the emergency budgets return negative values. In the moderate adaptation case, the incremental annual investments are smaller, and the decreases in emergency expenses are slower. However, with increasing intensity of climate change, the non-quantifiable emergency expenses might significantly increase. In total, approximately 13 – 14 billion THB is additionally needed to enhance the climate adaptability of the transport infrastructure. The sources of funding along with the policy options to facilitate the obtainment of the funds will be discussed in Chapter 7.

6.5 Revisiting Total Investment and Investment Flow in Adaptation Scenarios

6.5.1 Matrix for Climate Adaptation Investment in Transportation

As mentioned in section 6.2.3, unit price for each climate adaptation countermeasure was multiplied by the total distance for target roads or applicable spots for target rails to obtain the matrix for climate adaptation investment. Since consultation meeting with direct stakeholders has contributed to changes in the unit prices and the countermeasures, revision of the metrices for climate adaptation investment for road and rail infrastructures were made and summarized in Table 21 and Table 22, respectively.

Table 21 Revised matrix for climate adaptation investment on road infrastructures (million THB)

Tier	Flood Management		Flood Avoidance		Structure Reinforcement
	Drainage System Improvement	Ditch Lining	Water Passage (box culvert)	AC Resurfacing & Laying the road higher	Mechanically Stabilized Earthwall
1	420	11	4	112	2,426
2	1,427	37	13	379	8,238

Table 22 Revised matrix for climate adaptation investment on rail infrastructures (million THB)

Tier	**Flood Management**	
	Water Passage (box culvert)	Water passage (concrete bridge construction) and Water passage (steel bridge construction)
1	332	110
2	N/A	N/A

It can be seen in Table 21 that the number of countermeasures for road infrastructures were reduced from seven to five in accordance with DOH and DRR suggestions. The remaining five countermeasures were ensured to have technical and political viability to implement in Thailand by the direct stakeholders and they have already been implemented in some areas in the country. Essentially, MSE is a preferable countermeasure even with a higher price than other. It became the dominant part of the total investment. On the other land, two countermeasures, including pumping water from one side to another and underground tunnel were excluded due to the inappropriateness of the assumed implementation and the requirement of large amount of investment, respectively. Pumping water is considered as overlapping countermeasures with water management of RID. Though water gates of RID are basically for agricultural purpose, it can also serve for flood management. Additionally, rather than installing pumps along the road, it is more feasible to have several pumps store with local administrative organizations to be used during floods. Therefore, the countermeasure was rejected. Underground tunnel is known for its lack of economical friendliness. The countermeasure was applied in global leading cities to facilitate road journeys and avoid facing flood during commuting. In addition, the tunnel requires a large-scale construction, which may negatively affect the environment nearby. With these reasons, it was rejected. Furthermore, modifications to several assumptions were advised to receive realistic costs. It was suggested to apply drainage system improvement, ditch lining, water passage (box culvert), and resurfacing and laying the road higher only to five percent of the target roads to be more realistic. The number of lanes were advised to be changed to four lanes for roads in tier 1 and 2 and road widths were suggested to be 3.5 meters per lane. Unlike the previous selection of countermeasures which was not made with mutual agreement of all parties, countermeasures and unit prices in this revised matrix were ensured by the stakeholders. The revised matrix shows the total investment of selected countermeasures. The total distances of target roads divided into tier 1 and 2 are 66.1 and 224.3 kilometers, respectively. When applying the countermeasures to the road, the total costs for roads in tier 1 and 2 are 3.0 billion THB and 10.1 billion THB, respectively. MSE contributed to the large portion of the total investment in both tiers. MSE alone requires 2.4 billion THB investment in tier 1 and 8.2 billion THB investment in tier 2. The revised costs were significantly different from previous ones since not only the countermeasures but also the assumptions were changed as mentioned above.

Similar to the matrix for climate adaptation investment for roads, changes were made to rail countermeasures and unit prices based on the consultation with SRT. Initially, the study proposed four countermeasures to climate adaptation in rail transportation. After having discussion with key stakeholder, SRT, two countermeasures remained, which are water passage (box culvert) and water passage (bridge construction). As mentioned above, underground tunnel is considered one of the highly priced countermeasures applying in developed cities and not environmental friendly. The countermeasure was therefore excluded from the revised matrix. Another rejected countermeasure was sleeper replacement. SRT representative

confirmed that sleeper replacement is considered as a soft climate adaptation strategy which is included in maintenance phase, and hence, the countermeasure was excluded from the analysis which focuses on investment. Several assumptions for railway were also advised to be changed. It was suggested that a steel bridge is more suitable for railway than a concrete bridge. It is more stable and is able to bear with high flow rate of water. Therefore, the bridge construction should be applied to the location where the rail runs perpendicular to a river or a canal. However, it comes with a higher price. On the other hand, a concrete bridge is constructed when it is required to complete the construction within the fiscal year. To have an accurate estimation of investment costs, calculation of steel and concrete bridge was assumed to be half each. Water passage (box culvert) was considered as appropriate for railways adjacent to a mountain. The total number of selected locations is ten all being included in tier 1 and the total investment for the tier is 0.4 billion THB.

6.5.2 Investment and Financial Flows

The consultation meetings with key stakeholders for roads and rails contributed to significant change in climate adaptation investment metrices. The investment flows along with O&M costs became more realistic and practical. Revised cumulative discounted IF, FF, and O&M estimates by investment type, investment entity, and funding source of the adaptation scenario are shown in Table 23 and Table 24. Revised annual IF, FF, and O&M estimates by investment type are shown in Table 25 and Table 26. The revised cumulative and annual estimates are also illustrated using bar graphs and line stacks in Figure 32 to Figure 35 in order to visualize the size of investment. This also leads to the re-estimation of the incremental investment. Revised incremental annual IF, FF, and O&M estimates by investment type of progressive adaptation case and moderate adaptation case are shown in Table 27 and Table 28. The incremental annual estimates are also illustrated using line stacks in Figure 36 and Figure 37.

Table 23 Adaptation scenario: revised cumulative discounted IF, FF, and O&M estimates by investment type, investment entity, and funding source (progressive adaptation case)

Category of Investment Entity	Source of I&FF Funds [million THB]		General Budget [million THB]									Emergency Budget [million THB]		
			IF	FF	O&M	Climate adaptation for roads			Climate adaptation for rails			IF	FF	O&M
						IF	FF	O&M	IF	FF	O&M			
Government	Domestic	Domestic funds DOH	985,936	18,028	53,923	12,736	0	637	0	0	0	0	1,458	0
		Domestic funds DRR	442,023	0	55,240	0	0	0	0	0	0	0	725	0
		Domestic funds SRT	41,312	75,701	186,439	0	0	0	637	0	22	0	0	0
	Total Domestic Sources	**1,874,815**												
	Foreign	Foreign borrowing (loans)	48,462	0	0	0	0	0	0	0	0	0	0	0
		Bilateral foreign aid (bilateral ODA)	266,736	0	0	0	0	0	0	0	0	0	0	0
		Multilateral foreign aid (multilateral ODA)	4,009	0	0	0	0	0	0	0	0	0	0	0
		Private donor	4	0	0	0	0	0	0	0	0	0	0	0
	Total Foreign Sources	**319,211**	0	0	0	0	0	0	0	0	0	0	0	0
	Total Government Funds	**2,194,026**												
Corporations	Domestic	PPP (public–private partnership)	254,210	0	0	0	0	0	0	0	0	0	0	0
	Total Corporation Funds	**254,210**												
Total			**2,042,692**	**93,729**	**295,602**	**12,736**	**0**	**637**	**637**	**0**	**22**	**0**	**2,183**	**0**

Table 24 Adaptation scenario: revised cumulative discounted IF, FF, and O&M estimates by investment type, investment entity, and funding source (moderate adaptation case)

Category of Investment Entity	Source of I&FF Funds [million THB]		General Budget [million THB]									Emergency Budget [million THB]		
			IF	FF	O&M	Climate adaptation for roads			Climate adaptation for rails			IF	FF	O&M
						IF	FF	O&M	IF	FF	O&M			
Government	Domestic	Domestic funds DOH	985,936	18,028	53,923	16,143	0	807	0	0	0	0	5,448	0
		Domestic funds DRR	442,023	0	55,240	0	0	0	0	0	0	0	2,707	0
		Domestic funds SRT	41,312	75,701	186,439	0	0	0	546	0	27	0	0	0
	Total Domestic Sources	**1,884,280**												
	Foreign	Foreign borrowing (loans)	48,462	0	0	0	0	0	0	0	0	0	0	0
		Bilateral foreign aid (bilateral ODA)	266,736	0	0	0	0	0	0	0	0	0	0	0
		Multilateral foreign aid (multilateral ODA)	4,009	0	0	0	0	0	0	0	0	0	0	0
		Private donor	4	0	0	0	0	0	0	0	0	0	0	0
	Total Foreign Sources	**319,211**												
	Total Government Funds	**2,203,491**												
Corporations	Domestic	PPP (public–private partnership)	254,210	0	0	0	0	0	0	0	0	0	0	0
	Total Corporation Funds	**254,210**												
Total			**2,042,692**	**93,729**	**295,602**	**16,143**	**0**	**807**	**546**	**0**	**27**	**0**	**8,155**	**0**

Table 25 Adaptation scenario: revised annual IF, FF, and O&M estimates by investment type (progressive adaptation case)

Year	General Budget [million THB]									Emergency Budget [million THB]		
	IF	FF	O&M	Climate adaptation for roads			Climate adaptation for rails			IF	FF	O&M
				IF	FF	O&M	IF	FF	O&M			
2022	212,910	9,595	28,479	1,327	0	66	45	0	2	0	306	0
2023	216,295	9,747	28,932	1,349	0	67	46	0	2	0	291	0
2024	219,735	9,902	29,392	1,370	0	68	46	0	2	0	276	0
2025	223,228	10,060	29,860	1,392	0	70	47	0	2	0	261	0
2026	226,778	10,219	30,334	1,414	0	71	48	0	2	0	244	0
2027	230,383	10,382	30,817	1,436	0	72	49	0	2	0	228	0
2028	234,046	10,547	31,307	1,459	0	73	49	0	2	0	210	0
2029	237,768	10,715	31,804	1,482	0	74	50	0	3	0	192	0
2030	241,548	10,885	32,310	1,506	0	75	51	0	3	0	174	0

Table 26 Adaptation scenario: revised annual IF, FF, and O&M estimates by investment type (moderate adaptation case)

Year	General Budget [million THB]									Emergency Budget [million THB]		
	IF	FF	O&M	Climate adaptation for roads			Climate adaptation for rails			IF	FF	O&M
				IF	FF	O&M	IF	FF	O&M			
2022	212,910	9,595	28,479	442	0	22	15	0	1	0	306	0
2023	216,295	9,747	28,932	450	0	22	15	0	1	0	305	0
2024	219,735	9,902	29,392	457	0	23	15	0	1	0	305	0
2025	223,228	10,060	29,860	464	0	23	16	0	1	0	304	0
2026	226,778	10,219	30,334	471	0	24	16	0	1	0	303	0
2027	230,383	10,382	30,817	479	0	24	16	0	1	0	302	0
2028	234,046	10,547	31,307	486	0	24	16	0	1	0	300	0
2029	237,768	10,715	31,804	494	0	25	17	0	1	0	299	0
2030	241,548	10,885	32,310	502	0	25	17	0	1	0	298	0
2031	245,389	11,058	32,824	510	0	25	17	0	1	0	296	0
2032	249,291	11,234	33,346	518	0	26	18	0	1	0	294	0
2033	253,254	11,413	33,876	526	0	26	18	0	1	0	293	0
2034	257,281	11,594	34,415	535	0	27	18	0	1	0	291	0
2035	261,372	11,778	34,962	543	0	27	18	0	1	0	288	0
2036	265,528	11,966	35,518	552	0	28	19	0	1	0	286	0
2037	269,750	12,156	36,082	561	0	28	19	0	1	0	284	0
2038	274,039	12,349	36,656	570	0	28	19	0	1	0	281	0
2039	278,396	12,546	37,239	579	0	29	20	0	1	0	279	0
2040	282,822	12,745	37,831	588	0	29	20	0	1	0	276	0

Year	General Budget [million THB]									Emergency Budget [million THB]		
	IF	FF	O&M	Climate adaptation for roads			Climate adaptation for rails			IF	FF	O&M
				IF	FF	O&M	IF	FF	O&M			
2041	287,319	12,948	38,433	597	0	30	20	0	1	0	273	0
2042	291,888	13,154	39,044	607	0	30	21	0	1	0	270	0
2043	296,529	13,363	39,664	616	0	31	21	0	1	0	266	0
2044	301,243	13,575	40,295	626	0	31	21	0	1	0	263	0
2045	306,033	13,791	40,936	636	0	32	22	0	1	0	259	0
2046	310,899	14,010	41,587	646	0	32	22	0	1	0	255	0
2047	315,842	14,233	42,248	656	0	33	22	0	1	0	251	0
2048	320,864	14,459	42,920	667	0	33	23	0	1	0	247	0
2049	325,966	14,689	43,602	677	0	34	23	0	1	0	243	0
2050	331,149	14,923	44,295	688	0	34	23	0	1	0	238	0

Table 27 Revised incremental annual IF, FF, and O&M estimates by investment type (progressive adaptation case)

Year	General Budget [million THB]									Emergency Budget [million THB]		
	IF	FF	O&M	Climate adaptation for roads			Climate adaptation for rails			IF	FF	O&M
				IF	FF	O&M	IF	FF	O&M			
2022	0	0	0	1,327	0	66	45	0	2	0	0	0
2023	0	0	0	1,349	0	67	46	0	2	0	-19	0
2024	0	0	0	1,370	0	68	46	0	2	0	-39	0
2025	0	0	0	1,392	0	70	47	0	2	0	-60	0
2026	0	0	0	1,414	0	71	48	0	2	0	-81	0
2027	0	0	0	1,436	0	72	49	0	2	0	-103	0
2028	0	0	0	1,459	0	73	49	0	2	0	-126	0
2029	0	0	0	1,482	0	74	50	0	3	0	-150	0
2030	0	0	0	1,506	0	75	51	0	3	0	-174	0

Table 28 Revised incremental annual IF, FF, and O&M estimates by investment type (moderate adaptation case)

Year	General Budget [million THB]									Emergency Budget [million THB]		
	IF	FF	O&M	Climate adaptation for roads			Climate adaptation for rails			IF	FF	O&M
				IF	FF	O&M	IF	FF	O&M			
2022	0	0	0	442	0	22	15	0	1	0	0	0
2023	0	0	0	450	0	22	15	0	1	0	-6	0

Year	General Budget [million THB]									Emergency Budget [million THB]		
	IF	FF	O&M	Climate adaptation for roads			Climate adaptation for rails			IF	FF	O&M
				IF	FF	O&M	IF	FF	O&M			
2024	0	0	0	457	0	23	15	0	1	0	-11	0
2025	0	0	0	464	0	23	16	0	1	0	-17	0
2026	0	0	0	471	0	24	16	0	1	0	-23	0
2027	0	0	0	479	0	24	16	0	1	0	-30	0
2028	0	0	0	486	0	24	16	0	1	0	-36	0
2029	0	0	0	494	0	25	17	0	1	0	-43	0
2030	0	0	0	502	0	25	17	0	1	0	-50	0
2031	0	0	0	510	0	25	17	0	1	0	-57	0
2032	0	0	0	518	0	26	18	0	1	0	-64	0
2033	0	0	0	526	0	26	18	0	1	0	-72	0
2034	0	0	0	535	0	27	18	0	1	0	-79	0
2035	0	0	0	543	0	27	18	0	1	0	-87	0
2036	0	0	0	552	0	28	19	0	1	0	-95	0
2037	0	0	0	561	0	28	19	0	1	0	-104	0
2038	0	0	0	570	0	28	19	0	1	0	-113	0
2039	0	0	0	579	0	29	20	0	1	0	-121	0
2040	0	0	0	588	0	29	20	0	1	0	-131	0
2041	0	0	0	597	0	30	20	0	1	0	-140	0
2042	0	0	0	607	0	30	21	0	1	0	-150	0
2043	0	0	0	616	0	31	21	0	1	0	-160	0
2044	0	0	0	626	0	31	21	0	1	0	-170	0
2045	0	0	0	636	0	32	22	0	1	0	-181	0
2046	0	0	0	646	0	32	22	0	1	0	-192	0
2047	0	0	0	656	0	33	22	0	1	0	-203	0
2048	0	0	0	667	0	33	23	0	1	0	-214	0
2049	0	0	0	677	0	34	23	0	1	0	-226	0
2050	0	0	0	688	0	34	23	0	1	0	-238	0

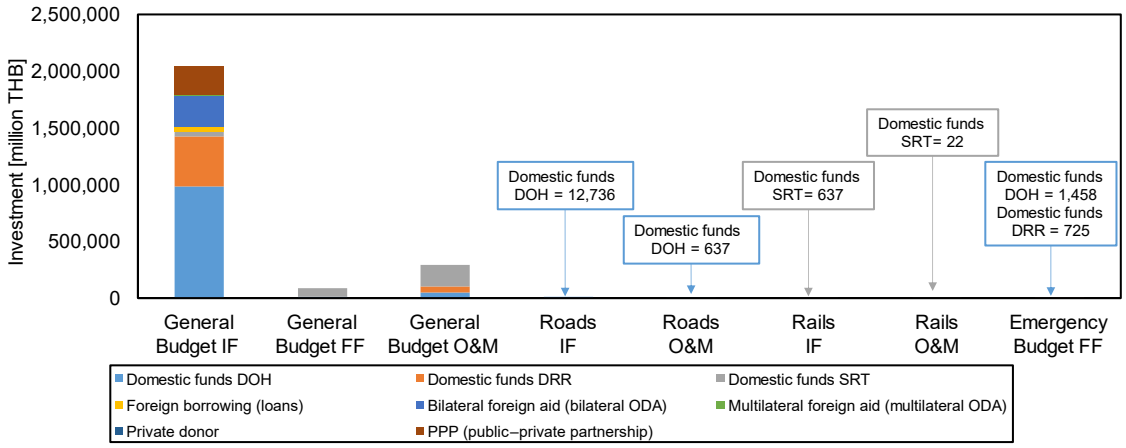

Figure 32 Adaptation scenario: revised cumulative discounted IF, FF, and O&M estimates by investment type, investment entity, and funding source (progressive adaptation case)

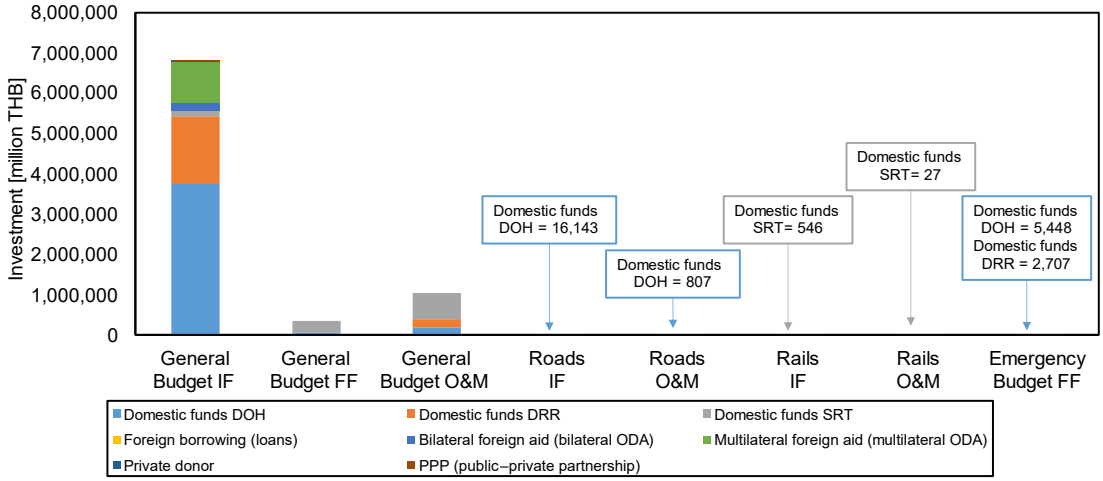

Figure 33 Adaptation scenario: revised cumulative discounted IF, FF, and O&M estimates by investment type, investment entity, and funding source (moderate adaptation case)

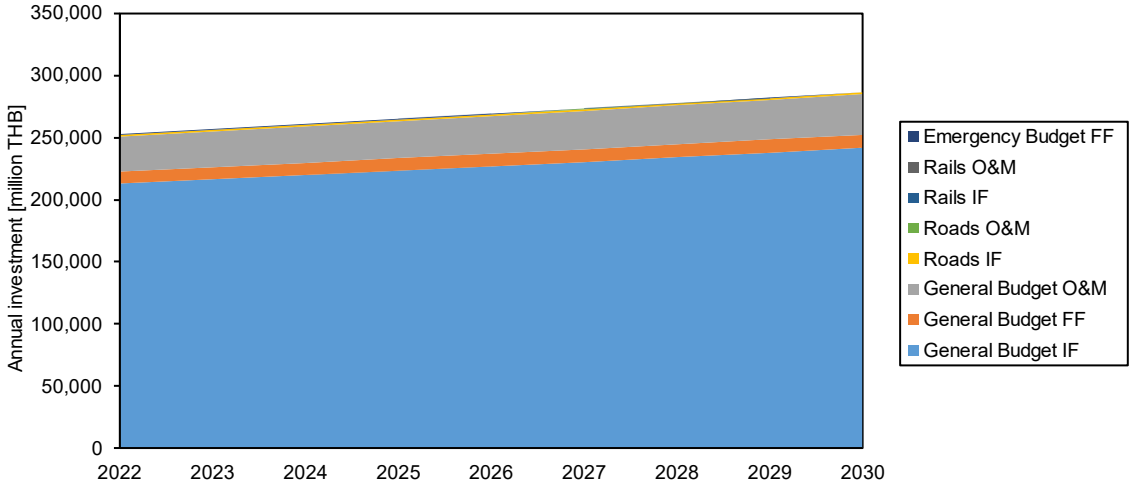

Figure 34 Adaptation scenario: revised annual IF, FF, and O&M estimates by investment type (progressive adaptation case)

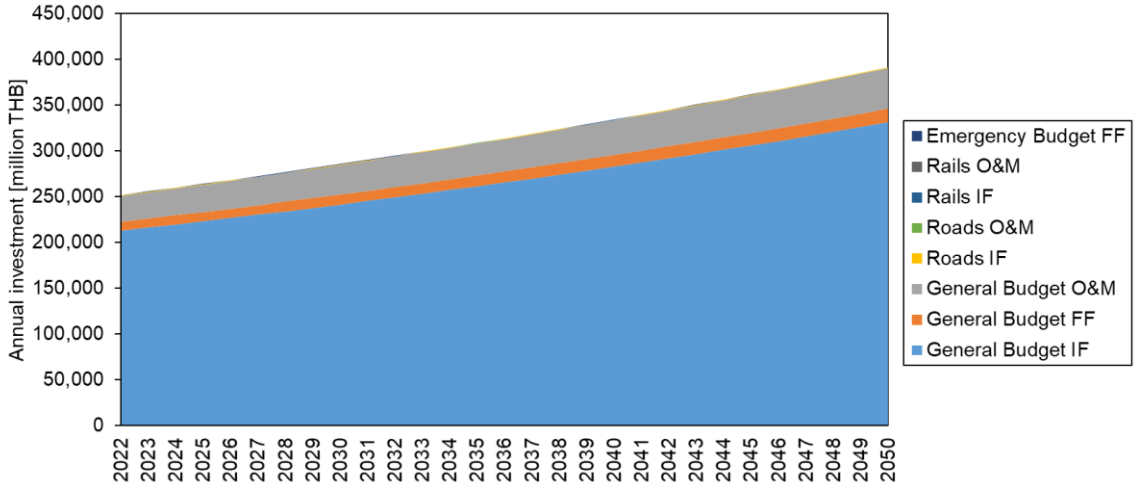

Figure 35 Adaptation scenario: revised annual IF, FF, and O&M estimates by investment type (moderate adaptation case)

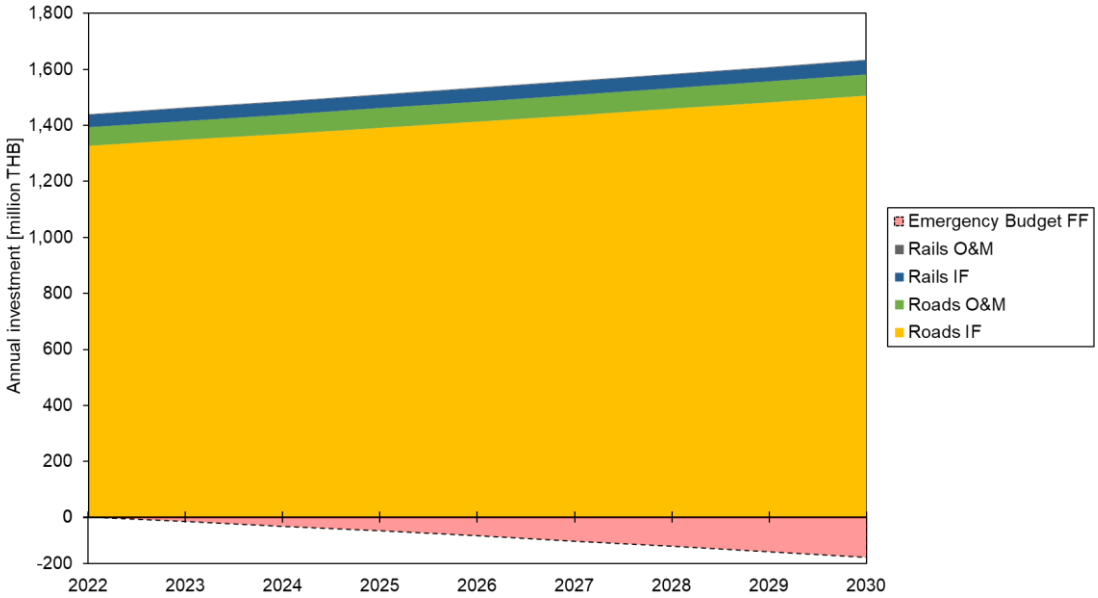

Figure 36 Revised incremental annual IF, FF, and O&M estimates by investment type (progressive adaptation case)

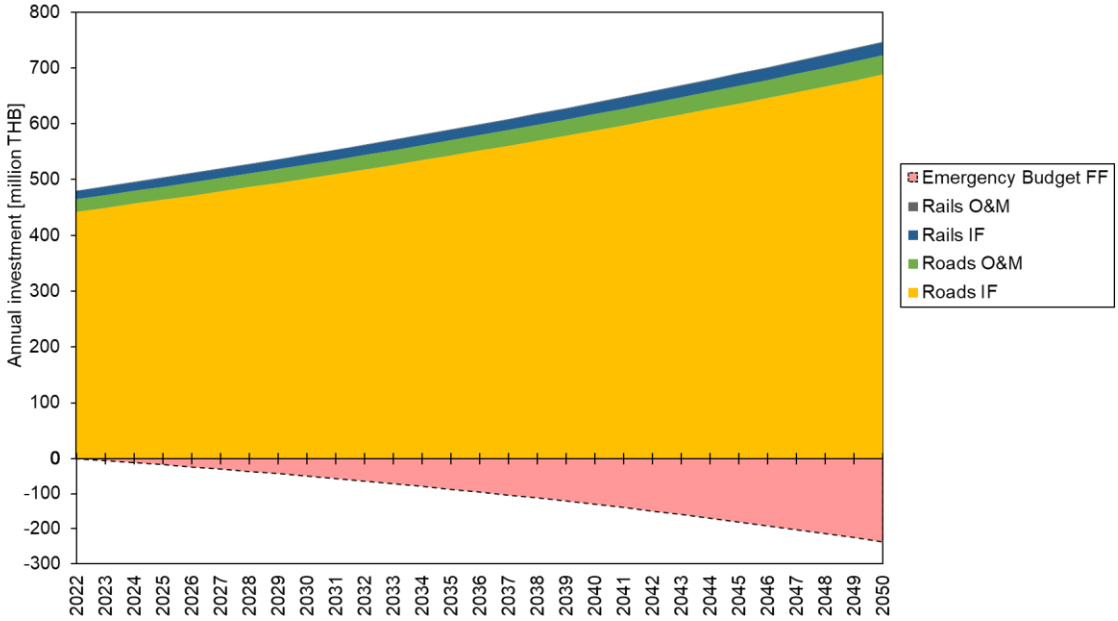

Figure 37 Revised incremental annual IF, FF, and O&M estimates by investment type (progressive adaptation case)

6.5.3 Discussion

The new matrices of both roads and rails were developed in accordance with key stakeholders' advice. All inapplicable countermeasures, namely underground tunnel and pumping water from one side to another were excluded from the investment flows to be realistic and practical. Discussion with the stakeholders also provided many important insights, which will benefit for the application of the countermeasures in each tier of roads. It was suggested that some countermeasures should not be applied to the entire road distance. In this study, drainage system improvement, ditch lining, and water passage (box culvert) were assumed to be applied to 5 percent of the total target roads to represent realistic application. However, some countermeasures, such as MSE should be applied to entire distance of the selected roads regardless of its expensive investment because the relevant entities have implemented this countermeasure to many of the roads and obtained positive results.

Even though the unit prices were slightly adjusted corresponding the advice from various contributors, the water passage (box culvert) was still the cheapest countermeasure for roads, but not for rails. MSE still resulted in the highest investment cost, followed by drainage system improvement, asphalt concrete resurfacing and laying the road higher, and ditch lining.

For railway climate-proofing investment, there were eight and two locations close by a mountain and perpendicular to a waterway, respectively, which satisfied the selection criteria. Initially, water passage (box culvert) was applied to the railways that run perpendicular to a river. But it was later changed to the location that is near by a mountain. This significantly increased the total investment of the water passage (box culvert) from its original values. SRT currently utilizes two types of bridge, namely concrete bridge and steel bridge. However, only water passage (concrete bridge construction) was included in the initial calculation which does not cover the actual operational scenarios.

The new unit cost for water passage (steel bridge construction) was thus introduced. These two-unit prices were averaged to estimate the total investment of water passage. The final price of this countermeasure was three times lower than the water passage (box culvert) since there were only two locations applicable to this countermeasure.

Since the selection of countermeasures are optimized according to the consultations with relevant stakeholders, the total investment decreased by over a half, which consequently decrease the IF, FF, and O&M estimates for climate-proofing countermeasures. This emphasizes the necessity of careful consultation with responsible organizations in order to confirm the appropriateness of the countermeasures. These consultation meetings also provided them the opportunity to realize the incremental investment, the potential decrease in emergency expenses, and start thinking about the way to get funds for climate-proofing investment.

7 Policy Options to Facilitate Climate Adaptation in Transport Sector

I&FF assessment typically provides information on incremental IF, FF, O&M costs, and subsidy costs needed for the realization of the proposed climate adaptation scenario(s). The incremental investment in this report is relatively low comparing to general budget in the sector. The investment could be financed by responsible entities using the national annual budget. However, increase in annual governmental investment to enhance climate adaptability can lead to competition with other national investment. If the urgency and importance of the climate-proofing investment are not recognized by the central government, the obtained national budget could be limited which could delay the implementation. Policy support can expedite the application of the countermeasures. Hence, the identification of local and international funding opportunities and enabling policies or mechanisms is essential for the stakeholders in order to secure sufficient financial resources for climate-proofing investment.

As previously discussed, the national budget is the primary source to support the acclimation projects. The scheme of national budgeting that can be expected for this particular investment is shown in Section 7.1. Since the world is putting more and more emphasis on climate adaptation, international aids and loans can also be another promising option for this kind of investment and should be considered right after the national budget (Section 7.6). If funding from these sources is not adequate for the total investment needed, carbon tax is another mechanism to obligate the private sector to contribute to climate adaptation (Section 7.2). The government can also make use of the Public-Private Partnership scheme to jointly invest on infrastructure construction projects (Section 7.3). However, this may not be attractive to private companies since the payback period is quite long. As additional options for the government to promote private investment, it can promote green, social, or sustainable bonds, on develop a scheme similar to carbon credit (Section 7.4 and 7.5).

7.1 Investment through National Budget

Figure 38 shows the overview of national budgeting in transportation sector in Thailand. With good coordination among relevant stakeholders, the national budget can be deemed as the initial and crucial source of funding through the flow specified in this figure. The figure includes governmental organizations responsible for the two selected modes of transportation: roads and rails, including Ministry of Transport and departments under its purview, local government organizations, and State Railway of Thailand which is a state enterprise and is not directly controlled by the Ministry of Transport. The organizations acquire four different types of budgets, in particular the annual budget, the additional budget act, the previous fiscal year budget act, and the investment out of the national budget. These budgets come from annual tax and past reserve money. Then the budget is allocated into two different categories: the operating budget and the investment budget. The investment budget can be used for IF and subsidy costs while the operating budget can be used for FF, O&M costs, and subsidy costs.

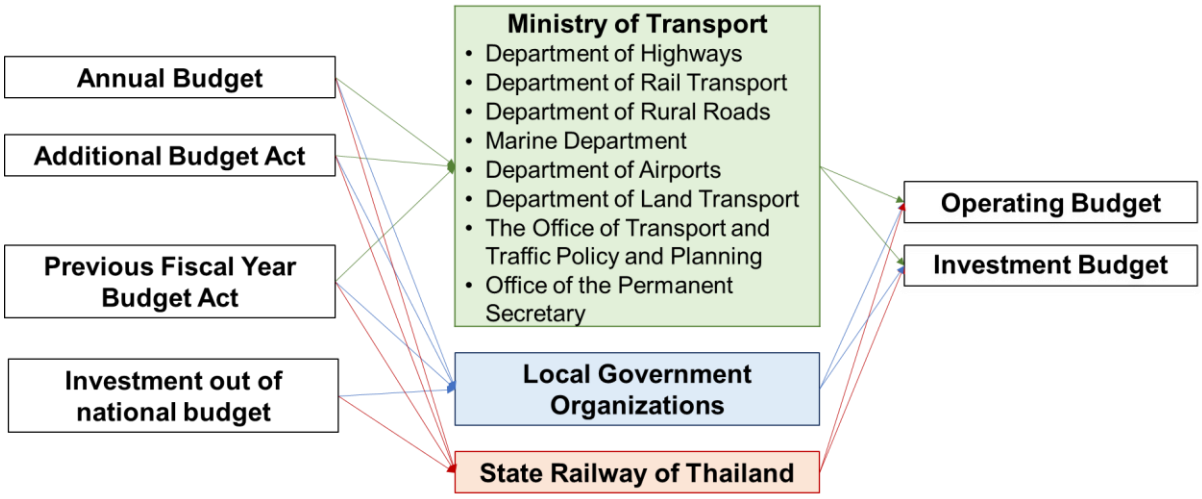

Figure 38 Flow of national budgeting for transportation in Thailand

7.2 Carbon Tax

Carbon tax has been used by many countries not only to obtain the money for climate mitigation and adaptation projects but also to encourage the industry to go for green and sustainable production. Carbon tax mainly targets hydrocarbon fuels when entering the local market. The retail prices of the fuels that are adjusted by the carbon tax will make renewable-based fuels more appealing to the customers when entering the market. However, the realization of this concept will be rather difficult if the transportation sector still relies heavily on fossil fuels. Carbon tax can lead to an economic crisis if most enterprises still count on fossil fuels in the operation of their business. For instance, the increase in fuel price from the end of 2021 to the beginning of 2022 resulted in a negative response from the market[88]. Thus, the shift from the hydrocarbon-based economy to an economy that rely more on renewable is the necessary step before introducing carbon tax to the market. Thailand has not enforced carbon tax yet. It is still a voluntary action. However, the Excise Department has already launched an investigation on the carbon emission tax in the industrial sector[89]. Carbon tax is a great idea to enforce climate mitigation and use the tax income to facilitate climate adaptation. It has already been applied in many countries. The unit price of the carbon tax varies from one country to another according to the countries' reliance on fossil fuels, the citizen response, and the economic circumstances. For instance, Japan charges 2.54 USD/tCO_2e while Singapore charges up to 10.9 USD/tCO_2e[90].

[88] Bangkok Post (2022) What's behind the oil price hike? Available at: https://www.bangkokpost.com/business/2261847/whats-behind-the-oil-price-hike-#:~:text=The%20first%20factor%20causing%20soaring,billion%20per%20month%20in%202021.
[89] Marklines (2021) Thailand excise department mulling over carbon emission tax on the industrial sector. Available at: https://www.marklines.com/en/news/259573
[90] UNDP (2018) Opportunities for carbon pricing in Vietnam. Available at: https://www1.undp.org/content/dam/vietnam/docs/Publications/Opportunities%20for%20Carbon%20Pricing%20in%20Vietnam_Eng.pdf

7.3 Promotion of Public-Private Partnership

Public-private partnership scheme provides opportunity to Thailand critical infrastructure by sharing project risks and interests among both parties. The scheme has been adopted since 1992 when The Act on Private Participation in State Undertakings Act B.E. 2535 (1992) was effective and evolved to Private Investments in State Undertakings Act B.E. 2556 (2013). Currently, Thai Cabinet puts countless effort to promote PPP for decades, creating environment for fair competition among private investors. There are 66 projects under Public Private Partnership Strategic Plan B.E. 2560 – 2564 (2017 – 2021). The plan facilitates PPP by building on vast experience, ensuring allocation of available resources with cost-effective and efficient implementation as the basis. It is also important to note that the investment is not only between government and private players, but also among private players. Government can act as either a co-borrower or a guarantor for a large loan from international banks, for example, World Bank, Asian Development Bank, Asian Infrastructure Investment Bank. With established regulations and policy support, PPP scheme can be a good way to encourage participation of private sector in climate-proofing investment.

7.4 Bonds and Financing

The aforementioned source of funding is the existing source embedded in the current governmental budgeting structure. However, since the national budget needs to cover all types of transportation-related investments, and the expected investment for climate adaptation could be limited, activities enabling climate adaptation in the transport sector might be decelerated if they rely solely on national annual budget. Therefore, the government needs to come up with a good strategy to attract climate-related investments. Green and social bonds are financial instruments used to fund projects that benefits environment or society. Thailand has recently launched sustainability bond which is a combination of green bond and social bond[91]. This brand-new finance scheme is not only just a proposed concept, but it has already started to fund many projects aiming to mitigate or adapt to climate change. As it is the nature of green bond, it allocates capital to projects with environment and climate benefits. In transport sector, a few projects have been conducted with the support of green bond. For example, some projects of the Bangkok Mass Transit System in the central of Thailand. Green bond is more common for transport sector while social bond is not so popular due to context of the sector. To apply the social bond, inclusivity aspect should be highlighted in a project.

Inclusivity should be considered at local, regional, and national levels. Particularly, transit service provision, inclusion of transport-disadvantaged groups, and equality in transit access and usage need to be ensured. Preventing loss of education, job and other opportunities, the aspect becomes more important when applying countermeasures to transport sector. In some cases, in rural areas, transit options to travel from a destination to another are fewer than urban areas. Railway and local bus services with limited routes are primary options and users can select to use only one of them for the whole journey since the departure times and traveling

[91] Securities and Exchange Commission (2019) Seminar on development of green bond in Thailand. Available at: https://www.set.or.th/dat/vdoArticle/attachFile/AttachFile_1571630161182.pdf

routes are entirely different. In this sense, disruption due to a natural event can significantly affect daily activities of the people, especially those who heavily rely on public transportation. Unavailability of the service prevents them from reaching the destinations and may consequently rips off their opportunity. Children may not be able to go to schools. Women may not be able to go pursue their daily work. Taking climate-proofing countermeasures into consideration in transport plan and policies can protect many opportunities loss derived by natural events. Highlighting inclusivity in the project, social bond can become another source of funding. In addition, a climate-friendly project with inclusivity aspect can be qualified for sustainability bond. According to public data provided by the Public Debt Management Office under the Ministry of Finance (MOF) in 2020, more than 60 billion THB has been issued under the scheme of sustainability bond to attract diverse investors inside and outside the country[92].

7.5 Carbon Credit

Carbon credit originally was born in 1997 at the United Framework Convention on Climate Change (UNFCCC) in Kyoto, Japan, to facilitate Clean Development Mechanism (CDM)[93]. It was proposed and expected to be one of the methods to reduce the emission of carbon dioxide and other greenhouse gases. The carbon credit acts as the status or permission to emit pollutants into the ambient environment. It creates good opportunities for the individual, private enterprise, or local administration to generate the credit, offset their emission, and trade the left-over credit with other entities who generate above the emission credit. It motivates private companies to participate in the scheme and invest more in low carbon energy because they get benefits from selling out the credit for emission reduction to other local or foreign entities that need to counterbalance their emission. The exchange of the credit in the market is commonly referred to as the cap-and-trade system or emission trading system (ETS)[94]. However, the exchange between the demand and supply may require the middle entities to facilitate and ensure a fair-trading scheme. Thailand recently has just launched a carbon credit exchange platform which is one of the initiatives of driving the Thai industry toward renewable energy[95]. The Ministry of Natural Resources and Environment (MNRE) with the cooperation with the Federation of Thai Industries (FTI) has established RE100 Thailand Club which acts as the trading center for both demand and supply sides. Right now, more than 500 institutions have already registered as a member of the RE100 Thailand Club[96].

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[92] Public Debt Management Office (2020) The kingdom of Thailand's inaugural sustainability bond issuance is well re received. Available at: https://www.pdmo.go.th/pdmomedia/documents/2020/Aug/Press%20Sustainability%20Bond%20v5.pdf

[93] Will Kenton (2021) Carbon credit. Available at: https://www.investopedia.com/terms/c/carbon_credit.asp#:~:text=A%20carbon%20credit%20is%20a,one%20ton%20of%20carbon%20dioxide.

[94] The World Bank (2022) What is carbon pricing. Available at: https://www.worldbank.org/en/programs/pricing-carbon#a

[95] Bangkok Business (2021) Launching of Thailand carbon credit exchange platform, a central platform for buying-selling green carbon (Translated from Thai). Available at: https://www.bangkokbiznews.com/business/948667

[96] RE100 (2022) Homepage of RE100 Thailand Club. Available at: https://re100th.org/en/re100-eng/

As can be seen above, carbon credit is a concept that can significantly facilitate the engagement of private sector in investment on carbon emission reduction, i.e., climate mitigation. If climate adaptation investments can be included as a part of this existing scheme, or if we can establish a separate scheme similar to carbon credit, it will create an opportunity for private sector to contribute to climate adaptation in transportation sector.

7.6 International Funds and Loans

Apart from the domestic source of funding, many foreign funds are available to facilitate the implementation of each country according to the pledge made at COP26. One of the main goals of COP26 was to accelerate international climate financing to reach up to $100 billion[97]. Financing is expected to come from developed countries, such as the United States, England, Germany, Canada, France, Japan, China, and so on. Special funds for developing countries to mitigate and adapt to climate change have been created across the globe, e.g., Climate Investment Funds (CIF)[98], Green Climate Fund (GCF)[99], Clean Technology Fund[100], Global Environment Facility (GEF)[101], Special Climate Change Fund (SCCF)[102], and Investment Framework for Green Growth (OECD)[103]. These are well-established funding programs which policymakers can consider as the external sources of funding. For example, the Climate Investment Fund (CIF) was launched back in 2008 and the goal was to facilitate developing countries both technically and financially to shift to low carbon and climate-resilient society. At the end of 2021, Malaysia underwent a deadly flood in Negeri Sembilan, resulting in road closures and needs to mobilize nearly 70,000 people[104]. Due to this reason, the Minister of Environment of Malaysia has requested approximately $3 million from GCF to strengthen the national plan to deal with climate change and its effects. The budget is essentially for water, agricultural and food security, public health, forestry, and infrastructure reconstruction, including transport infrastructure. Additionally, loans for climate-proofing projects can be expected from international banks, for instance, World Bank, Asian Development Bank, and Asian Infrastructure Investment Bank. These banks are providing increasing amount of loans to climate-friendly and sustainability-linked projects. Yet it is to be noted that international banks generally provide loans to promising projects with high return on investment; and hence, the interest can be rather high comparing

[97] COP26 (2021) Climate finance delivery plan: meeting the US$100 billion goal. Available at: https://ukcop26.org/wp-content/uploads/2021/10/Climate-Finance-Delivery-Plan-1.pdf
[98] Climate Investment Funds. Available at: https://www.climateinvestmentfunds.org/
[99] Green Climate Fund. Available at: https://www.greenclimate.fund/
[100] Clean Technology Fund. Available at: https://climatefundsupdate.org/the-funds/clean-technology-fund/
[101] Global Environmental Facility. Available at: https://www.thegef.org/
[102] The Special Climate Change Fund. Available at: https://unfccc.int/topics/climate-finance/resources/reports-of-the-special-climate-change-fund#:~:text=The%20Special%20Climate%20Change%20Fund%20(SCCF)%20was%20established%20under%20the,waste%20management%3B%20and%20economic%20diversification.
[103] OECD (2021) Investment for green growth. Available at: https://www.oecd.org/investment/green.htm
[104] Rozanna Latiff (2021) Malaysia seeks U.N. climate adaptation funds amid deadly floods. Available at: https://www.reuters.com/markets/commodities/malaysia-seeks-un-climate-adaptation-funds-amid-deadly-floods-2021-12-27/

to domestic banks. However, since investment in critical infrastructure often requires large amount of cash layout, it would be difficult to convince domestic banks to provide the loans. Therefore, it is necessary to carefully evaluate the feasibility of the climate-proofing projects before relying on the international loans.

8 Recommendations and Way Forward

8.1 Conclusions

This final report summarized the efforts of Thai government in initiating climate adaptation investment in transportation sector. This was an extension to the preceding cost-benefit analysis which demonstrated that the investment on selected climate-proofing countermeasures focusing on adaptation to floods of specific routes would be economically feasible. To explore whether the finding would be applicable to the whole transportation sector in Thailand, an investment and financial flow assessment was carried out covering the entire roads owned by Department of Highways (DOH) and Department of Rural Roads (DRR), and the entire rails owned by State Railway of Thailand (SRT). This report determined the country's baseline scenarios corresponding to the efforts of Thai government and private sector in the investment to address climate issues for the whole transportation sector. The scope of the investment narrows down to domestic efforts including DOH, DRR, and SRT investments, and international efforts including international loans and aids, and public-private partnership (PPP). All investment figures were collected and used to determine the country's baseline. A matrix was developed covering possible countermeasures for roads and rails based on domestic and international experience. Consultation meetings were held with the Office of Transport and Traffic Policy and planning (OTP), DOH, DRR, and SRT to determine the reasonable total investment on selected countermeasures to be used for the development of investment and financial flows of the adaptation scenario. Speaking of the timeframes, the report adopted two milestones indicated in the Nationally Determined Contribution (NDC): 2022-2030 (progressive adaptation case) and 2022-2050 (moderate adaptation case) as the timeframes for both scenarios. Candidates for road adaptation countermeasures include drainage system improvement and ditch lining which are flood management countermeasures; installation of box culverts, asphalt concrete resurfacing and laying the road higher which aim for flood avoidance; and mechanically stabilized earthwall which is a countermeasure for structure reinforcement. Candidates for rail adaptation countermeasures include water passage in the forms of box culvert or bridge construction for flood management, and sleeper replacement and ballast refill for structure reinforcement. Target roads and rails were classified into tiers according to their importance, and only parts that are vulnerable to floods were selected as the targets of the study. Unit price of each countermeasure was estimated based on domestic and international past experience, in order to develop the matrix that show the approximate investment for each countermeasure when implemented on selected tier of roads or rails. However, since the countermeasures will not be applicable to the entire length of the target roads and rails, it is necessary to introduce a factor to indicate the actual length of the roads or rails where the countermeasures should be applied. It was also suggested that road countermeasures should be implemented only on tiers 1 and 2 roads, and rail countermeasure should be implemented only on tier 1 rails. All key organizations recommended a more thorough investigation of roads and rails in order to select the most suitable set of countermeasures for each route. Based on the aforementioned suggestions, the total investments on climate adaptation of roads and rails could be estimated. To realize the total investment of baseline scenario in the target sector,

cumulative discounted and annual IF, FF and O&M estimates were explored. The total investment in adaptation scenario was assessed by adding IF, FF, and O&M of investment on climate-proofing countermeasures and the assumption of decrease in emergency expenditures on top of the cumulative discounted and annual IF, FF and O&M estimates of the baseline scenario. Essentially, incremental annual IF, FF and O&M estimates were assessed by subtracting baseline scenario annual estimates from adaptation scenario annual estimates. This shows the differences in additional investment in a chronological manner. Comparing incremental estimates of progressive adaptation case and moderate adaptation case, stakeholders can realize the relationship between the annual incremental investment and the length of timeframe. To increase participation from relevant stakeholders, it is important to note that policies to facilitate further government and private investment, and mobilization of international funds to Thailand would be inevitable to enable this large-scale and long-term climate adaptation investment in transportation sector.

8.2 Policy Implications and Recommendations

As stated above, the annual investment budget allocated for DOH, DRR, and SRT is much larger than the annual investment and operation and maintenance expenses for the proposed climate adaptation countermeasures. Therefore, it would not be very difficult to allocate budget for climate adaptation investment once the relevant stakeholders realize the necessity, the benefits from the investment, and the fact that the additional investment for acclimation can reduce the need for national emergency budget. Office of Natural Resources and Environmental Policy and Planning (ONEP) needs to set a clear national goal for climate adaptation and joins hands with Office of Transport and Traffic Policy and Planning (OTP) to set specific target(s) for transportation sector. Necessity of the implementation of climate-proofing countermeasures along with their economic and political viabilities must be clearly communicated to all organizations that are responsible for the implementation of the countermeasures: DOH, DRR, and SRT. Since national budget has to be spent in an optimized manner, the justification of the investment should be done in consultation with Bureau of the Budget (BB) which approves the usage of national budget, and Comptroller General's Department (CGD) which ensures lawful use of the budget. Throughout the discussions among stakeholders, technical support regarding climate change, disaster risk reduction, and weather statistics could be obtained from Thailand Greenhouse Gas Management Organization (TGO), Department of Disaster Prevention and Mitigation (DDPM), and Thai Meteorological Department (TMD), respectively. If the aforementioned stakeholders understand the necessity and believe in the feasibility of the climate adaptation countermeasures, significant amount of investment can be expected from the national budget.

There are several policy options to facilitate and accelerate government investment. Carbon tax is a means adopted by many countries to receive revenue in terms of tax from greenhouse gas emitters and use it to invest in climate change mitigation and adaptation. Implementation of carbon tax in Thailand, especially in industrial sector, is being promoted by TGO. If the revenue through carbon tax reaches the required annual investment on the proposed countermeasures, climate adaptation investment can be done without disturbing other investments planned by DOH, DRR, and SRT. Another option that would facilitate government green

investment is international funds, e.g., Climate Investment Funds (CIF), Green Climate Fund (GCF), Clean Technology Fund, Global Environment Facility (GEF), Special Climate Change Fund (SCCF), Investment Framework for Green Growth (OECD).

The private sector can also play a very important role in climate adaptation investment. This can happen especially when the countermeasures directly or indirectly benefit the private companies, e.g., enhance the climate adaptability of the roads around the industrial estate, contribute to corporate branding for companies that aim to build an image of environmental-friendly and sustainable corporate. If climate adaptation investments can be included as a part of the carbon credit scheme, or if we can establish a separate scheme similar to it, private sector will be able to contribute to climate adaptation in transportation sector. Government can also provide incentives to expedite private investment on climate adaptation which can be in terms of financial incentives or tax exemptions. In addition, Bank of Thailand (BOT) could promote sustainable banking and financing, and the Office of Board of Investment (BOI) may promote climate-related investment both in Thailand and Thai overseas. Securities and Exchange Commission (SEC) is another organization that can play a vital role in supporting Thai firms in issuing sustainability-linked bond (SLB) which will ease private investment in climate adaptation. For the cases that the climate-proofing investment benefits both government and private sector, public-private partnership (PPP) mechanism can be used to assist the investment. However, government needs to ensure smooth procurement and minimize various risks: political risks, business risks, and technical risks.

8.3 Constraints, Risks, and Uncertainties

The main constraint of the implementation of countermeasures to adapt to floods on roads running along a river/canal or rails running perpendicular to a river/canal happens at the decision-making phase. Lands around rivers or canals often belong to the state. Construction related to state properties must be permitted and approved by Treasury Department (TD). As the rivers/canals are basically used by Royal Irrigation Department (RID) to facilitate agricultural activities of the people living along those rivers/canals, DOH, DRR, or SRT shall make an agreement with RID and enclose the consent letter when submitting the request to TD. If a nationwide implementation of climate-proofing countermeasures is expected, aforementioned stakeholders should discuss to establish a mechanism to ease this procedure.

There could also be constraints emerged from the society that could impede the climate adaptation investment. Constructing the roads and rails could bring inconveniences to the communities around which may lead to public opposition. Environmental Impact Assessment (EIA) which is required for a large-scale construction basically include public hearing during the assessment, and this could assist public understanding towards the investment, the construction, and the contribution of the investment on climate adaptation. Another possible constraint is the relation between politicians and citizens which could result in benefits for a particular group of people and short-termism. Implementing organizations have to always be aware of these possible constraints and find the ways to avoid them.

Several types of technical, regulatory, or political risks and uncertainties during the implementation of the countermeasures may result in project delay, or even

project termination, e.g., insufficient experience of subcontractors, unsuccessful contract negotiation, complicated regulatory procedure, failure in cooperation with local administrative organizations. Project implementing organizations, i.e., DOH, DRR, and SRT shall be aware of these risks and try to minimize them. Apart from these risks, there are external risks which are often uncontrollable, e.g., changes in global trends, changes in international geopolitics, or changes in national directions. These could possibly turn down all planned projects. All involved stakeholders must be aware of these external risks and prepare to be able to adapt to the changes in case they happen.

8.4 Way Forward

With this study on investment and financial flow assessment of climate adaptation investment in transportation sector in Thailand, target roads and rails (which were classified into tiers) as well as climate adaptation countermeasures (which were categorized based on their functions) were identified. The study further pointed out the possible required investments and their flows, involved stakeholders and the way they interact, and the policy options to enable and facilitate the investment. The next step would be to motivate the stakeholders to actually invest on climate adaptation.

- For indirect stakeholders that are not familiar with the concept of climate adaptation and its contribution to resilience of transportation sector against climate change, meetings or workshops to urge their awareness on the importance of the topic and the necessity of timely implementation of the countermeasures are needed.
- For stakeholders that have realized the significance of climate adaptation in transportation sector, meetings, workshops, or hands-on activities to deepen the understanding on the countermeasures, the ways to facilitate the investment, and the ways to successfully implement the countermeasures and sustain the resulting infrastructure are needed.
- Meetings or workshops to explore domestic funding entities and mechanisms that can contribute to climate-proofing investments, as well as to identify external funding that can be obtained from private sector or international funds should also be held.
- Estimated incremental investment obtained from the I&FF assessments paved forward the ways to materialize the proposed adaptation scenario. Promising pathways should be built upon by responsible organizations to actualize financial activities and policy support. Collaboration among major stakeholders is encouraged in order to further promote climate adaptation investment in transport sector by jointly establishing clear action plan and timeline.
- Finally, a pilot project to explore the practicalities of different climate adaptation countermeasures and their applicability to selected target roads or rails and estimate the actual expenditure on those countermeasures needs to be carried out to validate the results of this investment and financial flow assessment.

8.5 Feedback to UNDP I&FF methodology and lessons learned from I&FF assessments

The implementation of I&FF assessment of climate adaptation investment in transportation sector according to the UNDP methodology helped the responsible organizations recognize the necessity and urgency of climate-proofing investment in the sector and provide a broad picture of the needed cumulative investments and their flows. Generally, the methodology was well-established providing detailed instructions that guide the assessors throughout the assessment. The approach of having a general guideline for the methodology being accompanied by case studies for the assessors to learn how they can tailor the assessment to match their sector(s) seems to be appropriate. Even though there has not been an I&FF assessment for climate adaptation investment particularly for the transport sector, the assessing team could recognize specific needs for this I&FF assessment by referring to the case studies of climate mitigation investment of transportation sector or climate adaptation investment of other sectors. Yet there are quite a number of lessons that the team learned along the journey of the I&FF assessment that we believe would be beneficial for one who would like to perform such assessments.

The team started from a cost-benefit analysis (CBA) that suggested that many of the proposed climate adaptation countermeasures are economically feasible and are worth being further considered for the actual implementation to increase the national climate adaptability of the transportation sector. Therefore, the team proceeded further to the I&FF assessment. However, even if the countermeasures resulted in a great deal of indirect benefits, it would be difficult to invite the stakeholders to consider a large-scale investment unless the countermeasures are economically feasible with their direct economic benefits. In addition, since CBA is basically performed on a case-by-case basis, it is not as simple as assuming that the countermeasures that are deemed feasible in the CBA can be extended to infrastructures with similar conditions across the country. This is the reason that this report revisited all plausible countermeasures, reconfirmed their viability with major stakeholders, re-identified target roads and rails where the countermeasures could enhance their climate adaptability, and constructed the matrices that show possible combinations of countermeasures and target roads/rails. It would be beneficial to the future assessors if there is a guideline on how the combinations of countermeasures and target infrastructures should be explored, and how the total investment to be used for the adaptation scenario can be determined.

Moving to the UNDP methodology for I&FF assessment, though the manual provides a step-by-step guideline for the assessment, it seems that climate mitigation investment was used to design the methodology which somehow makes the assessor lost at some steps of the assessment. For example, though it is relatively straightforward to extract existing investment on climate mitigation to develop the baseline scenario since we can simply extract all investments related to greenhouse gas emission reductions, it is hard to distinguish investment to enhance the climate adaptability of the infrastructure from the investment to simply strengthen it. Another example is the determination of adaptation scenario, it is again difficult to have a scenario that all parties agree upon since there is no explicit adaptation target while it is a clear target for greenhouse gas emission reduction which the climate mitigation investment can be designed to fulfill. This was the actual problem the team faced while

conducting the assessment, and it would be very helpful to the future assessors if there are suggestions on how to determine the scope of consideration for baseline and adaptation scenarios. This is because appropriate determination of the baseline and adaptation scenarios is inevitable to the smooth estimation of IF, FF, O&M, and incremental investment. Therefore, it is advisable for the assessors to go back and forth between scenario development and data gathering to ensure that the scenarios suit the purpose of the assessment and look acceptable to all major stakeholders, and that all available data are properly gathered and synthesized.

Apart from the feedback and lessons learned related to the UNDP methodology, there were several obstacles the team faced during the assessment which are worth sharing so that the future assessors can prepare themselves and develop the strategy to deal with. First is the issue of data availability. It was difficult to find a documentation on an adaptation target or action plan for transportation sector. Exploring historical data on investment to strengthen the road or rail infrastructure, the team could hardly differentiate the investments for climate adaptation from those for other purposes. This is a critical issue because it requires effort to make numerous assumptions to be able to estimate IF, FF, and O&M if the historical data on existing investments which is used to develop the baseline scenario or on planned investment which is necessity for the determination of the adaptation scenario is not available. Next is the issue of outliers or one-time events. In most studies, the unplanned or emergency expenditures are expected to gradually increase with the intensity of climate change. This is true to some extent; for instance, climate change increases the annual rainfall which could result in more frequent or longer floods. The final issue is the difficulty in finding correct representative(s) from the responsible organizations, especially the organizations that are not directly involved with climate adaptation or transportation. For example, though the Bureau of the Budget is an important stakeholder that determines whether the national budget can be used for climate adaptation investment, the topic is often out of the scope of interest of the representative. Even for the directly related organizations, climate-related investments in transportation sector have been focusing on aftermath of disasters, and it is sometimes difficult to convince the representatives that it is important to invest on climate adaptation before the infrastructures are damaged. Tireless communication to increase the stakeholders' awareness of the significance of climate adaptation in the transportation sector is the key to the success of future climate adaptation investments.

Appendix 1: Consultation Meeting with OTP

Consultation Meeting: Office of Transport and Traffic Policy and Planning (OTP)
Online Venue: virtual meeting via Zoom on February 15th, 2022

About the meeting

The consultation meeting with Office of Transport and Traffic Policy and Planning was held virtually through Zoom which was scheduled from 10:00 am to 11:00 am on February 15th, 2022. The meeting aimed to present I&FF assessment primarily result. Dr. Nuwong and Dr. Kampanart presented background and importance of climate-proofing investment and financial mechanism, followed by goals of I&FF assessment of investment on climate adaptation in transport sector in Thailand. Later, scope of the assessment, adaptation scenario, and various countermeasures for road and rail transports were introduced. Each countermeasure has been studied carefully and comes up with unit price. Technical and political viability, including involved stakeholders and potential constraints has been investigated in order to ensure the implication of countermeasures. Dr. Kampanart had presented road and rail classification, and countermeasure categorization procedures in detail. He also descriptively pictured the investment scales for each countermeasure towards aiming targets of road and rail. Throughout the presentation, policy options were also provided.

Main contribution

Based on the experience and vast knowledge of OTP and UNDP officers, the assessment was clearly in detail and the presented countermeasures and aiming targets for road and rail were full of detail. They gave comments upon the selecting targets that further projects in incoming year should have onsite observation in order to understand the actual condition to implement the countermeasures. Public-private partnership become an interesting way for transport infrastructure investment. However, emission reduction should be shown explicitly and measured to ensure the public sector participation. Furthermore, while public sector placed importance to economic benefits, sustainability fund and sustainable finance initiative of Thailand are potential to carry out. At the end of the meeting, OTP and UNDP officers agreed upon the consultation meetings with closely involved stakeholders which are DRR, DOH, and SRT. Finally, to publicize the results of study, workshop will be conducted and include all relevant stakeholders.

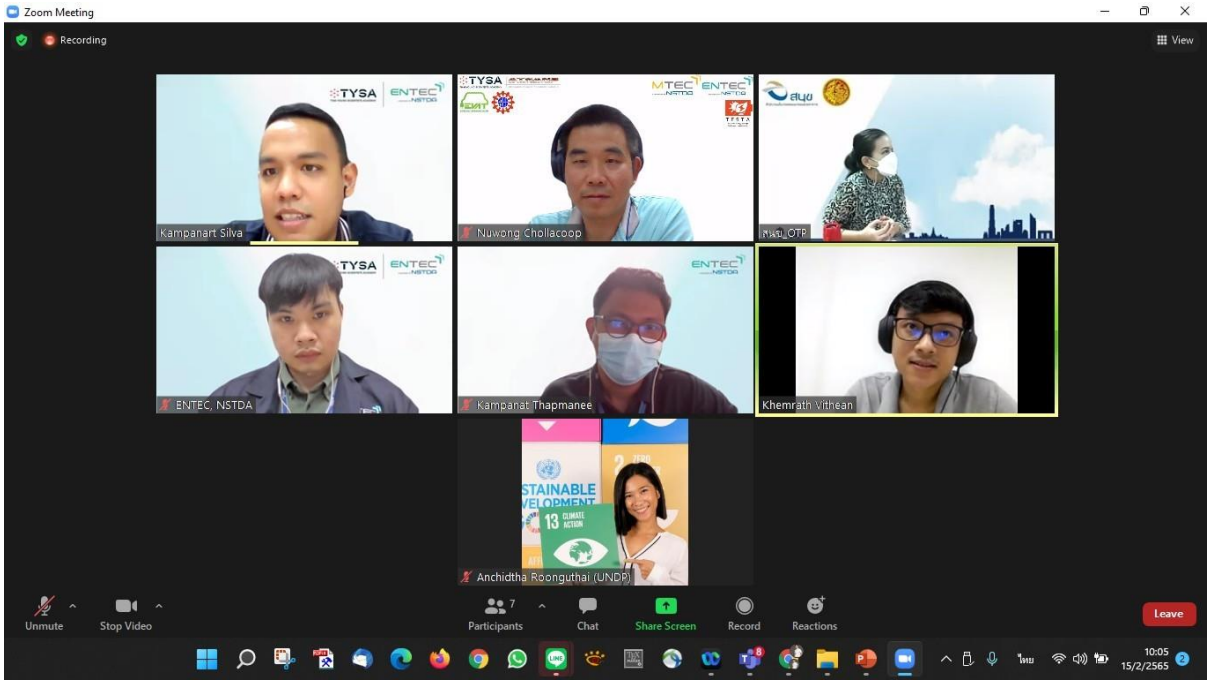
Meeting participants

The following Table 29 shows participating members of the first consultation meeting with Office of Transport and Traffic Policy and Planning which is a total of 7 attendees, comprised of 1 attendee from OTP, 1 attendee from UNDP, and 5 attendees from ENTEC.

Table 29 List of participants in the first meeting with Office of Transport and Traffic Policy and Planning (OTP)

No.	Name	Position	Organization
1	Mrs. Chutinthorn Mankhong	Chief	Office of Transport and Traffic Policy and planning (OTP)
2	Ms. Anchidtha Roonguthai	Project Manager	United Nations Development Programme (UNDP)
3	Mr. Nuwong Chollacoop	Renewable Energy and Energy Efficiency Research Team Leader	National Energy Technology Center (ENTEC)
4	Mr. Kampanart Silva	Researcher	National Energy Technology Center (ENTEC)
5	Mr. Kampanat Thapmanee	Researcher Assistant	National Energy Technology Center (ENTEC)
6	Mr. Pidpong Janta	Researcher Assistant	National Energy Technology Center (ENTEC)
7	Mr. Khemrath Vithean	Researcher Assistant	National Energy Technology Center (ENTEC)

Photo gallery




Recording...
You are viewing Kampanart Silva's screen
View Options
View
ENTEC
a member of NSTDA
I&FF Assessment
Primary Results
Nuwong Chollacoop, Ph.D.
Kampanart Silva, Ph.D.
Renewable Energy and Energy Efficiency Research Team
National Energy Technology Center (ENTEC)
National Science and Technology Development Agency (NSTDA)
nuwong.cho@entec.or.th
TYSA
ENTEC
Kampanart Silva
Unmute
Start Video
Security
Participants
7
Polls
Chat
Share Screen
Pause/Stop Recording
Breakout Rooms
Reactions
More
End

Appendix 2: Consultation Meeting with DOH

Consultation Meeting: Department of Highways (DOH)
Online Venue: virtual meeting via Zoom on February 24th, 2022

About the meeting

The consultation meeting with representatives of Department of Highways (DOH) was held virtually and scheduled from 10:30 – 11:30 am on February 24th, 2022. The meeting, led by National Energy Technology Center (ENTEC) team along with observers from the Office of Transport and Traffic Policy and planning (OTP) and United Nations Development Programme (UNDP), introduces the background of the project "Economic Analysis of Climate-Proofing Investment in Road and Rail Transport Sectors" to the representatives from DOH. Dr. Nuwong and Dr. Kampanart presented importance of climate-proofing investment and enabling financial mechanism, which was the motivation of this I&FF assessment. Technical viability of the proposed climate-proofing countermeasures and political viability including involved stakeholders and constrains towards countermeasure applications were explained in detail. Essentially, various countermeasures, screening criteria and road classification primarily designed by ENTEC were introduced, expecting for fruitful feedback.

Main contribution

Throughout the back-and-forth discussion between ENTEC and DOH representatives, feedback was given on road classification, validity and actual implementation of the proposed countermeasures along with the appropriateness of the assumptions for unit price estimation. DOH representatives advised that road classification varied based on the purpose of the project, in which road width and volume of vehicle are commonly practical. The officers also described how the road width is estimated and suggested to update them to the commonly used values. DOH offered to assist in finding further road width-related information. Speaking of countermeasures, the discussion placed importance on how assumptions for unit price estimation of each countermeasure were derived, implicitly suggesting that some of them may need to be revisited and revised, especially box culvert, water pumping, road leveling and resurfacing. Additionally, attention is called for regarding the implementation of several countermeasures as the construction should be done selectively and effectively, e.g., ditch lining, drainage system improvement, water pumping, and road leveling and resurfacing. ENTEC may need to introduce factors when considering the applicable distance for aforementioned countermeasures. The head of DOH also emphasized the time-consuming nature of concrete surfacing to which attention has to be paid during the selection of the countermeasures.

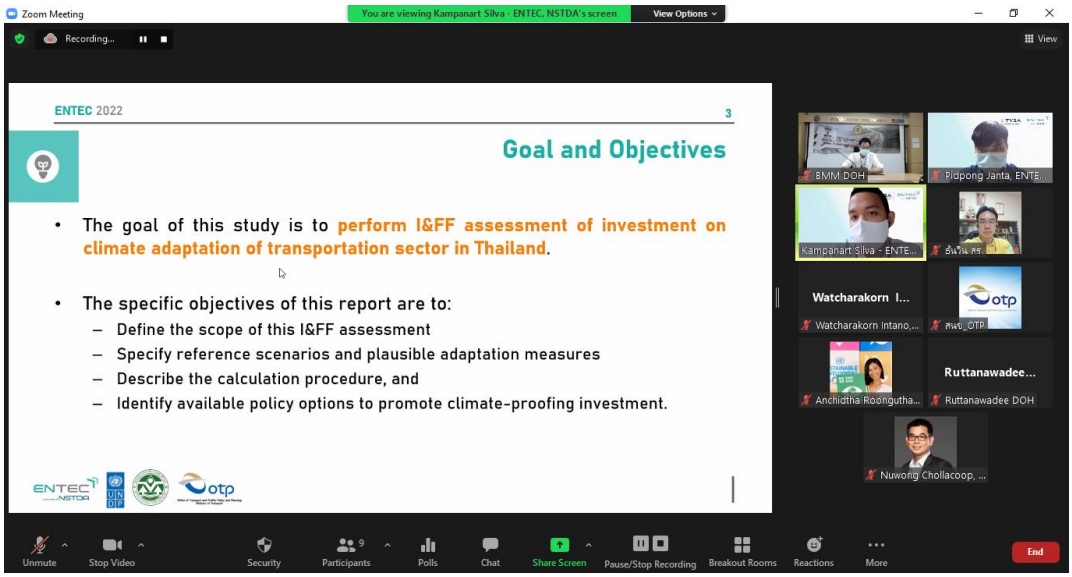
Meeting participants

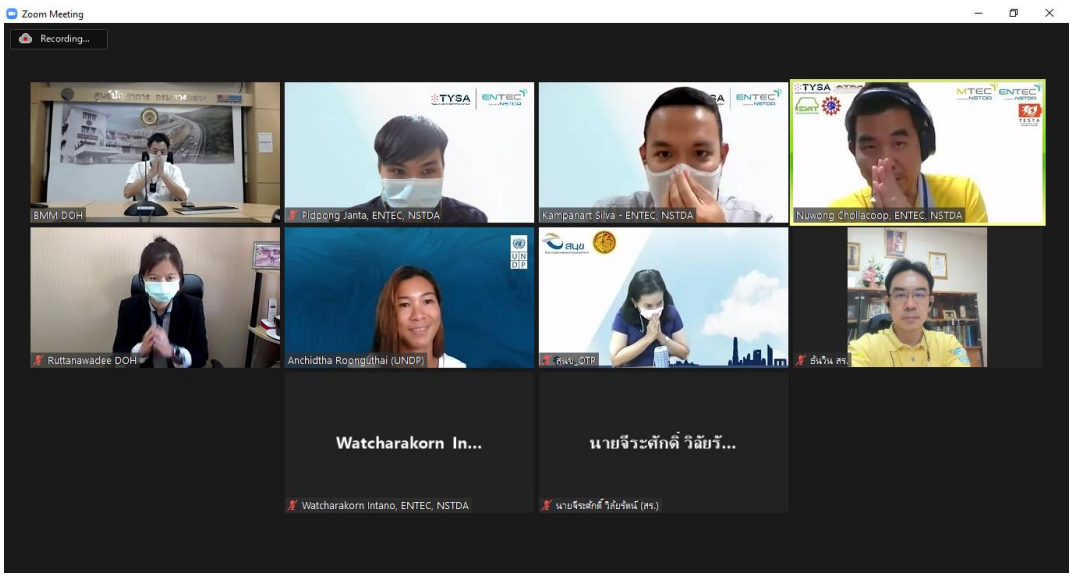
The following Table 30 shows participating members of the second consultation meeting with Department of Highways which is a total of 12 attendees, comprised of 4 attendees from DOH, 3 attendees from OTP, 1 attendee from UNDP, and 4 attendees from ENTEC.

Table 30 List of participants in the second meeting with Department of Highways (DOH)

No.	Name	Position	Organization
1	Mrs. Chutinthorn Mankhong	Chief	Office of Transport and Traffic Policy and planning (OTP)
2	Ms. Supanat Chalermsupanimit	Policy and Plan Analyst, Professional level	Office of Transport and Traffic Policy and planning (OTP)
3	Mr. Varut Fuangthin	Policy and Plan Analyst, Practitioner Level	Office of Transport and Traffic Policy and planning (OTP)
4	Ms. Anchidtha Roonguthai	Project Manager	United Nations Development Programme (UNDP)
5		Civil Engineer, Expert Level	Department of Highways (DOH)
6	Dr. Tunwin Svasdisant	Civil Engineer, Expert Level	Department of Highways (DOH)
7	Ms. Ruttanawadee Phukham	Civil Engineer, Professional Level	Department of Highways (DOH)
8	Ms. Suladda Sapsin	Civil Engineer, Professional Level	Department of Highways (DOH)
9	Mr. Nuwong Chollacoop	Renewable Energy and Energy Efficiency Research Team Leader	National Energy Technology Center (ENTEC)
10	Mr. Kampanart Silva	Researcher	National Energy Technology Center (ENTEC)
11	Mr. Pidpong Janta	Researcher Assistant	National Energy Technology Center (ENTEC)
12	Mr. Watcharakorn Intano	Researcher Assistant	National Energy Technology Center (ENTEC)

Photo gallery





Appendix 3: Consultation Meeting with DRR

Consultation Meeting: Department of Rural Roads (DRR)
Online Venue: virtual meeting via Zoom on February 24th, 2022

About the meeting

The consultation meeting with Department of Rural Roads (DRR) was held virtually through Zoom which was scheduled from 13:00 am to 14:00 am on February 24th, 2022. The meeting aimed to present overview of "Economic Analysis of Climate-Proofing Investment in Road and Rail Transport Sectors" project and cooperate with Department of Rural Roads for feedback. National Energy Technology Center (ENTEC) team, led by Dr. Nuwong and Dr. Kampanart along with observers from the Office of Transport and Traffic Policy and planning (OTP) and United Nations Development Programme (UNDP) introduced the importance of climate investment and importance of climate change adaptation in transport sector. Dr. Kampanart delivered the project on I&FF assessment in detail, starting from the introduction of various countermeasures for roads. He also presented their technical and political viability, involved implementing and budgeting stakeholders and political, regulatory, and societal constraints to DRR representatives. Essentially, road classification and countermeasure categorization along with the resulted climate-proofing investment matrix were discussed and policy options both in domestic and international aspects were also provided.

Main contribution

After the detailed presentation on road countermeasures and its categorization, road classification, and unit price of each countermeasure, DRR gave several useful suggestions. The representatives assured that the road screening criteria designed by ENTEC is practical since the routes nearby canals tend to have a higher risk when floods occur. However, they argued that pumping water as a countermeasure is rarely implemented in DRR road network and suggested to reconsider its application. Road classification into tiers is discussed thoroughly where DRR representatives recommended the team to use passenger car unit (PCU) to categorize rural roads. The officers added that assumptions of unit price need to by revised according to standard price determined by Bureau of the Budget (BB) and Comptroller General Department (CGD). DRR officers offered to send the criteria for road classification based on PCU being used by DRR, and the unit price of the countermeasures which aligns with the standard prices of CGD.

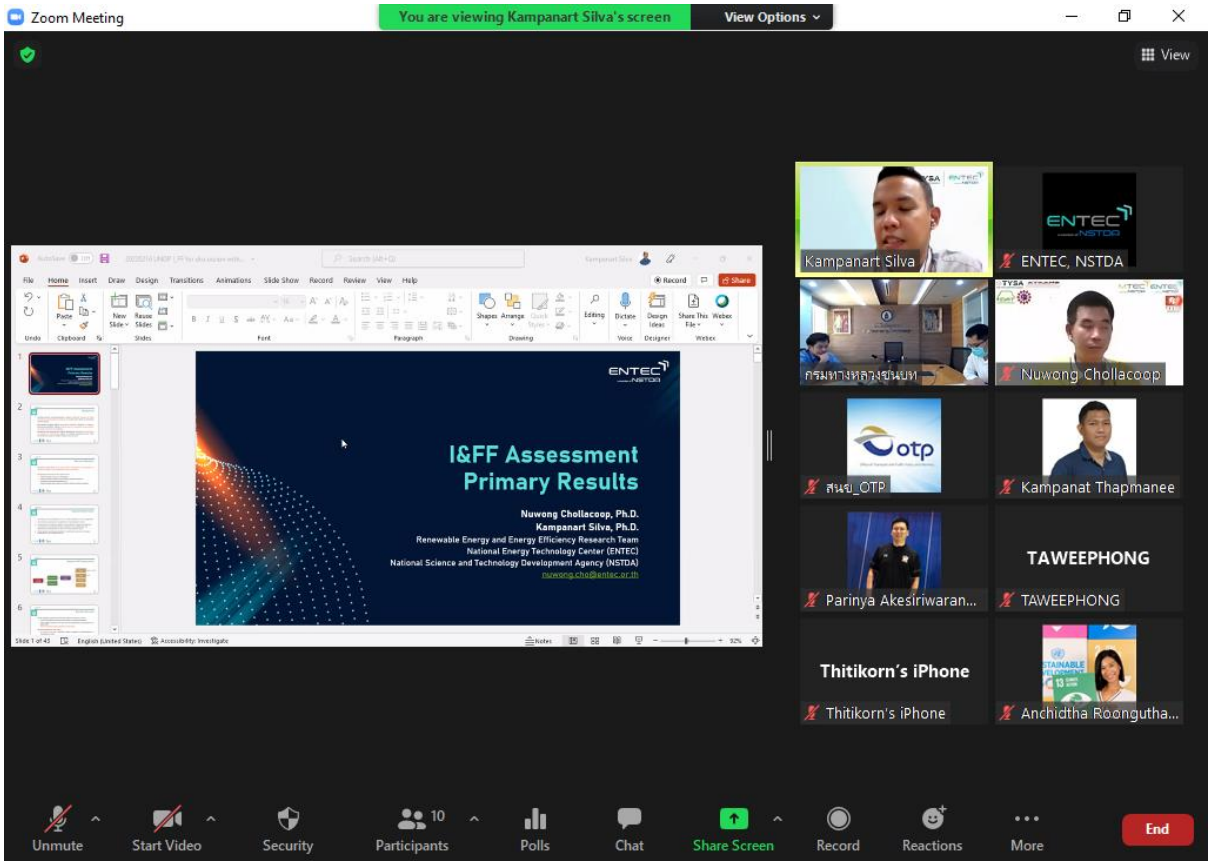
Meeting participants

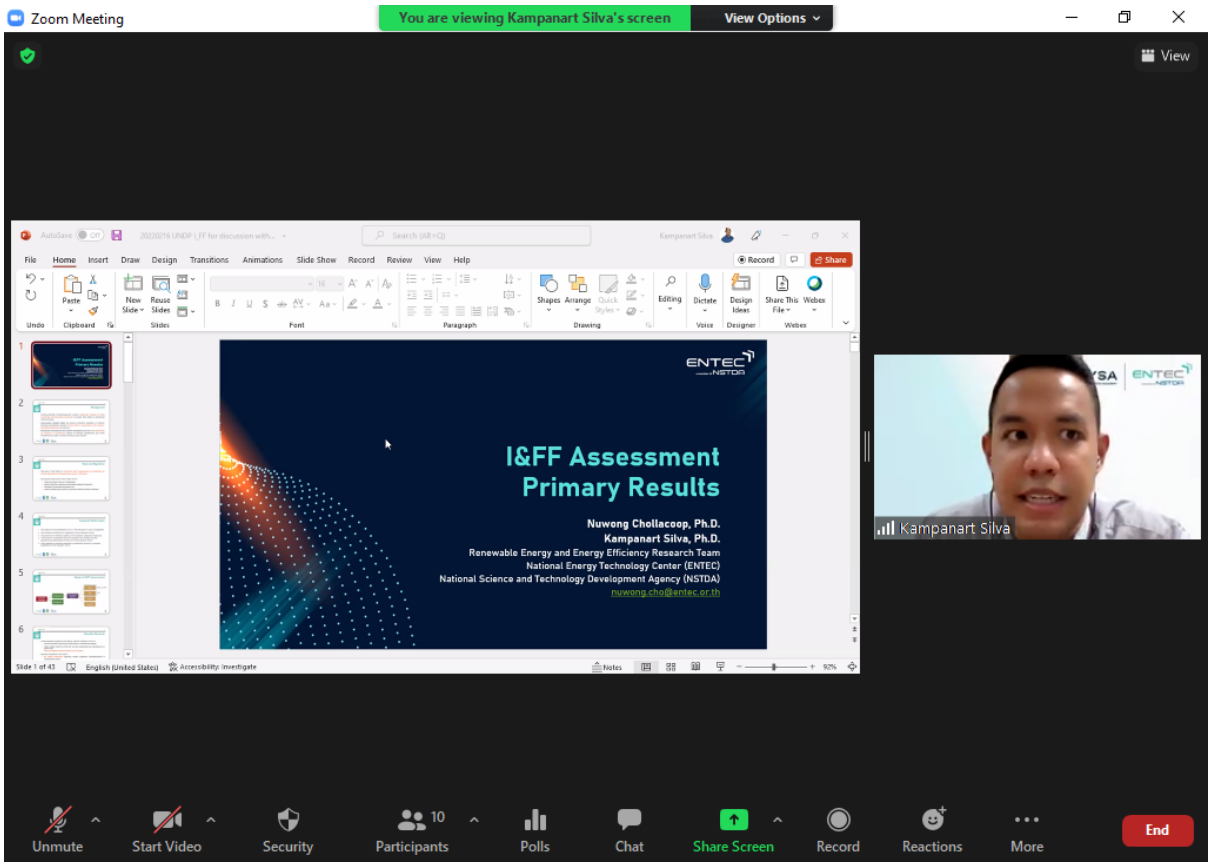
The following Table 31 shows participating members of the third consultation meeting with Department of Rural Roads which is a total of 15 attendees, comprised of 7 attendees from DRR, 3 attendees from OTP, 1 attendee from UNDP, and 4 attendees from ENTEC.

Table 31 List of participants in the third meeting with Department of Rural Roads (DRR)

No.	Name	Position	Organization
1	Mrs. Chutinthorn Mankhong	Chief	Office of Transport and Traffic Policy and planning (OTP)
2	Ms. Supanat Chalermsupanimit	Policy and Plan Analyst, Professional level	Office of Transport and Traffic Policy and planning (OTP)
3	Mr. Varut Fuangthin	Policy and Plan Analyst, Practitioner Level	Office of Transport and Traffic Policy and planning (OTP)
4	Ms. Anchidtha Roonguthai	Project Manager	United Nations Development Programme (UNDP)
5	Dr. Koson Janmonta		Department of Rural Roads (DRR)
6	Dr. Thitikorn Posribink		Department of Rural Roads (DRR)
7	Dr. Taweephong Suksawat		Department of Rural Roads (DRR)
8	Mr. Parinya Akesiriwaranont		Department of Rural Roads (DRR)
9	Mr. Chalermlap Sinkong		Department of Rural Roads (DRR)
10	Mr. Noppadol Siangboon	Civil Engineer	Department of Rural Roads (DRR)
11	Mr. Voraphong Raicharoen	Civil Engineer	Department of Rural Roads (DRR)
12	Mr. Nuwong Chollacoop	Renewable Energy and Energy Efficiency Research Team Leader	National Energy Technology Center (ENTEC)
13	Mr. Kampanart Silva	Researcher	National Energy Technology Center (ENTEC)
14	Mr. Kampanat Thapmanee	Researcher Assistant	National Energy Technology Center (ENTEC)
15	Mr. Pidpong Janta	Researcher Assistant	National Energy Technology Center (ENTEC)

Photo gallery





Appendix 4: Consultation Meeting with SRT

Consultation Meeting: State Railway of Thailand (SRT)
Online Venue: virtual meeting via Zoom on March 2nd, 2022

About the meeting

The consultation meeting with State Railway of Thailand was held virtually through Zoom which was scheduled from 13:00 am to 14:00 am on March 2nd, 2022. The meeting aimed to present I&FF assessment's primarily results for railways, to receive opinions from SRT representative. It started with a brief introduction of the project by ENTEC representatives, Dr. Nuwong and Dr. Kampanart, which includes background and importance of climate-proofing investment, goals of the I&FF assessment of investment on climate adaptation scenario in transport sector. Additionally, the scope of the assessment and various countermeasures against flooding events in railways were delivered by Dr. Kampanart. Countermeasures were developed based on previous cost-benefit analysis (CBA) results, and technical and political viability were also studied in order to ensure the feasibility of the countermeasures. Spots with high flood risk were screened throughout the country. Then, the spots and countermeasures were categorized into tiers. Dr. Kampanart also showed investment scale for the countermeasures in each railway tier. At the end of the presentation, policy options were introduced to point out possible domestic and international sources of funding.

Main contribution

The SRT representative gave several comments towards countermeasures and unit costs. It was mentioned that bridge construction is a common countermeasure applied to railway that goes across a waterway. There are two types of bridge: concrete bridge and steel bridge. The representative suggested that each type has different advantages, and their costs vary. It was important to revisit the unit prices. The assumption of box culvert seems reasonable but needed to be redefined into price per box culvert to follow the usual practice. Sleeper replacement is a common strategy to enhance the strength of railway, though most sleepers in Thailand have already been renewed to concrete ones. Ballast refill should also be included in the analysis as a temporary measure to make the rail usable during floods. Towards underground tunnel, it is considered as a high-priced measure to drain large amount of water and is often impactful to environment. However, since the unit cost is extremely high, it seems not to be economically feasible in Thailand. It was recommended that the first tier for railways should include main lines: northern, northeastern, and southern lines, and the second tier should cover sub lines, eastern and Maeklong lines. Importantly, targeted railway screening should include lowland areas since floods recently occurred in these areas even if it rarely occurred before. For example, Floods occurred in Chaiyaphum and Chumphon provinces last year.

Meeting participants

The following Table 32 shows participating members of the fourth consultation meeting with State Railway of Thailand with a total of 6 attendees, comprised of 1 attendee from SRT, 1 attendee from UNDP, and 4 attendees from ENTEC.

Table 32 List of participants in the fourth meeting with State Railway of Thailand (SRT)

No.	Name	Position	Organization
1	Mr. Nattapon Wattanarad	Divisional Engineer	State Railway of Thailand (SRT)
2	Ms. Anchidtha Roonguthai	Project Manager	United Nations Development Programme (UNDP)
3	Mr. Nuwong Chollacoop	Renewable Energy and Energy Efficiency Research Team Leader	National Energy Technology Center (ENTEC)
4	Mr. Kampanart Silva	Researcher	National Energy Technology Center (ENTEC)
5	Mr. Kampanat Thapmanee	Researcher Assistant	National Energy Technology Center (ENTEC)
6	Mr. Pidpong Janta	Researcher Assistant	National Energy Technology Center (ENTEC)

Photo gallery


Recording
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ENTEC
NSTDA
I&FF Assessment
Primary Results
Nuwong Chollacoop, Ph.D.
Kampanart Silva, Ph.D.
Renewable Energy and Energy Efficiency Research Team
National Energy Technology Center (ENTEC)
National Science and Technology Development Agency (NSTDA)
nuwong.cho@entec.or.th
Kampanart Silva
Nuwong Chollacoop
Nattapon Wattanarad
ENTEC, NSTDA
Kampanat Thapmanee
Unmute
Stop Video
Participants
Chat
Share Screen
Record
Reactions
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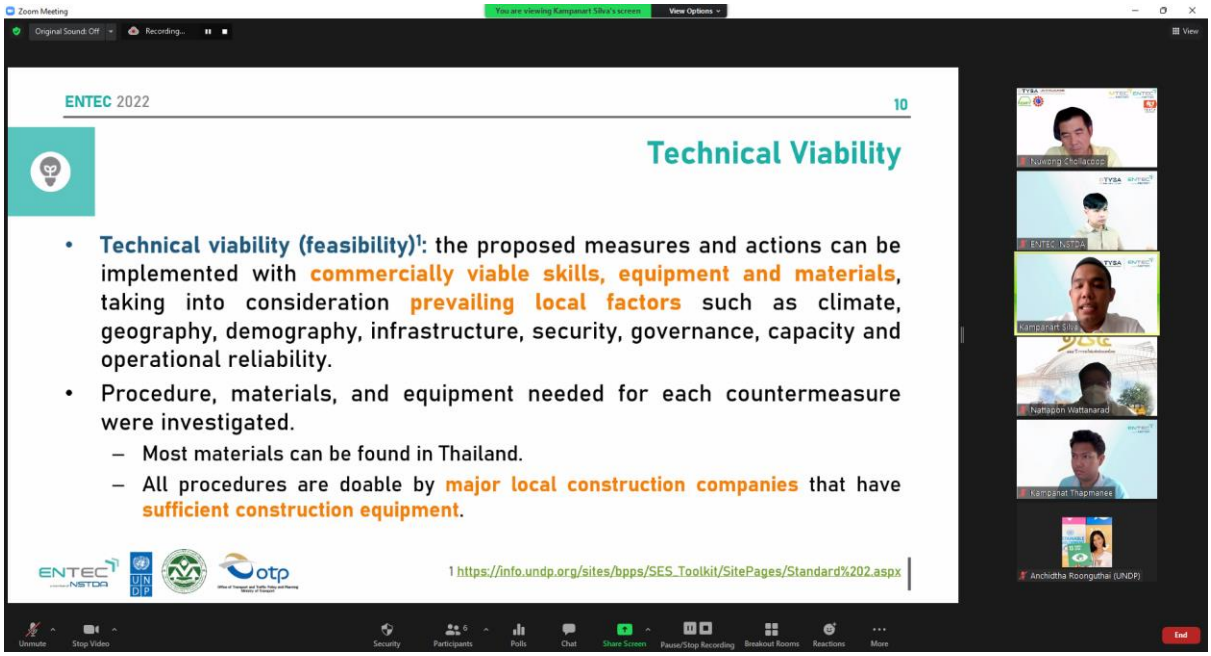
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ENTEC 2022
10
Technical Viability
• Technical viability (feasibility)[1]: the proposed measures and actions can be implemented with commercially viable skills, equipment and materials, taking into consideration prevailing local factors such as climate, geography, demography, infrastructure, security, governance, capacity and operational reliability.
• Procedure, materials, and equipment needed for each countermeasure were investigated.
– Most materials can be found in Thailand.
– All procedures are doable by major local construction companies that have sufficient construction equipment.
1 https://info.undp.org/sites/bpps/SES_Toolkit/SitePages/Standard%202.aspx
Nuwong Chollacoop
ENTEC, NSTDA
Kampanart Silva
Nattapon Wattanarad
Kampanat Thapmanee
Anchidtha Roongruthai (UNDP)
Unmute
Stop Video
Security
Participants
Polls
Chat
Share Screen
Pause/Stop Recording
Breakout Rooms
Reactions
More
End

Appendix 5: 2nd Consultation Meeting with SRT

Consultation Meeting: State Railway of Thailand (SRT)
Online Venue: virtual meeting via Zoom on March 14th, 2022

About the meeting

The 2nd consultation meeting with State Railway of Thailand was held virtually through Zoom which was scheduled from 09:00 am to 10:00 am on March 14th, 2022. The meeting was conducted with another group of SRT officers, aiming to receive further comments on assumptions and results of the I&FF assessment. The consultation started with the presentation of the preliminary results of the I&FF assessment for railways. Dr. Nuwong and Dr. Kampanart from ENTEC introduced climate adaptation background and importance of climate-proofing investment, the objectives of the I&FF assessment for investments in transport sector. In addition, Dr. Kampanart, presented various countermeasures in railways against flooding events. Besides, technical and political viability of the countermeasures were also presented to show the feasibility of their implementation. Before the presentation ends, Dr. Kampanart showed the total investment for each countermeasure and introduced policy options to receive domestic and international funding to implement the projects.

Main contribution

The SRT representatives gave useful feedback that improved understanding of SRT activities and the assumptions for climate adaptation countermeasures. It was suggested that flood events can be categorized into flash floods and overflowed floods based on geographical conditions. Flood countermeasures are designed in correspondence with the types of floods. SRT officers added that apart from proposed countermeasures, slope protection should also be studied and increasing the number of water bypasses (as in the case in Lopburi), should also be explored. In the cases of overflowed flood in Chumphon and Chaiyaphum, ballast refill is used as a temporary countermeasure to strengthen the railways against the event. There were plans for implementing elevated railways in the future double-track railway projects. To realize actual short- and long-term plan of SRT and select appropriate countermeasures, the representatives proposed to have a follow-up meeting to discuss in deeper detail.

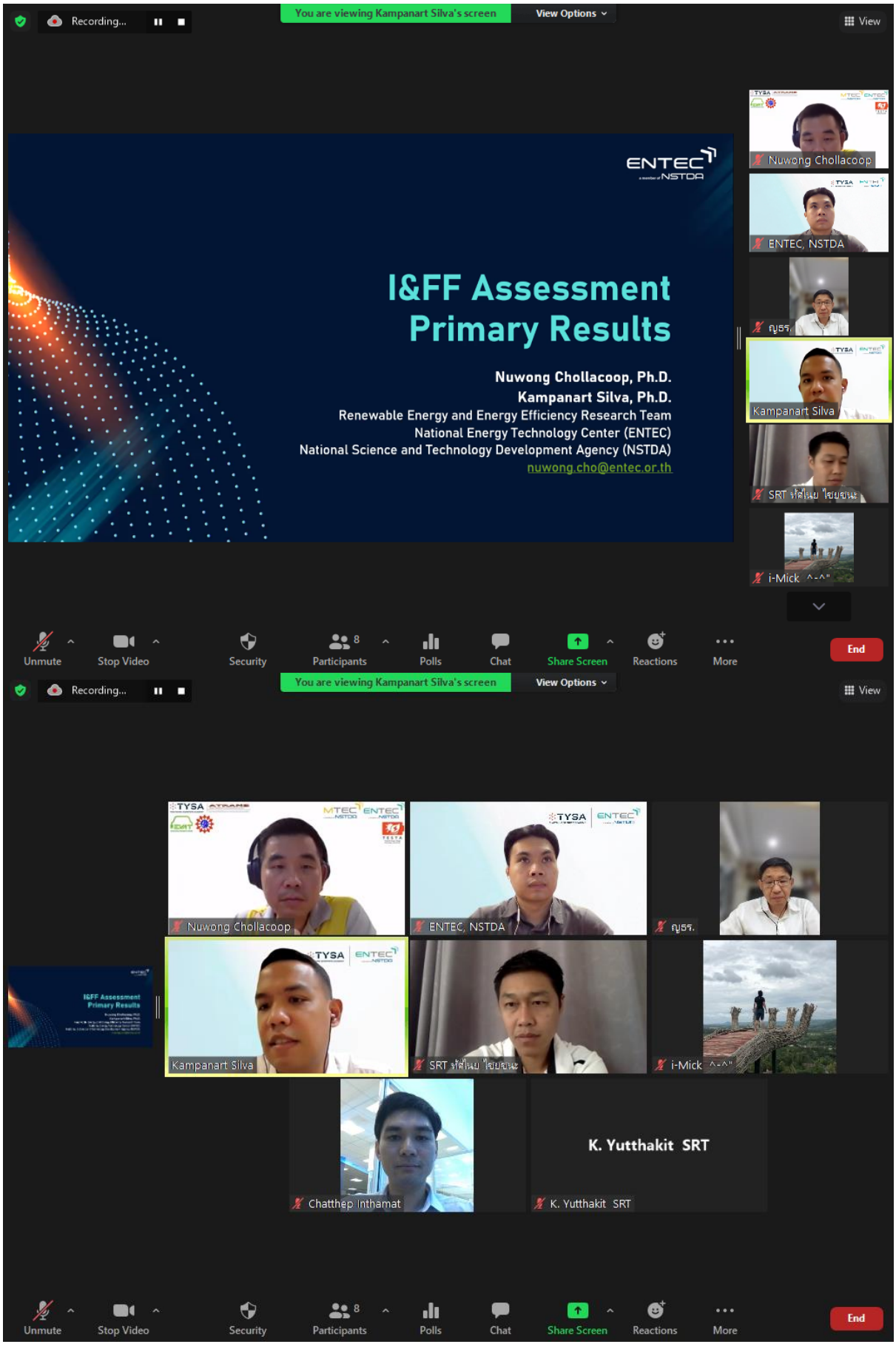
Meeting participants

The following Table 33 shows participating members of the second consultation meeting with State Railway of Thailand with a total of 7 attendees, comprised of 4 attendees from SRT, and 3 attendees from ENTEC.

Table 33 List of participants in the fifth meeting with State Railway of Thailand (SRT)

No.	Name	Position	Organization
1	Mr. Udom Maophet	Deputy Chief Civil Engineer (Maintenance)	State Railway of Thailand (SRT)
2	Mr. Chatthep Inthamat	Divisional Engineer, Track Maintenance Planning Division	State Railway of Thailand (SRT)
3	Mr. Yutthakit	Divisional Engineer, (Lampang) Permanent Way Maintenance Division	State Railway of Thailand (SRT)
4	Mr. Thassanai Chaichana	Divisional Engineer, (Nakhon Sawan) Permanent Way Maintenance Division	State Railway of Thailand (SRT)
5	Mr. Nuwong Chollacoop	Renewable Energy and Energy Efficiency Research Team Leader	National Energy Technology Center (ENTEC)
6	Mr. Kampanart Silva	Researcher	National Energy Technology Center (ENTEC)
7	Mr. Pidpong Janta	Researcher Assistant	National Energy Technology Center (ENTEC)

Photo gallery



Appendix 6: 2nd National Dialogues on The Resilient Transport Infrastructure Investment: Investment and Financial Flows Assessment

Final Workshop: with Office of Natural Resources and Environmental Policy and Planning (ONEP), Office of Transport and Traffic Policy and planning (OTP), and relevant stakeholders

Online Venue: virtual meeting via Zoom on April 4th, 2022

About the meeting

The 2nd National Dialogues on The Resilient Transport Infrastructure Investment: Investment and Financial Flows Assessment was held virtually through Zoom which was scheduled from 13:30 am to 16:00 am on April 4th, 2022, with the following agenda.

13:30 – 13:45	Opening remarks *Dr. Phirun Saiyasitpanich, Secretary General, Office of Natural Resources and Environmental Policy and Planning (ONEP)* *Ms. Wilairat Sirisoponsil, Deputy Director, Office of Transport and Traffic Policy and planning (OTP)* Welcome remarks *Ms. Lovita Ramgutee, Deputy Resident Representative, United National Development Programme Thailand*
13:45 – 14:30	Investment and Financial Flows (I&FF) Assessment Results *Dr. Nuwong Chollacoop and Dr. Kampanart Silva, National Energy Technology Center*
14:30 – 15:30	Q&A and discussion
15:30 – 16:00	Summary of the discussion and ways forward

The meeting aimed to receive comments from relevant stakeholders on the results of the investment and financial flow assessment of climate-proofing investment of transportation infrastructure and discuss the ways to facilitate such investment in Thailand. The discussion was planned to focus on the two following points:

1. Appropriateness of the assumptions and the results of the assessment;
2. Available sources of funding for climate-proofing investment of transportation infrastructure, focusing on gender and social equality, and sustainability, in line with the Sustainable Development Goals (SDGs).

Meeting participants

Invitation was sent to direct and indirect stakeholders listed in Table 34. The relationships between these stakeholders and the topic, which is an extension of Figure 4, are summarized in Figure 39. 57 people registered for the event, and over 60 people from the majority of the invited organizations participated. Below is the list of questions and comments from the relevant stakeholders along with the responses from the consultants. All questions and comments were carefully considered during the revision of the report.

Table 34 List of relevant stakeholders invited to the 2nd National Dialogue

No.	Organization
1	Office of Natural Resources and Environmental Policy and Planning (ONEP)
2	Office of Transport and Traffic Policy and Planning (OTP)
3	Energy Policy and Planning Office (EPPO)
4	Office of the National Economics and Social Development Council (NESDC)
5	Department of Alternative Energy Development and Efficiency (DEDE)
6	Bureau of the Budget (BB)
7	Fiscal Policy Office (FPO)
8	Office of Agricultural Economics (OAE)
9	Department of Fisheries (DOF)
10	Thai Meteorological Department (TMD)
11	National Human Rights Commission (NHRC)
12	Royal Irrigation Department (RID)
13	Department of Disaster Prevention and Mitigation (DDPM)
14	Department of Women's Affairs and Family Development (DWF)
15	Thailand Science Research and Innovation (TSRI)
16	Office of The National Water Resources (ONWR)
17	Joint Standing Committee on Commerce, Industry and Banking (JSCCIB)
18	Sustainable Development Foundation (SDF)
19	Department of Highways (DOH)
20	Department of Rural Roads (DRR)
21	State Railway of Thailand (SRT)
22	Department of Rail Transport (DRT)
23	Asian Disaster Preparedness Center (ADPC)
24	Comptroller General's Department (CGD)
25	Bank of Thailand (BOT)
26	Thailand Board of Investment (BOI)
27	Department of Public Works and Town & Country Planning (DPT)
28	Department of Local Administration (DLA)
29	Ministry of Transport (MOT)
30	Thailand Greenhouse Gas Management Organization (TGO)
31	Department of Marine and Coastal Resources (DMCR)
32	Treasury Department (TD)
33	Securities and Exchange Commission (SEC)
34	Public Debt Management Office (PDMO)
35	Thai Bond Market Association (ThaiBMA)

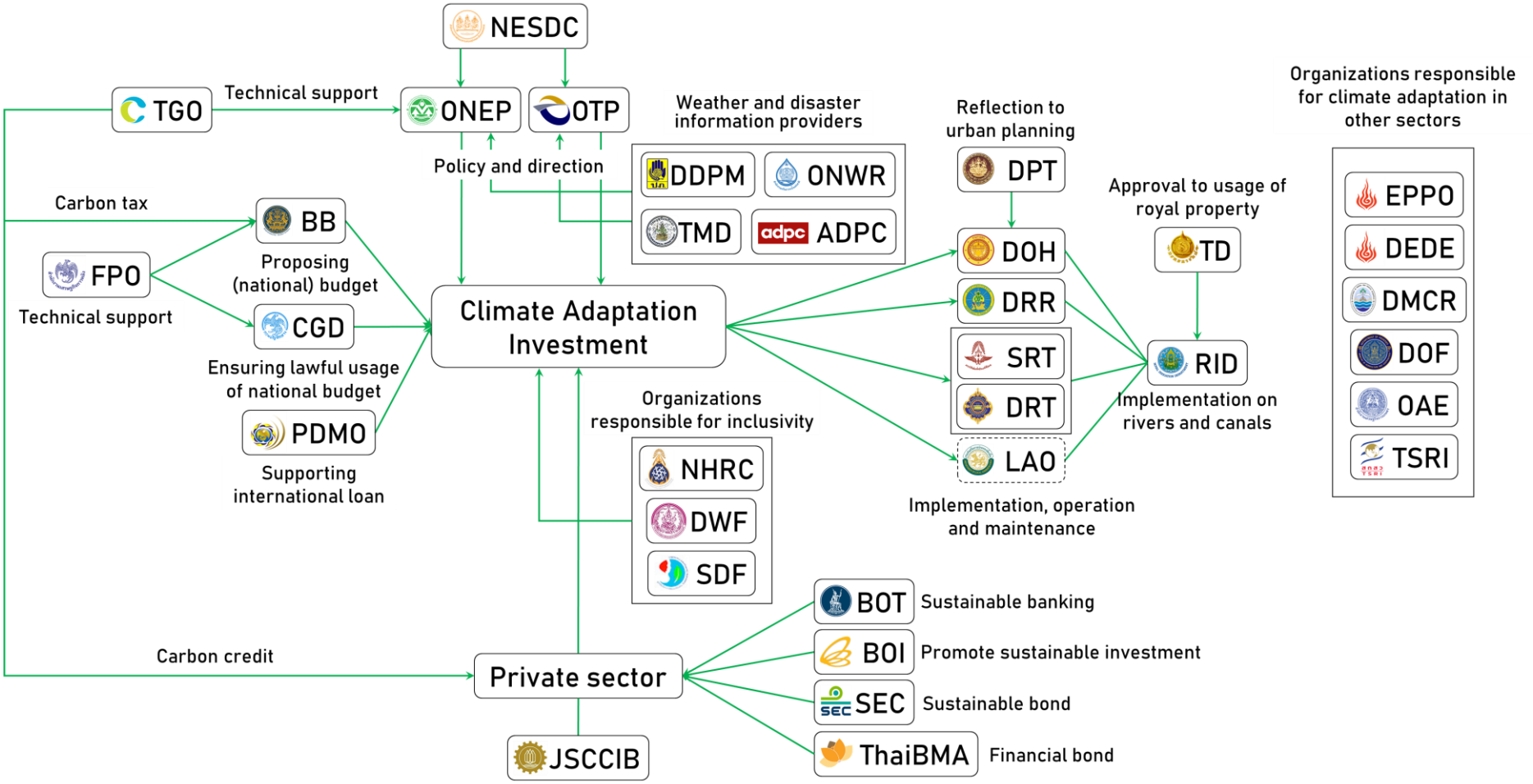


Figure 39 Involved stakeholders (extended version)

List of questions, comments, and responses

1. Question: The total distance of roads in Thailand is several hundred thousand kilometers. How we figure out the parts that will be severely affected by climate change and will require urgent attention?
   Response: It is certainly difficult to figure out which parts of the roads are the most vulnerable to climate change. This study focuses on flood which is natural event with highest frequency and severity in Thailand based on past statistics. As stated in subsection 5.2.1, since the past experience indicated that the floods that have affected the roads are flash floods, the roads that are along a river, a canal, or a waterway, or in its vicinity, are the high-risk areas. In addition, this study focuses on roads under the purview of Department of Highways (DOH) and Department of Rural Roads (DRR), which are inter-city roads and intra-city roads, respectively, since they affect the majority of the people living along the routes.
2. Question: How to distinguish the consequences of climate change on roads and rail from other consequences? Floods frequently occur in Thailand without the contribution of climate change. It would be beneficial if we can figure out how much OTP need to prepare more for climate proofing.
   Response: The baseline of flood occurrences can be estimated based on past statistics, though it is rather difficult to find such record in Thailand. In Chapter 6, general budget allocated for emergency expenses is included in the baseline scenario, and the incremental investment turns to be 2-7 times larger than this figure. However, rather than allocating the budget to cope with the consequences of the floods, this study suggests the responsible entities to make the climate-proofing investments beforehand in order to enhance the climate adaptability of the transportation infrastructure so that it can withstand or at least quickly recover after the floods.
3. Comment: The mechanism of international funds might be complicated. It would be beneficial to perform the study further to identify the conditions and the chance of being granted, or to prioritize the international funds based on projected opportunities.
4. Question: Can we forecast or evaluate the consequences of climate change on critical infrastructure, and how?
   Response: It is possible to forecast the impact of climate change on transportation infrastructure, though the accuracy might be questionable. Actually, the United Nations Development Programme (UNDP) has a good set of assessments to deal with investment on climate adaptation which involves high uncertainties. However, it is necessary to discuss with stakeholders to understand the actual conditions so that the assessment will not be just a paperwork, but a starting point for the discussion on actual investment on climate adaptation. It is also important to periodically review and update the results of each assessment to get the most out of them.
5. Comment: Social bond is a good way for financing the project. The investments being discussed in this study also seem relevant to the objective of the bond. However, it is uncertain whether a governmental entity can issue this kind of bond. It is necessary to carefully study the criteria of the bond[105]. In the past, government projects on an express way and on electricity generation successfully utilized the scheme of

[105] The Securities and Exchange Commission, Social Bond.
https://www.sec.or.th/TH/Pages/LawandRegulations/ResourceCenter-SocialBond.aspx

infrastructure fund[106], and public involvement is one of the key aspects. Inclusivity aspect can be explored further.

6. Comment: The Public Debt Management Office (PDMO) can help if the responsible organizations would like to issue a social bond. However, there have been no project in the past that a governmental organization issued the bond by itself. Ministry of Commerce will be the entity responsible for issuing the bond. However, for a state-owned enterprise, Ministry of Commerce can act as a guarantor for the bond to be issued.
7. Question: How is this study connected to national climate change plans? Are there any overlaps between the suggested actions and the planned actions? How could we evaluate these projects?
   Response: For the first question, even though there is no clear plan like climate mitigation, there is National Adaptation Plan which was launched in 2018. This study aims to indicate the ways that transportation sector can contribute to this plan. For the second question, although there are planned budgets for road and rail emergencies, they are for aftermath of the floods. On the other hand, the proposed climate-proofing investment is to be made beforehand in order to minimize the total cashflow. As for the last question, it would be difficult to estimate the actual benefits of the investment since the timeline is very long (typically 30-50 years). However, several past studies showed that the benefit-cost ratio of such investments is approximately four to six.
8. Comment: There is no significant issue in construction of roads along the canals which are Ratchaphatsadu Land used by Royal Irrigation Department. The request for construction permission should follow the Ministerial Regulation on Ratchaphatsadu Land Usage B.E. 2563 (2020). The timeline is also specified in the Ministerial Regulation. For example, for the case in Bangkok, Treasury Department will evaluate the request within 60 days.
9. Comment: Climate change is among the topics that the Minister of Commerce pays attention to. If the investment is not profitable, it is better to request for national budget. If the Bureau of Budget (BB) agrees, PDMO could assist in issuing bonds. If the projects involve private sector, it will also touch the Public Private Partnership (PPP) scheme. Governmental organizations can partner with private sector and seek for loans from World Bank, Asian Development Bank, or Asian Infrastructure Investment Bank, though the interest might be high. All three banks have clear policies in mitigating the consequences of climate change.
10. Comment: Vulnerable groups are not only women, but they also include young person, disables and elderlies. When the transportation infrastructure is designed, their safety should be carefully considered. Contact points when the vulnerable groups face problems should be made clear.

[106] The Securities and Exchange Commission, Infrastructure fund. https://www.sec.or.th/th/pages/lawandregulations/infrastructurefund.aspx

Photo gallery