Final Report





How climate change would impact transport system of Thailand: Adaptation That Thai engineers and planners should aware of

Submitted to

ATRANS
ASIAN TRANSPORTATION RESEARCH SOCIETY
สมาคมวิจัยวิทยาการขนส่งแห่งเอเชีย

October 2012

Content

Chapter 1
Introduction

1.1 Background

Increasing occurrences of natural disasters as well as change in weather patterns around the globe cause growing concerns on the on-going dreadful climate change phenomenon. Since industrial evolution, the large amount of greenhouse gases (GHGs) have been produced by the human activities; they have formed a dense layer in the atmosphere causing detrimental greenhouse effects to the earth. Identified impacts of climate change include the rise and drop in temperature, the change of precipitations, the change in weather patterns, the rise of sea level, the higher frequency and more severity of natural disasters. As the sizable quantity of greenhouse gas emission (such as, CO2, NOx,) still persists, the climate change effects would be more aggravated over time. Their impacts would have affected the transport system; and the impacts would vary from one region to another, depending on its geography and geographic location.

Research on climate change impacts has received relatively little attention from transport engineers, even though they are expected to affect transportation indisputably. People, when travel, will essentially expose to weather and climate, and they tend to adjust travel behavior in respond to the change of weather. Most of the transport infrastructures and vehicles are exposed to climate almost all the times, and they tend to deteriorate and fail fairly quickly if their designs do not match with the exposed weather patterns. Climate change is expected to cause impacts on transportation from the planning, designing, operating to maintaining of the system.

To the author knowledge, Koetse and Reitveld (2009) is the only transport research study that attempted to summarize the impact of climate and weather on transportation based primarily on literature. Although the study yields strong leads on what transport engineers must be aware, however, the findings appear generic, and mainly focus on the developed world (as most of the previous literature have conducted in the US and European countries).

The specific impacts of climate change on transport system in Thailand have not been realized or put in an organized manner. Thus, most of Thai traffic and transport engineers do not know what to expect, and how planning, designing, operating, maintaining of the transport system should be adapted, to reflect the upcoming change of climate and weather. The authors believe that certain policies, designs, operations and maintenance programs could better facilitate the transport system (than the existing ones) when climate change phenomenon get more severe.

1.2 Objectives

The objectives of this study are to:

1.2.1 Gather and summarize the current knowledge on the projection of weather and climate change specific to Thailand

1.2.2 Develop knowledge management of Thai authorities and select groups or people for the climate change impacts on transport and possible counter measures

1.2.3 Gather the current knowledge, researches, theories, standards, practices that facilitate safe and efficient transport in Thailand under the climate change phenomenon

1.2.4 Develop appropriate adaptation planning framework for Thai transport engineers

1.3 Research Method/technique

Other than literature (textbooks, study reports, research papers, etc.), the methodology of this study is primarily based on the gathering of current knowledge via 3 main sources:

1. Normal people who travel in a daily basis
2. Seasoned specialists who are responsible for planning, designing, operating and maintaining traffic and transport system on their works.
3. Academia, who teach classes and conduct researches for a number of years.

One way to investigate the climate change impact on transport is to compare the systems in different regions with various climatic conditions (Koetse and Reitveld, 2009). In Thailand, different regions have various weather patterns. For example, northern and western regions have low temperature during the winter than the rest of the countries; southern part has higher precipitations than the other regions. And those authorities and people who work and live in such areas would have, through their experience, developed knowledge specific to local areas, and it would be provide good clues/insights on what would happen with certain climatic conditions.

This research will include 4 major steps.

1. Study the expected climate change specific to Thailand
   We will collect and gather the forecast or prediction of climate change to various regions of Thailand in different seasons. The information sought will be on existing study reports, research papers, as well as from the opinions of the global climate change specialists. At least 10 experts will be interviewed to obtain their opinions or guidance.

2. Identify impacts of expected climate change to the transport system
   In this step, we will interview appropriate Thai local authorities who plan, design, manage, and maintain the transport system in various regions of Thailand to collect their knowledge of the identified weather changes on the transport system. For example, if it is expected more precipitation, we will interview the authorities in southern region that already experience higher precipitations nowadays, or if it is expected a high temperature, we will interview the authorities in western and northeastern region that already experience high temperature in summer time at present.

   At least 200 local authorities from various agencies and various regions will be interviewed, including both public (DOH, DOR, ETA, SRT, MRTA, BTS, DDPM authorities, emergency response units, traffic polices) and private sectors (BMTA bus, intercity buses, songtaews, tuk-tuks, normal people). Other than the impacts of climate change, we will also seek their opinions on how they will response to the extreme weather in everyday life.

   The results of this step will also be summarized in a series of casual loop diagrams, to explain the impacts in a comprehensible format.

3. Explore the transport knowledge that match the expected climate change
   In this step, we will explore theories as well as recent knowledge from transport engineering textbooks, study reports, research papers that suit the expected change of climate. For example, new pavement design or specification that would match to the new weather pattern, or new amenities that better accommodate the travel of people. Furthermore, we will discuss with academia in the related specific fields to collect their suggestions and knowledge of traffic and transport systems under new climatic patterns.

4. Develop adaptation planning framework for transport engineers
   Based on the knowledge collected from various sources, this study will summarize and develop appropriate adaptation planning framework for transport authorities, in order to plan, design, manage and maintain the transport system under climate change phenomenon.

1.4 Organization of the report

This report consists of 6 chapters as follows;

- Chapter 1: Introduction
- Chapter 2: Literature reviews
- Chapter 3: The projection of weather and climate change specific to Thailand
- Chapter 4: Expected impacts of climate change to transportation system
- Chapter 5: Explore the transport knowledge that match the expected climate change
- Chapter 6: Conclusion

Chapter 2
Literature reviews

In order to develop the adaptation framework for transport authorities, this study reviews various of existing study reports, research papers which are related to climate change specific to Thailand, expected impacts of climate change to transportation system, and the existing transport knowledge that match the expected climate change. The details of literatures are as follows;

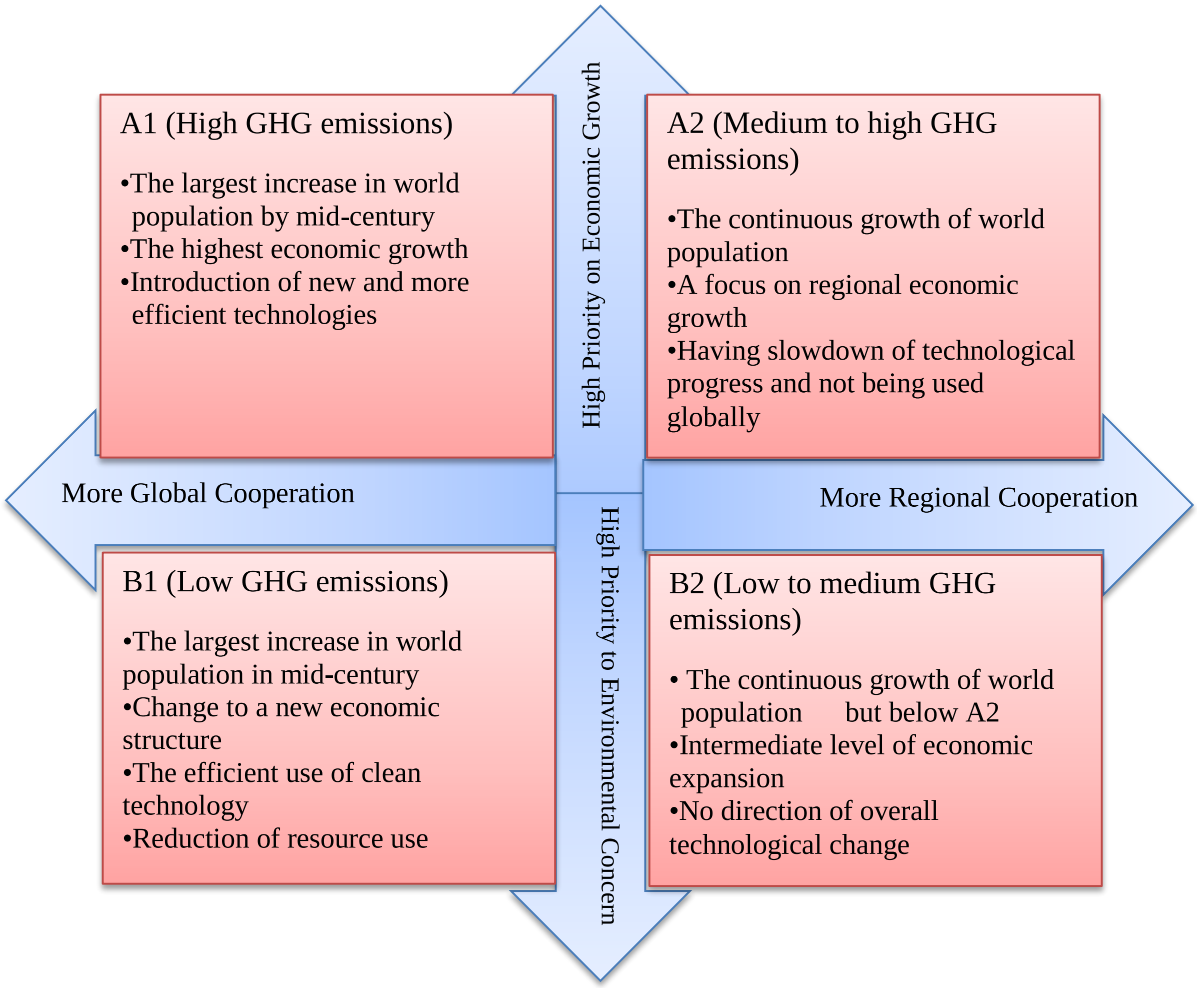
2.1 Climate model

Climate Model is a mathematical modeling that uses quantitative data to stimulate the interaction of energy in atmosphere, ocean, land surface, and sea ice. Application of the model has been elucidated in different objectives; for instance, the study of weather and climate system dynamics, which this module presently applied in the formulation of future climate scenarios caused by the changes of greenhouse gas (GHG) concentrations in atmosphere.

The amount of GHGs in the future atmosphere is an important piece of information used as input data for the climate model. Atmospheric GHG concentrations might be changed in the future underlying distinctly different directions of economic and social development. The Intergovernmental Panel on Climate Change or IPCC identified the possibility of development into 4 families as illustrated in Figure 2.1.

- Type A is the development which emphasizes on the economic growth as a core priority that is subdivided into:-

    - Group A1 defines future rapid economic growth with the world population that peaks in mid-century and slightly declines after that, the introduction of efficient technologies, personal development, and cultural interactions are existed with a substantial reduction in national income differences among regions. Emission scenario A1 can be classified into 3 sub-scenarios including:
        - A1FI (Fossil intensive): the development has greater reliance on fossil energy e.g., crude oil and coal;
        - A1T (Non-fossil energy sources and technology): the development is not principally focused on the use of fossil energy but applying different patterns of technological substitution;
        - A1B (Balance of all sources): the development has a balance of all energy resources and not emphasized on the use of fossil or renewable energy but mixed between the two;
    - Group A2 describes multi-patterns of future world development with more self-reliance within the region and preservation of local identities. The number of world population has been continuously increasing and more regional-oriented economic development is elicited. However, economic growth and technological changes are slower than other groups as well as distribution depending upon the local and regional contexts.



Source: IPCC, 2011.

Figure 2.1 IPCC Special Report on Emission Scenario or SRES

- Type B is the development that gives priority to environmental concerns over Type A, which is sub-divided into:

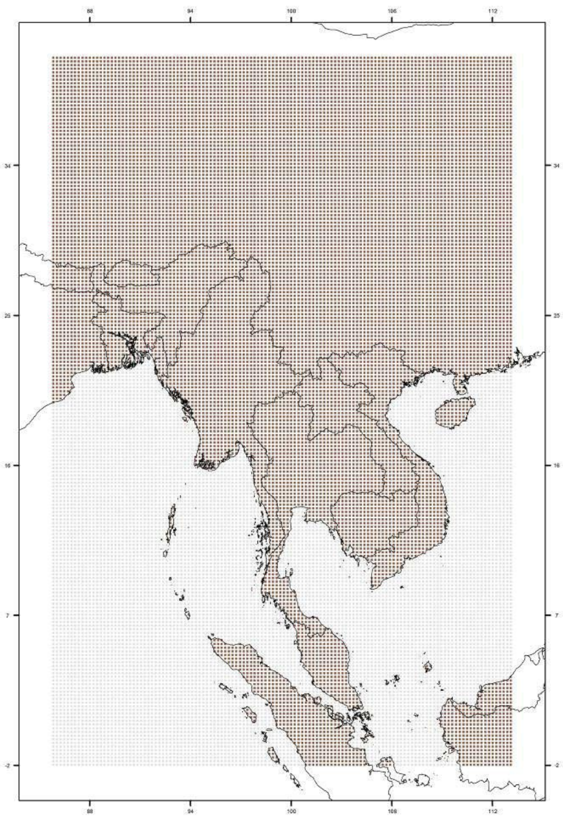
  - Group B1 is a scenario of future development with the peak of world population growth in the mid-century similar to Group A1 and declines afterwards, but economic structures have a rapid change towards service and information sectors, with reduction of material use and applications of clean technologies. The effort is primarily emphasized on providing the sustainable solutions of economic, social and environmental problems at national level with more equitable concerns, but without using climate initiatives.
  - Group B2 illustrates a development scenario focusing on the local and regional solutions of economic, social, and environmental sustainability. The scenario shows the continuous increase in population growth but lower than A2 with intermediate economic development. The technological change is evidently more varied and slower than B1 and A1. Simultaneously, environmental protection and social equity are intentionally considered at local and regional levels.

2.2 Climate change model for Thailand

For Thailand, 3 types of climate models 1) PRECIS Model 2) MM5 and 3) GFDL-R30 were used together with 2 types of the world economic and social development scenario including A2 and B2. Three models have been used with similar approach, in that these significant global models are based on the downscaling method. In case of areas of Thailand, each model has diverse characteristics in the analysis such as variables, scenario, location, year, etc.

2.2.1 The PRECIS Regional Climate Model

The PRECIS (Providing REgional Climates for Impacts Studies) Regional Climate Model performs the horizontal resolution of 0.22° or approximately 25 km (Figure 2.2) through using PRECIS developed by The Met Office Hadley Centre for Climate Prediction and Research, The United Kingdom.



Source: Chidthaisong, A. (2011)

Figure 2.2 The scope area using for future climate model calculations

In this study, the formulation of future climate change scenarios in Thailand involves the prediction of weather in Thailand and its vicinity through using the results of future climate modeling based on the ECHAM4 model, developed by Max Planck Institute for Meteorology and German Climate Computing Centre, Germany as based-information for the calculation. Moreover, additional calculation was carried out by the PRECIS model in forms of grid size 20x20 km; accordingly the results were illustrated by the series of daily time scales over the 21st century. As well, data from the record obtained by past monitoring station are used as benchmark and then consistently re-adjusted according to the assumption that the results from climate model elicit the relative changes when compared to past and future simulation model results. It regards that future changes are the changes from current climate state.

2.2.2 The MM5 Regional Climate Model

The MM5 model (The Fifth Generation Penn State/NCAR Mesoscale Model) is a regional climate model collaboratively developed between Pennsylvania State University and National Center for Atmospheric Research or NCAR, USA. It can be used for the analysis of change in weather conditions from 3km to >100 km through the consideration of topography and thermal convection in the analysis areas. As well, land-surface model was included for analyzing rainfall volumes associated with water resources in the study area.

2.2.3 The GFDL-R30 Global Climate Model

For the GFDL-R30 (Geophysical Fluid Dynamics Laboratory-R30) global climate model, it proposes to simulate the weather conditions by using the statistical method for downscaling the results of GFDL-R30 under two-types of economic and social development , population growth and future technologies (Special Report on Emission Scenarios, SRES) including SRES A2 and B2. Grid resolution based on downscaling denotes 0.5° latitude x 0.5° longitude in size or areas of approximately 50 x50 km. Resolution climate data consists of daily data of average temperature, maximum temperature, minimum temperature, precipitation volume, atmospheric pressure, photoperiod, relative humidity, and velocity.

2.3 Climate change specific to Thailand

According to Thailand Climate Change Information report by The Thailand Research Fund (TRF), Chidthaisong, A (2011) summarized the expected impacts into 4 main topics as follows,

- Temperature
  - Increase in average maximum temperature
  - A warm period is longer.
  - A cold period is shorter.
- Rainfall pattern
  - Annual cumulative precipitation in Thailand was decreased slightly in the Central and East region.
  - Annual cumulative precipitation in Thailand was significantly increased in the North and North-East region.
- Tropical Strom
  - Since 1951-2009, the number of tropical strom is about 0.7 storms per year
  - The number of storms is likely to decline. However, the severity of the storm is not clear.
- Sea level
  - The sea level in the Gulf of Thailand is still not clear in conclusion. The past studies found the sea-level is not change, decrease by 0.3 mm per year, and increase in the rate of 0.6 to 5.0 mm per year.
  -

2.4 Expected global warming impacts

At present, global warming studies are found in three different types (Eddowes et al., 2003) including

Mitigation purpose is regarded as researches focusing on an approach of global warming impact reduction e.g., the use of alternative energy or optimal energy utilization and how to reduce the potential greenhouse gases per economic/social activity unit.

Adaptation purpose refers to the study involving scrutinizing the management of expected global warming impacts and the intensity of greenhouse gases in global atmosphere affecting global warming and climate conditions. Although the level of greenhouse gases has not been increased, its previous accumulation is expected to *continuously* generate global warming phenomenon until the 2050.

The research on adaptation aims to assess the results of any changes that influence the people's lifestyles as a means to avoid the risks caused by global warming. It includes an evaluation on the improvement of infrastructure design with durability for global warming and climate conditions in the next 50 years as well as agricultural yield investigation and expectation enabling adaptation to the future effects of global warming.

Vulnerability purpose is as a research for investigating key vulnerabilities response to the variability of global ecosystem associated with global warming in order to assess the major global areas where any changes caused by global warming might be occurred, especially the greater vulnerabilities signify critical threat levels of specific areas such as Ganges delta or some Pacific Island countries (PCIs).

Transportation plays an important role for economic and quality of life of people; therefore transportation planning and design must consider multidimensional factors, especially factors related to the changes in global warming. Global warming have far-reaching effects to transport infrastructure safety, management and maintenance and the climate change consequences influence all types of transportation – land, air and water transportation.
The research on "How climate change would impact transport system of Thailand: Adaptation That Thai engineers and planners should aware of" as adaptation to global warming study aims to gather knowledge related global warming phenomenon in Thailand and other countries together with impacts to transportation caused by such a problem. Data collection would contribute toward a provision of transportation adaptation to the future global warming.

Some documents and studies related to traffic and transportation from various countries can be labeled as follows:

Hyman et al. (2008) conducted the study at Gulf Coast to investigate the transportation infrastructure impacts in terms of management and services. This research involves examining potential effects on transportation that might be arisen from the climate variability. Data obtained by the study were applied by planners and executives to assess and make a decision of the future transportation network planning. According to literature review and previous researches, the study found that transportation impacts are more likely to be potentially felt both its infrastructure and management systems.

The findings indicated 4 significant impacts of global warming on transportation including:

- **Higher temperatures** can possibly damage to transportation infrastructures, in that increased temperatures result in the lower surface water levels and impacts of melting and reducing arctic ice cap.
- **Higher rainfalls** can affect physical infrastructures and increase rates of soil erosion.

- **Higher sea levels** tend to have effects on transportation infrastructures along the side of sea coast and river.
- **Storms** are more likely to potentially destroy transportation infrastructures and management due to its greater severity.

Eddowes et al. (2003) addressed global warming impacts on rail transportation system in The United Kingdom by gathering climate data and risks to the rail system. The former and current management based on three data sources were comprehensively considered such as,

- Knowledge skills and management of safety and impacts on rail system associated with climate change.
- Rail system data – to predict climate conditions under global warming that might pose a risk to rail system in the future.
- Global warming studies – involve the research endeavor on environmental conditions which may cause effects on rail system.

The study adopted all parts of data to analyze global warming impacts based on climate factors such as

- rainfalls
- hails
- snow/ice
- fogs
- wind
- temperatures
- lightning
- sunlight
- sea levels
- plants, etc.

Evaluating effects of global warming using these influential variables that affect the rail system can be carried out regarding some steps: firstly, searching the rail characteristics in line with the climate conditions; secondly, prioritizing situations underlying the possible risks determined by Rail Safety and Standards Board; and finally, providing the appropriate preventive measures.

The prediction of this study used the case of an average global temperature raised by 1-2 degree Celsius, average velocity increased by 4-10%, rainfall levels reduced by 5-15% and sea level increased by 20-60 cm, so the study found the significant impacts on the following variables including,

- rails (due to increased temperatures)
- soil tasks (due to reduced rainfalls)
- drainage (due to reduced rainfalls)
- equipment and tool costs (due to increased velocity)
- rail structures along the sea coast and river (due to increased sea levels)

In this study, it was demonstrated that although rail infrastructures and its body are strong enough, the efficiency of safety management is likely to be affected by climate change caused by global warming, even in relatively low risk levels. Hence, when considering the changed climatic conditions by global warming, the RSSB as a responsible unit is required to take actions focusing on the integration of data obtained from all functional divisions so as to consider the overall picture at national level. As well, RSSB needs to provide the noteworthy data for all related authorities.

Jaroszweski et al. (2010) evaluated the transportation impacts that might be occurred by climate change with regards to the future social and economic situations. This research aims to enable researchers and stakeholders considering the overall transportation adaptation to global warming.

Kirshen et al. (2004) verified that passengers will face in excess of 80% travel delay due to flooding in Boston. The study estimated the total cost when applying adaptive strategies in transport sector and then found it will be lower than getting nothing done.

Kinsella and McGuire (2005) calculated the total expenditure that might have to be spent for infrastructure upgrades to serve the higher rainfalls caused by global warming. The findings demonstrated the costs of initial construction will be increased by 10%, albeit the infrastructure will have long-term operations and more durable, which introduce the value of investment.

Love et al. (2010) addressed that transportation activities are the major causes of air pollution and GHGs leading to changes in climate in terms of temperature, velocity, storm, precipitation, and sea level. Presently, global warming data has not yet been included in the decision analysis for long-term infrastructure investment, transportation planning and design in transportation sector; hence in the future, such data should be incorporated by the transportation decision-making process. This research suggested transportation adaptation, planning and design corresponding to global warming based on reviewing and considering the comparison between the current global warming and existing transportation system towards the future management approach. The researcher addressed that the effective of adaptation strategies and actions require the continuous monitoring and evaluation of outcomes.

PIANC (2008) illustrated the impacts of global warming to a pilot-scale project in water transportation system. This report conducted the reviews of global warming impacts on water transportation. The main variables involve sea-level rise, velocity, wave, tide, storm, ocean circulation, coastal condition, sea-water chemistry, marine protected areas, sea ice, river, brackish water, and hydrologic variability. Based on the findings, water transportation adaptation policies and strategies are required since global warming might affect basic infrastructures, vessels and water transportation management. Hence, it should consider strategies for water transportation infrastructure improvement together with application of knowledge and technologies to develop alternative solutions on sustainable planning.

Regmi and Hanaoka (2011) carried out the examination of climate change impacts on transportation infrastructures and adaptation strategies in the Asia Region. The study involves the investigation of global warming awareness affecting road transportation and stakeholders in Asian countries. The research focuses on design and planning in regard to global warming impacts that consists of these following issues:

- Emergency preparedness
- Infrastructure design and operation standards
- Policies
- Organizations/institutions
- Coordination and cooperation in application of transportation adaptation

The study cited that Asian countries still have a few policies and application of adaptation to global warming. After policy direction is adjusted, the improvement of road construction and management is needed as well such as planning, design, construction, management and maintenance. The results of this study provide the suggestions on sustainable development in the Asia Region as follows:

- Raising awareness of global warming impacts on transportation sector to related organizations and stakeholders
- Reviewing road design and standards as well as the current construction techniques associated with global warming impacts
- Providing suggestions on assessment of global warming impacts
- Setting the specific organization responsible for the strategy operation of transportation adaptation to global warming
- Increasing the efficiency of coordination among stakeholders in infrastructure development

Transportation Research Board (2008) discussed GHGs are derived from various human activities. Albeit, the global warming studies remain widespread in various areas, such issue related to transportation is quite rare. This document highlights on effects of global warming on transportation & traffic infrastructure and management in The United states, that some parts mentioned global warming impacts and transportation adaptation. Since the current transportation construction or operation still truly lack the consideration on global warming, the perception on such problem will reduce a risk of wasting investment in the future. The main target of this document entails the prerequisite of transportation policy-making authorities & stakeholders in providing the operation, which is the most appropriate for the future global warming.

FHWA (2012) accentuated global warming has effects on transportation infrastructure and system construction, design, safety, management and maintenance. The greater potential of global warming will affect temperature, precipitation, storm, etc., which unavoidably impacts on transportation infrastructures e.g., roads, airports, railways, large transportation system, pipeline transportation, vessel transportation and ports.

Any changes caused by global warming are considered as the challenge of transportation sector in terms of transportation planning, construction, management and maintenance. It is vital to comprehend the future impacts on environmental conditions. This document purposely enables transportation stakeholders (e.g., engineers, planners and executives) reviewing and improving the transportation planning process in associate with the changed climate conditions in the future. The understanding of the climatic variation will provide the improvement of measures in readiness to global warming. The endeavor could be possibly avoidable the damages and reduce the risk of future hazards. This document provides global warming information on transportation to authorities and stakeholders through data gathering from experts at national and regional levels. In addition, the study used the forecasting model for different geographical areas, so its results indicate specific variables in each location.

The Royal Academy of Engineering (2011) suggested engineers should be considered as the core transportation adaptation process to global warming in terms of the existing infrastructure protection and the new infrastructure development in appropriate for changes in climate conditions. The investment on infrastructure protection will reduce the potential risks of global warming effects to people and national economy as well as provide maximum utilization of the existing natural resources.

In this document, it illustrates the examination of infrastructures affected by the current global warming and its adaptation approach. Transportation adaptations were purposed by the study into two management patterns including adaptation management for long-term global warming impacts (e.g., sea-level rise) and immediately severe impacts (e.g., flash flood).

In the United Kingdom, an infrastructure management substantially requires the national long-term planning, enforcement and framework as the challenge and opportunity of the engineering sector to provide a new transportation infrastructure plan, design and maintenance which is ready to global warming at the national and local levels.

2.5 Climate Change and Transport

Likewise, other countries such as the North America (the United States) and the European countries have been posed by the potential impacts of climate change on transportation sector. Presently, just some of transportation experts are aware of climate change effects, hence existing transportation infrastructures seem to have a design considering only the normal climate conditions without regarding the problems of climate change.

Numerous studies alluded that global warming is influentially linked with transportation sector in both infrastructure and management function. According to reviewing previous researches in many countries, the potential issues in brief can be exemplified as follows:

Hyman et al. (2008) addressed that global warming impacts on transportation sector comprise two major types including direct and indirect impacts such as,

Increase in global temperature can cause the potential effects on road surface damage (e.g., enlarging the crack and accelerating erosion), expanding and buckling the rail tracks that might pose the risk of derailment, lower water levels not allowing large vessels to pass through the canals, etc.

Increase in rainfalls cause direct impacts on transportation structures such as accelerating damage of roads, bridges, airport runways, pedestrian paths and railway sleepers.

Rising sea levels possibly result in the lower roads leading to coastal erosion that significantly affect the harbors.

Changes in storm might be occurred in the form of greater intensity and severity near the coastal areas causing floods that have direct effects on road, railway, and airport structures. Another storm impact includes increase in velocity and thunder/ lightning that pose a major treat to electronic system in all transportation types.

Furthermore, indirect impacts of global warming associated with transportation sector impacts possibly include economic and environmental situations as well as safety of people in the nation.

Jaroszweski et al. (2010) reported that higher temperatures caused by global warming have effects on railway structures as similar to the study of **Hyman et al. (2008)**. As well, such impacts are substantially required the greater maintenance.

The Royal Academy of Engineering (2011) stated both transportation infrastructure and operational system will be considerably affected by global warming. Expected climate change impacts to such system in the United Kingdom can be described as following;

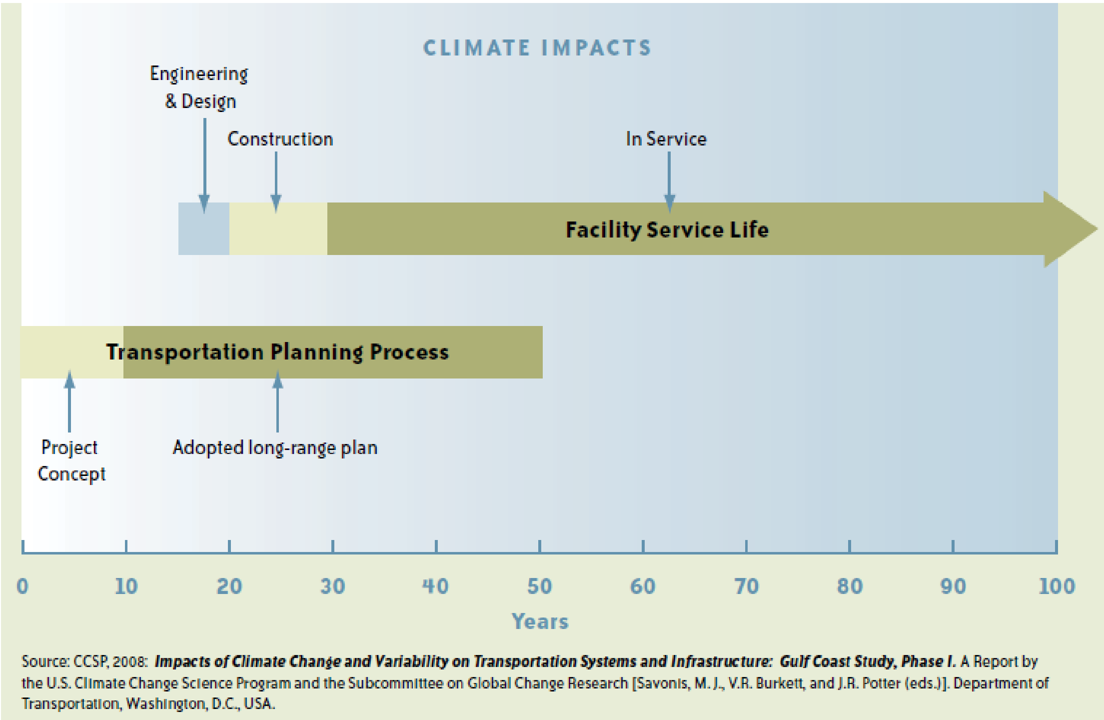
Table 2.1: Expected climate change impacts to such system in the UK (The Royal Academy of Engineering, 2011)

Affected infrastructures and management	Climate conditions
Roads	Storm surge, increase in rainfalls, floods, drought, heavy snow, ice melting, strong winds, thick fog, landslides
Pedestrian paths	Snowy
Bike lanes	Floods
Rail system (ground)	Storm surge, higher rainfalls, floods, snowy, strong winds, warmer temperatures, humidity affecting rail equipment
Rail system (underground)	Increase in rainfalls and temperatures
Airport	Electrical storm, floods, drought, snowy, strong winds, thick fog
Air travel	Electrical storm, strong winds
Bus terminal/ passenger terminal buildings	Drought
Coastal structures	Higher sea levels, storm surge, floods, thick fog
Harbors	Higher sea levels, storm surge, floods, thick fog, drought, landslides
Cut and fill soils	Higher water levels, storm surge, higher rainfalls, floods
Tunnels	Floods
Bridges	Storm surge, higher rainfalls, floods, changes in wind direction, erosion by water
Pipeline transportation	Higher rainfalls, floods
Control system	Storm surge, higher rainfalls
GPS	Electrical storm
Fuel transportation	Higher water levels, storm surge, floods
Gas transportation	Higher water levels, storm surge, floods
Electric car charging networks	Electrical storm, higher rainfalls, floods
CO2 transport	Floods

As aforementioned, all parts in transportation sector have effects on changes in climate conditions due to global warming. Currently, the improvement of transportation infrastructure and management system in both mitigation and adaptation has been provided; nevertheless data related to air transportation impacts and wind speed and direction are relatively rare. In the future, researchers are required to conduct the studies on this topic deeply because changes in wind velocity are the major factor affecting harbor impacts as well.

FHWA (2012) mentioned that based on researches, altering climatic conditions or global warming including changes in temperatures, amount of rainfalls, storms, sea levels, and wind speed that impact to transportation sector e.g., weakened bridges, flooded roads, road surface damage. Moreover, such problem also affects people's safety and a driving force of the national economy.

Bipartisan Policy Center (2009) pointed out the impacts of climate change to transportation system service life in various dimensions such as planning designing construction and operation as shown in figure 2.3



Source: Bipartisan Policy Center (2009) adapted from CCSP.

Figure 2.3: Impacts of climate change to transportation system concept

Transportation Research Board (2008) indicated the major impacts from climate change or global warming in North America include eroded or flooded roads along coastal areas or river banks, damage to large transportation systems and runways caused by higher sea levels, storm surge and landslides in some areas. Presently, more than 53% of the number of US population lived near coastal areas with a high density.
Global warming impacts to all types of transportation sector including land, water and air transportation as illustrated in Table 2.2 which indicates changes in climate conditions caused by global warming as well as the potential impacts on transportation sector categorized by land transportation (roads, rail system, and pipeline system), marine transportation and air transportation. Such effects will be demonstrated in both negative and positive ways e.g., higher temperatures might increase the round-trip frequency of maritime shipping due to reduce in a season of sea ice.

Table 2.2: Global warming and its associated impacts on transportation sector

Changes in climate conditions due to global warming	Impacts					
	Land transportation (road, rail system, pipeline transportation)		Marine transportation		Air transportation	
	Management	**Infrastructure**	**Management**	**Infrastructure**	**Management**	**Infrastructure**
Temperature Increased temperatures with heat waves	Limitation period for construction as a result of workers' fatigue derived from heat and safety reason Increase in heat throughout the machines and degraded tires Plant growth and shedding near roadways causing slippery road surface and affecting drivers' vision	Effects on road surface and concrete structure Thermal expansion of bridge structure, joints and paved surface Aesthetic impacts on roadways and corridors Pavement integrity values e.g., asphalt melting and softening, and rutting  Irregular rail tracks when temperature > 43 degree Celsius that might result in equipment damage	Impacts on vessel transportation due to lowered water level caused by higher temperatures		Flight delay due to periods of extreme heat Higher temperatures will cause a decrease in air density affecting efficiency of aircraft and engine power, thus it must have longer runways and more horsepower or specific weight limits Increase in energy consumption on earth	More heat due to climate conditions causing road surface and concrete buckles More heat due to climate conditions affecting vehicle storages

Table 2.2: Global warming and its associated impacts on transportation sector (continued)

Changes in climate conditions due to global warming	**Impacts**					
	Land transportation (road, rail system, pipeline transportation)		**Marine transportation**		**Air transportation**	
	Management	**Infrastructure**	**Management**	**Infrastructure**	**Management**	**Infrastructure**
Temperature Decrease in the number of cold days	Changes of circumstances, ice and snow conditions and expenses on abolishing and using chemical and salt (usually lower) Decrease in cold weather affecting operational regulations of workers	Reducing the use of avoided roads with packed snow reduces	Ice accumulation in vessels and harbors, and reduce in ice fog Reducing a stuck in vessel transportation caused by sea ice		Changes of expenses for abolishing ice and snow due to the use of chemical and salt Reduce of deicing  Reduce in the limitation of airport staff's operations on earth due to regulations related to work break when temperature lower than -29 degree Celsius	

Table 2.2: Global warming and its associated impacts on transportation sector (continued)

Changes in climate conditions due to global warming	**Impacts**					
	Land transportation (road, rail system, pipeline transportation)		**Marine transportation**		**Air transportation**	
	Management	**Infrastructure**	**Management**	**Infrastructure**	**Management**	**Infrastructure**
Temperature Increase in temperatures in the Arctic		Ice melting causes the collapse of road embankments, rail tracks, bridges, tunnels and pipelines Reduce in season of ice roads	Longer periods of time of marine transport			Ice melting causes the holes at runway foundation
Temperature During the change in seasons	Changes in regulations related to weight restrictions corresponding to the season Changes in fuel consumption in each season (usually more fuel uses in cold season) Longer periods of construction season	Decrease in degraded roads caused by ice and snow	More round trips of freight shipping due to decrease in ice periods			

Table 2.2: Global warming and its associated impacts on transportation sector (continued)

Changes in climate conditions due to global warming	**Impacts**					
	Land transportation (road, rail system, pipeline transportation)		**Marine transportation**		**Air transportation**	
	Management	**Infrastructure**	**Management**	**Infrastructure**	**Management**	**Infrastructure**
Increase in sea levels and storm surges	Having more frequently halt in travels along coastal areas due to the lower roads and no railway service operation caused by storm surge  Increase in the severity of storm surge forcing people to migrate into the other areas	Flooded road and rail structures near coastal areas  Flood severity in underground tunnels and low level structures Accelerating eroded roads and bridges Bridge erosion Lower clearance under bridges Loss of coastal areas and embankments caused by landslides	Increase in the severity of storm surge forcing people to migrate into the other areas	Altering harbor structure due to high waves and storm surge Lower clearance under waterway bridges Changes in vessel schedule since not all areas can be accessed (the deep sea levels will allow an access but not for shallow zones)	Close or not allow to use 50 large airports which are located near coastal areas influentially affecting the national service	Flooded runways near coastal areas

Table 2.2: Global warming and its associated impacts on transportation sector (continued)

Changes in climate conditions due to global warming	**Impacts**					
	Land transportation (road, rail system, pipeline transportation)		**Marine transportation**		**Air transportation**	
	Management	**Infrastructure**	**Management**	**Infrastructure**	**Management**	**Infrastructure**
Rainfall amounts High intensity rainfalls	More travel delays Traffic congestion or traffic stop Increase in flooded roads Halting construction activities Changes of rainfall and flood conditions influencing safety and maintenance	Increase in roads, rail tracks and tunnels flooding Peak flows over drainage design More damages on roads and rails due to high rates of erosion by rain and landslides Impacts to soil humidity levels affecting road , bridge and tunnel structures Effects on water in road surface layers More works on pipeline cleaning that possibly cause a pipe damage	More travel delays	Impacts on harbor structures from waves and storm surges Altering ship routing system for deep water due to sediment accumulations and particles	More travel delays Floods as a result of water flow over drainage or carrying capacity that cause flight delays or perhaps have to close the airport Impacts on planning in case of emergency for equipment maintenance and safety management of the airport	Effects on airport facilities Disturbing the airport pilot equipment Damages on Runways and other structures due to floods/water logging and inefficient drainage system

Table 2.2: Global warming and its associated impacts on transportation sector (continued)

Changes in climate conditions due to global warming	**Impacts**					
	Land transportation (road, rail system, pipeline transportation)		**Marine transportation**		**Air transportation**	
	Management	**Infrastructure**	**Management**	**Infrastructure**	**Management**	**Infrastructure**
Rainfall amounts Little rainfall and drought	Increasing opportunity of forest fire that affects roads being closed and drivers' vision caused by smoke 	Forest fire can cause a direct impact on damaging transportation infrastructure system May cause mud flows in forest fire areas	Impacts on ship routing and navigation season		Forest fire may cause visual impacts on such areas	
Rainfall amounts *Irregular* rain which does not fall in usual season and water flow changes	Positive impacts on travel safety	Increasing the risks of floods and landslides affecting damages on roads and rail systems  	Periodically closing of navigational channel or strict embargo due to flood situations	Changes in sediment accumulation conditions resulting in deep-water reducing and pilot impacts	Positive impacts on travel safety	Inadequate drainage system causing damage to runways

Table 2.2: Global warming and its associated impacts on transportation sector (continued)

Changes in climate conditions due to global warming	**Impacts**					
	Land transportation (road, rail system, pipeline transportation)		**Marine transportation**		**Air transportation**	
	Management	**Infrastructure**	**Management**	**Infrastructure**	**Management**	**Infrastructure**
Storm Increase in its frequency and severity	A large number of particles on roads and rail tracks causing travel and freight disruption Increase in emergency migration	Increasing opportunity of infrastructure damage by storms Storm significantly affects stability of the bridge structures  Increasing opportunity of damage to LED spotlights and other road facilities Decrease in lifespan of roads	Impacts on emergency planning for equipment maintenance and navigational safety management	Impacts to infrastructure durability Damage to harbor and its infrastructures caused by waves and storm surges  Damage to harbors, cranes and warehouses	Halting services	Damage to areas and buildings in the airport e.g., passenger terminal buildings, gates, signs, etc.

2.6 Transport Adaptation reviews

In other countries, some potential transportation and traffic adaptation policies and measures have been initiated to combat the future global warming. Many studies have suggested some solutions that are summarized by the research team as follows:

Regmi and Hanaoka (2011) stated transportation infrastructures and management are the major challenge of adaptative strategy development to maintain the existing structures which may be posed the risks of global warming impacts. Yet, the Asian countries quite delay to issue policies and implement some measures for prevention. Researchers illustrate adaptive strategies and measures for transportation sector as below:

Table 2.3: Adaptive strategies and measures for transportation sector (Regmi and Hanaoka, 2011)

Alternatives/strategies	Policy frameworks	Limitations	Opportunity
Adjusting standard design and drainage system Changing positions and planning of roads and other infrastructures	Bringing the changes in climate conditions caused by global warming into consideration of the national policies Providing the investment of studies and researches of concerned situations or areas	Financial and technological conditions Effects on routes or areas with low significance	Technological development and integration with other related fields such as energy

To develop road infrastructures with the most sustainable and flexible transportation practices, the main consideration includes the impact assessment of trends of climate change. The next step involves reviewing the potential policies and planning of design and operations. Since global warming impacts possibly occur in all areas of local, provincial and national levels, the actual operation substantially requires cooperation from all sectors.

Love et al. (2010) concluded that transportation adaptation to global warming requires the suitable implementations including,

- Infrastructure planning and design with a consideration of climatic uncertainty
- Cooperative studies with multidisciplinary experts such as meteorology, hydrology, ecology, engineering, statistics, biology, economics, and financial management
- Infrastructure management for the entire operation
- Regularly improving risk assessment and analysis of adaptive strategies' benefits and costs
- Continuously emphasizing the need of researches and development with a focus on climate changes and variability
- Improving the global warming forecast
- Improving and extending a period of geographic-related data collection as well as data exchange among research units
- Managing the emergency preparedness and response for severe incident plan

The Royal Academy of Engineering (2011) addressed that regarding impacts on transportation sector, improvement of design standard and management must be required. Measurement of adaptive measures needs to collect data related to daily maintenance practices and lifespan of construction materials as well as consideration on the prevention of main structures with high investment which are not possible to move such as railways near coastal areas. As well, new construction should be complied with the new standards which bring the future global warming factors into consideration. Furthermore, data from service users and passengers are vital for developing adaptive strategies of transportation sector to provide the understanding of relationship between service users and passengers; behaviors and global warming conditions

Transportation Research Board (2008) discussed that the existing transportation sector cannot avoid the potential impacts on changes in climatic conditions caused by the release of GHGs to the atmosphere from the past decades. Transportation adaptation is considered as a proactive initiative of experts in this field by proposing various alternatives of adaptation. One of them includes improving transportation management and maintenance practices.

In making a decision or planning of transportation infrastructure rehabilitation or improvement for the long lifespan, transport planners and engineers must consider the possible changes in climatic conditions that might affect the facilities in 50 years ahead. Infrastructure must be designed to be more durable, especially the risk areas where global warming impacts are expected to be occurred.

In some cases, a consideration possibly suggests to move the location of transportation system e.g., roads and railways near coastal areas; while a case of high residential density and land values may be considered to build dam or wall to protect such area instead. The most efficient strategies for reducing the risks of facing global warming problems involve avoiding the construction of infrastructures and communities in the risk locations. The proficient land use control should be implemented to reduce the development on such concerned areas.

The central government regulations on transportation planning need the cooperation of transport planners in bringing climate change data into consideration. The effort includes collaborative implementation with land use management authorities that enables the construction of any infrastructures having a well-plan and reducing waste investment. Considering the first priority and most significance of adaptive strategies of transportation sector, transportation experts must accept that climate change is a major problem to transportation sector related to the risks of investment decision-making that requires long-term solutions.

Table 2.4: Adaptation of land transportation

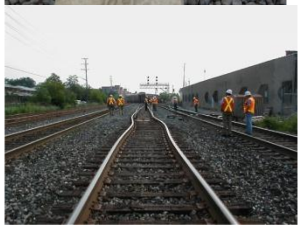
Changes in climatic conditions caused by global warming	**Land transportation (road, rail system, pipeline transportation)**		**Adaptation Options**		
	Management	**Infrastructure**	**Changes in management**	**Changes in design and materials**	**Others**
Temperature Higher temperatures with heat waves	Limitation period for construction as a result of workers' fatigue derived from heat and safety reason Increase in heat throughout the machines and degraded tires	Effects on road surface and concrete structure Thermal expansion of bridge structure, joints and paved surface Aesthetic impacts on roadways and corridors Pavement integrity values e.g., asphalt melting and softening, and rutting 	Change the construction schedule into the colder periods	Development of durable traffic surface materials with more heat tolerance Use of a highly *durable heat* insulating *ma terials* for scenic road management Making the *rail tracks seamless* to reduce buckling  	

Table 2.4: Adaptation of land transportation (continued)

Changes in climatic conditions caused by global warming	**Land transportation (road, rail system, pipeline transportation)**		**Adaptation Options**		
	Management	**Infrastructure**	**Changes in management**	**Changes in design and materials**	**Others**
Temperature Higher temperatures with heat waves	Plant growth and shedding near roadways causing slippery road surface and affecting drivers' vision	Irregular rail tracks when temperature > 43 degree Celsius that might result in equipment damage	Plant and tree management & growing easy care-plants for preventive purpose Checking, repairing and maintenance of rail tracks, rail sensor system and light signals Giving suggestions and warnings of climate and rail conditions		
Temperature Decrease of the number of cold days	Changes of circumstances, ice and snow conditions and expenses on abolishing and using chemical and salt (usually lower) Decrease in cold weather affecting operational regulations of workers	Reducing the use of avoided roads with packed snow reduces	Reduction of snow and ice removal Extension of construction and maintenance periods		

Table 2.4: Adaptation of land transportation (continued)

Changes in climatic conditions caused by global warming	Land transportation (road, rail system, pipeline transportation)		Adaptation Options		
	Management	**Infrastructure**	**Changes in management**	**Changes in design and materials**	**Others**
Temperature Increase in temperatures in the Arctic		Ice melting causes the collapse of road embankments, rail tracks, bridges, tunnels and pipelines Reduce in season of ice roads	Longer construction periods Increase in the use of sonar to monitor the stream flow and bridge erosion	Use of equipment to keep low temperature levels such as thermosiphons 	Changing road and railway locations on areas which are not susceptible to erosion/ collapse
Temperature During the change in seasons	Changes in regulations related to weight restrictions corresponding to the season Changes in fuel consumption in each season (usually more fuel uses in cold season) Longer periods of construction season	Decrease in degraded roads caused by ice and snow	Attenuation of truck weight limits		

Table 2.4: Adaptation of land transportation (continued)

Changes in climatic conditions caused by global warming	**Land transportation (road, rail system, pipeline transportation)**		**Adaptation Options**		
	Management	**Infrastructure**	**Changes in management**	**Changes in design and materials**	**Others**
Increase in sea levels and storm surges	Having more frequently halt in travels along coastal areas due to the lower roads and no railway service operation caused by storm surge  Increase in the severity of storm surge forcing people to migrate into the other areas	Flooded road and rail structures near coastal areas  Flood severity in underground tunnels and low level structures Accelerating eroded roads and bridges Bridge erosion Lower clearance under bridges Loss of coastal areas and embankments caused by landslides		Upgrading roads, bridges and rail tracks Increasing the number of water distribution canals near roads along coastal areas Upgrading and protecting bridges, tunnels, and large transportation system entrances Increasing drainage pumps and its capacity for better water release inside tunnels	Moving road and railway locations located in the affected areas Prevention of significant areas by building dams, walls and ditches Improving the durability and height of dams, walls and ditches Increasing amount of insurance to limit the growth of flooded-prone areas Reinstatement of coastal *areas* to their natural conditions

Table 2.4: Adaptation of land transportation (continued)

Changes in climatic conditions caused by global warming	**Land transportation (road, rail system, pipeline transportation)**		**Adaptation Options**		
	Management	**Infrastructure**	**Changes in management**	**Changes in design and materials**	**Others**
Rainfall amounts High intensity rainfalls	More travel delays Traffic congestion or traffic stop Increase in flooded roads Halting construction activities Changes of rainfall and flood conditions influencing safety and maintenance	Increase in roads, rail tracks and tunnels flooding Peak flows over drainage design More damages on roads and rails due to high rates of erosion by rain and landslides Impacts to soil humidity levels affecting road , bridge and tunnel structures Effects on water in road surface layers More works on pipeline cleaning that possibly cause a pipe damage	Increasing the monitoring of bridge pier and abutment erosion  Increasing the monitoring of slop areas and drainage system Increasing the monitoring of rupture and erosion in marine pipelines Increasing the monitoring of flood levels in real-time Conducting integrated emergency migration stages	Preventing migration routes and improving drainage system Using stones for bridge pier and abutment prevention  Increasing drainage system and pump capacity within tunnels Providing slope retention for landslide protection 	Using sensors for water flow measurement Prohibition of development in floodplains  floodplains 

		Improving standards of drainage capacity for new infrastructure construction and upgrading project e.g., change of the resistant construction regulations due to storm events from 100 years to 500 years	

Table 2.4: Adaptation of land transportation (continued)

Changes in climatic conditions caused by global warming	**Land transportation (road, rail system, pipeline transportation)**		**Adaptation Options**		
	Management	**Infrastructure**	**Changes in management**	**Changes in design and materials**	**Others**
Rainfall amounts Little rainfall and drought	Increasing opportunity of forest fire that affects roads being closed and drivers' vision caused by smoke 	Forest fire can cause a direct impact on damaging transportation infrastructure system May cause mud flows in forest fire areas	Plant and tree management		
Rainfall amounts *Irregular* rain which does not fall in usual season and water flow changes	Positive impacts on travel safety	Increasing the risks of floods and landslides affecting damages on roads and rail systems			

Table 2.4: Adaptation of land transportation (continued)

Changes in climatic conditions caused by global warming	**Land transportation (road, rail system, pipeline transportation)**		**Adaptation Options**		
	Management	**Infrastructure**	**Changes in management**	**Changes in design and materials**	**Others**
Storm Increase in its frequency and severity	A large number of particles on roads and rail tracks causing travel and freight disruption Increase in emergency migration	Increasing opportunity of infrastructure damage by storms  Storm significantly affects stability of the bridge structures Increasing opportunity of damage to LED spotlights and other road facilities	Increase in the frequency of migration preparedness program Improving rainfall and storm direction prediction Improving road monitoring and real-time warning system for drivers Improving a emergency migration modeling	Change traditional bridge to suspension bridge design enabling safety of support structures and increase in a strong foundation  Improving standards of drainage capacity for new infrastructure construction and upgrading project Removal of traffic bottlenecks on migration routes	Increasing a durability and height of dams Limiting development near the coastal areas Increasing amount of insurance to limit the growth of prone areas Reinstatement of coastal *areas* to their natural conditions

Table 2.4: Adaptation of land transportation (continued)

Changes in climatic conditions caused by global warming	**Land transportation (road, rail system, pipeline transportation)**		**Adaptation Options**		
	Management	**Infrastructure**	**Changes in management**	**Changes in design and materials**	**Others**
Storm Increase in its frequency and severity		Decrease in lifespan of roads		Applying modular construction techniques for susceptible infrastructures  Improving traffic equipment and signals in easy for installation  	

Table 2.5: Adaptation of marine transportation

Changes in climatic conditions caused by global warming	Marine Transportation		Adaptation Options		
	Management	**Infrastructure**	**Changes in management**	**Changes in design and materials**	**Others**
Temperature Higher temperatures with heat waves	Impacts on vessel transportation due to lowered water level caused by higher temperatures		Change in navigation routes		Increasing water levels by *releasing water stored* in the reservoirs
Temperature Decrease of the number of cold days	Ice accumulation in vessels and harbors, and reduce in ice fog Reducing a stuck in vessel transportation caused by sea ice		Improving management due to decrease in snow, ice and fog		
Temperature Increase in temperatures in the Arctic	Longer periods of time of marine transport		Increasing an access to the remote areas		
Temperature During the change in seasons	More round trips of freight shipping due to decrease in ice periods		Setting weight limits in warm season	Providing a shallow-bottom vessel design easy for navigation	More canal cleaning Change to other transportation types

Table 2.5: Adaptation of marine transportation (continued)

Changes in climatic conditions caused by global warming	**Marine Transportation**		**Adaptation Options**		
	Management	**Infrastructure**	**Changes in management**	**Changes in design and materials**	**Others**
Temperature Increase in sea levels and storm surges	Increase in the severity of storm surge forcing people to migrate into the other areas	Altering harbor structure due to high waves and storm surge Lower clearance under waterway bridges Changes in vessel schedule since not all areas can be accessed (the deep sea levels will allow an access but not for shallow zones caused by sediment accumulation)	Frequent bridge opening for vessel passing	Increasing harbors and pier levels as well as improving equipment with appropriate distance Protecting marine terminals and warehouses Upgrading bridges and other structures	*Excavation of* the shipping routes Increasing the height or constructing jetties and walls to protect a harbor  jetties
Rainfall amounts High intensity rainfalls	More travel delays	Impacts on harbor structures from waves and storm surges Altering ship routing system for deep water due to sediment accumulations and particles		Strengthening the design of harbors and their structures to prevent storm surge and wave damage Protecting marine terminals and warehouses from floods	*Excavation of* the shipping routes

Table 2.5: Adaptation of marine transportation (continued)

Changes in climatic conditions caused by global warming	**Marine Transportation**		**Adaptation Options**		
	Management	**Infrastructure**	**Changes in management**	**Changes in design and materials**	**Others**
Rainfall amounts Little rainfall and drought	Impacts on ship routing and navigation season		Setting freight limits due to changes of the river depth		*Excavation of* the shipping routes Releasing water from reservoirs to increase water levels Change to other transportation types
Rainfall amounts *Irregular* rain which does not fall in usual season and water flow	Periodically closing of navigational channel or strict embargo due to flood situations	Changes in sediment accumulation conditions resulting in deep-water reducing and pilot impacts	Setting freight limits due to changes of the river depth		*Excavation of* the shipping routes
Storm Increase in its frequency and severity	Impacts on emergency planning for equipment maintenance and navigational safety management	Impacts to infrastructure durability Damage to harbor and its infrastructures caused by waves and storm surges Damage to harbors, cranes and warehouses	Frequently practicing migration preparedness	Strengthening the design of harbors , piers and terminals that are possibly affected by waves and storm surges	

Table 2.6: Adaptation of air transportation

Changes in climatic conditions caused by global warming	Air transportation		Adaptation Options		
	Management	**Infrastructure**	**Changes in management**	**Changes in design and materials**	**Others**
Temperature Higher temperatures with heat waves	Flight delay due to periods of extreme heat Higher temperatures will cause a decrease in air density affecting efficiency of aircraft and engine power, thus it must have longer runways and more horsepower or specific weight limits Increase in energy consumption on earth	More heat due to climate conditions causing road surface and concrete buckles More heat due to climate conditions affecting vehicle storages	Increasing weight restrictions on high-level flight aircrafts or airports in warmer areas Canceling a flight involving any hazards or risks of aviation	Developing traffic surface materials which are durable more heats Increasing the length of runways having high-level flight aircrafts or hot weather flying	
Temperature Decrease of the number of cold days	Changes of expenses for abolishing ice and snow due to the use of chemical and salt Reduce of deicing Reduce in the limitation of airport staff's operations on earth due to regulations related to work break when temperature lower than -29 degree Celsius		Reducing the frequency of snow and ice removals Decrease of aircraft deicing		

Table 2.6: Adaptation of air transportation (continued)

Changes in climatic conditions caused by global warming	Air transportation		Adaptation Options		
	Management	Infrastructure	Changes in management	Changes in design and materials	Others
Temperature Increase in temperatures in the Arctic		Ice melting causes the holes at runway foundation		Providing a new traffic surface development and repairing runways	Changing the landing position
Temperature Increase in sea levels and storm surges	Close or not allow to use 50 large airports which are located near coastal areas influentially affecting the national service	Flooded runways near coastal areas		Upgrading runways	Providing construction or upgrading ditch levels/ embankments Changing the runway location in some cases
Rainfall amounts High intensity rainfalls	More travel delays Floods as a result of water flow over drainage or carrying capacity that cause flight delays or perhaps have to close the airport Impacts on planning in case of emergency for equipment maintenance and safety management of the airport	Effects on airport facilities Disturbing the airport pilot equipment Damages on Runways and other structures due to floods/water logging and inefficient drainage system	Increasing service halts and delays Frequently closing the airport	Increasing drainage capacity and improving drainage system of runways	

Table 2.6: Adaptation of air transportation (continued)

Changes in climatic conditions caused by global warming	Air transportation		Adaptation Options		
	Management	Infrastructure	Changes in management	Changes in design and materials	Others
Rainfall amounts Little rainfall and drought	Forest fire may cause visual impacts on such areas				
Rainfall amounts *Irregular* rain which does not fall in usual season and water flow	Positive impacts on travel safety	Inadequate drainage system causing damage to runways		Increasing drainage capacity and improving drainage system of runways	
Storm Increase in its frequency and severity	Halting services	Damage to areas and buildings in the airport e.g., passenger terminal buildings, gates, signs, etc.		Strengthening passenger terminal buildings and other facilities	

Regarding global warming solutions of transportation sector in other countries, the results found that the trends of inevitable impacts of global warming on transportation have been increasing for all countries, even in Thailand. In the future, Thailand must review the potential policies for transportation infrastructure management and improve design and maintenance standards in line with changes in climatic conditions in order to reduce the loss of economic development and investment as well as allocate the most efficient use of existing resources.

The main purpose of this project study is to gather data related to the current problems of transportation sector on changes in climatic conditions caused by global warming. This endeavor involves bringing the significant findings from survey into analysis and conclusion to find appropriate solutions suggested by transportation experts *or* other *engineering-related field* experts towards adaptive measures of transportation sector in Thailand for sustainably combating the future global warming.

Chapter 3
Part 1: The projection of weather and climate change specific to Thailand

In the study of expected climate change specific to Thailand, many reports and paper related to the climate change have been reviewed. Moreover, a few specialists and experts in Thai global climate change and other related fields have been interviewed. The expected impacts can be summarized into 2 main topics as follows,

- Temperature
  - Increase in average maximum temperature
  - A warm period is longer.
  - A cold period is shorter.
- Rainfall pattern
  - Annual cumulative precipitation in Thailand was decreased slightly in the Central and East region.
  - Annual cumulative precipitation in Thailand was significantly increased in the North and North-East region.

In order to understand the projection of weather and climate change specific to Thailand, 3 climate models were reviewed in chapter 2. Hence, the projection of weather and climate change specific to Thailand from PRECIS Model, MM5 and GFDL-R30 are shown below.

3.1 Thailand Climate Change Scenarios during 2010-2090 by the PRECIS Regional Climate Model

Future climate change scenarios in Thailand provide a brief summary of climate change over the next 80 years during 2010-2090 by covering a set of variables used for the analysis including the maximum temperature, number of days with the maximum temperature greater than or equivalent to 35 degree Celsius, the minimum temperature, a cool period per annum, annual rainfall, and number of rainy days. For Thailand, above climate variables were used to simulate two GHG emission scenarios including scenario A2 and scenario B2. Under greenhouse effect phenomenon following economic and social development of scenario A2, the maximum temperature in Thailand in the early of 21st century has been changed in an upward direction since the late of 20th century. As well, the future maximum temperature underlying greenhouse effect along with economic and social development of scenario B2 is projected to increase in almost all areas in Thailand, but increasing by a slightly lower level than that of scenario A2 (Figure 3.1-3.2). In terms of warm periods in the year or days with the highest temperature larger than or equal to 35 degree Celsius, the scenario predicts prolonged warm periods in almost all areas in Thailand and might longer than the former period up to 2-4 months in the end of this century as illustrated in Figure 3.3-3.4.

Future climate change conditions manifest that average daily minimum temperature in overall Thailand areas presents the increasing trend towards 3-4 degree Celsius in the end of century under situation of greenhouse effect based on social and economic development of scenario A 2. Under B2 situation, the trend of average daily minimum temperature has been concurrently increasing, but the increase levels are lower than A2 situation of about 2-3 degree Celsius as illustrated in Figure 3.5-3.6. When considering the cool period by year or number of days at temperature below 16 degree Celsius, the study found that under greenhouse effect phenomenon following economic and social development approach of scenario A2, areas with temperature less than 16 degree Celsius remain only some mountains; however B2 situation presents a smaller changes of temperatures, in that temperatures stay cool around one month in of some parts of Upper Northern and Upper Northeastern, Thailand. Albeit, temperature data of such areas obviously displayed a decreasing trend as shown in Figure 3.7-3.8.

While, scenario of change of annual rainfall demonstrates the increasing trend of all regions in Thailand in both volume (it might increase up to 10-40% in many areas in the end of century) and prolonged rainy days in the future as illustrated in Figure 3.9-3.10. Due to the increasing trend of annual volumes of rainfall and number of rainy days, it might indicate that rainfall volumes each time in the future will increase or in another term, heavier rains will possibly be seen in the future as compared to the past. It means that Thailand has greatly a potential risk of flash/ immerse flood as well as disasters caused by the deluge.

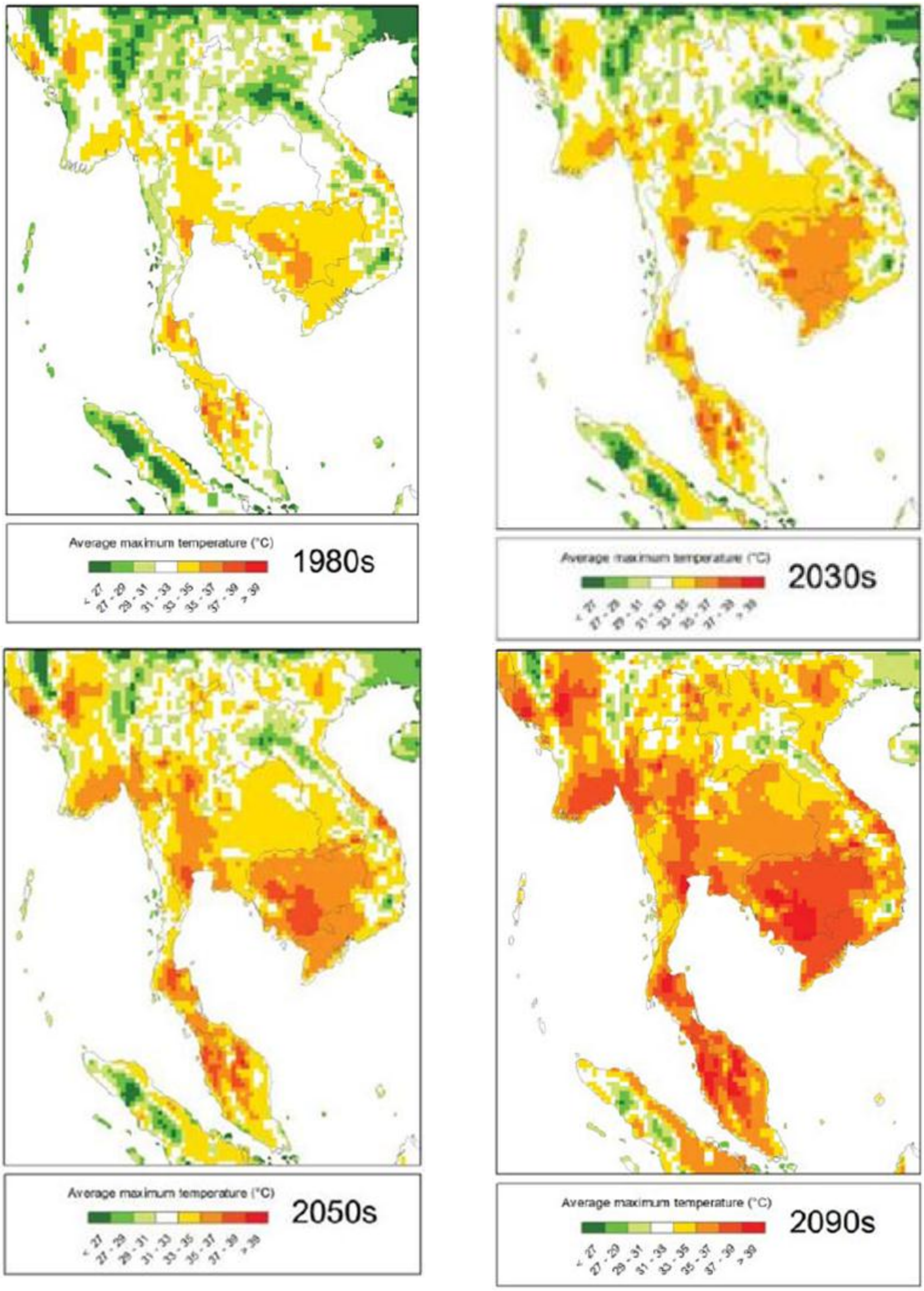


Figure 3.1 Average maximum temperature in Thailand and its vicinity over the 21st century under SRES A2 (Chidthaisong, A., 2011)

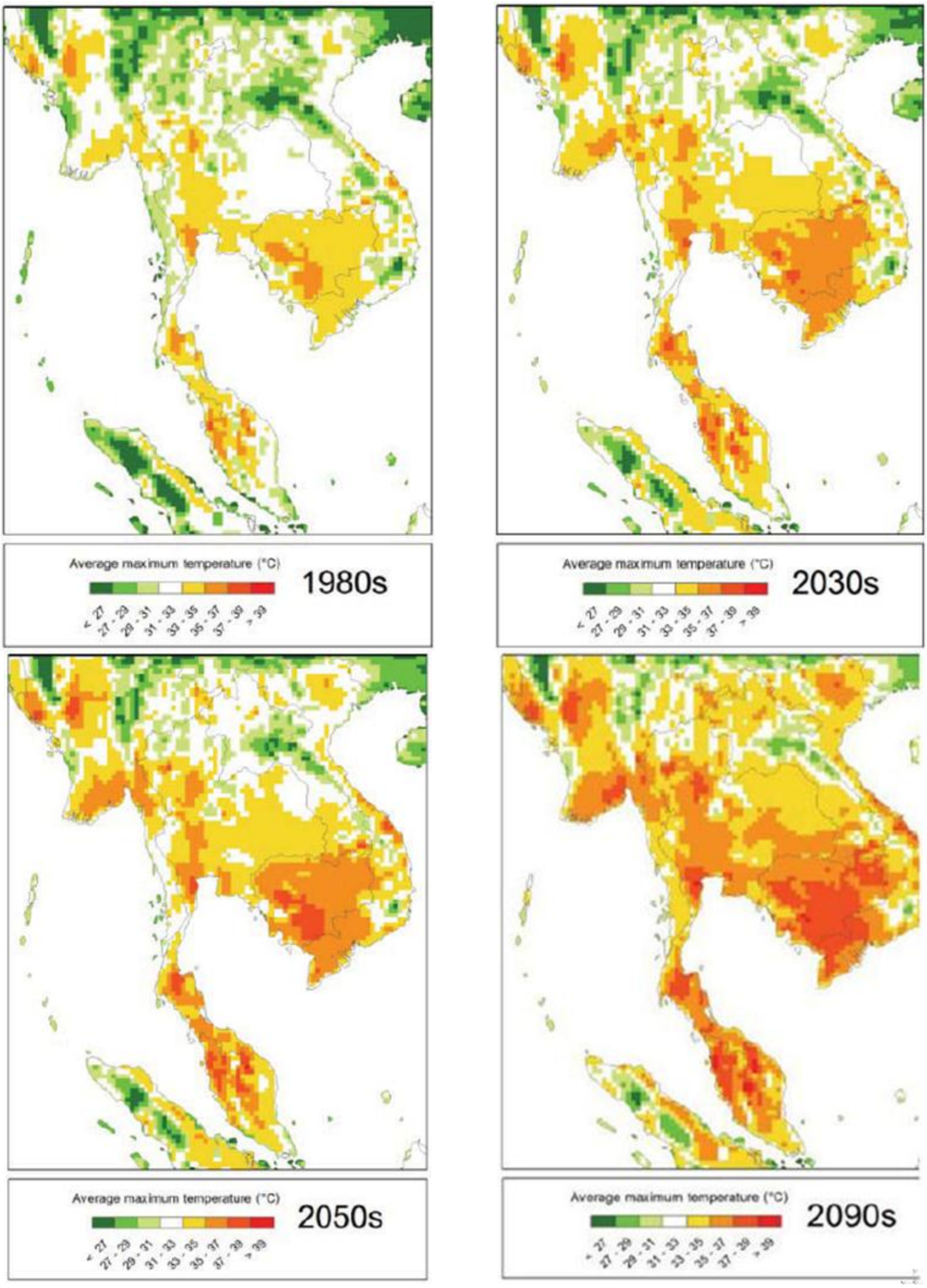


Figure 3.2 Average maximum temperature in Thailand and its vicinity over the 21st century under SRES B2 (Chidthaisong, A., 2011)

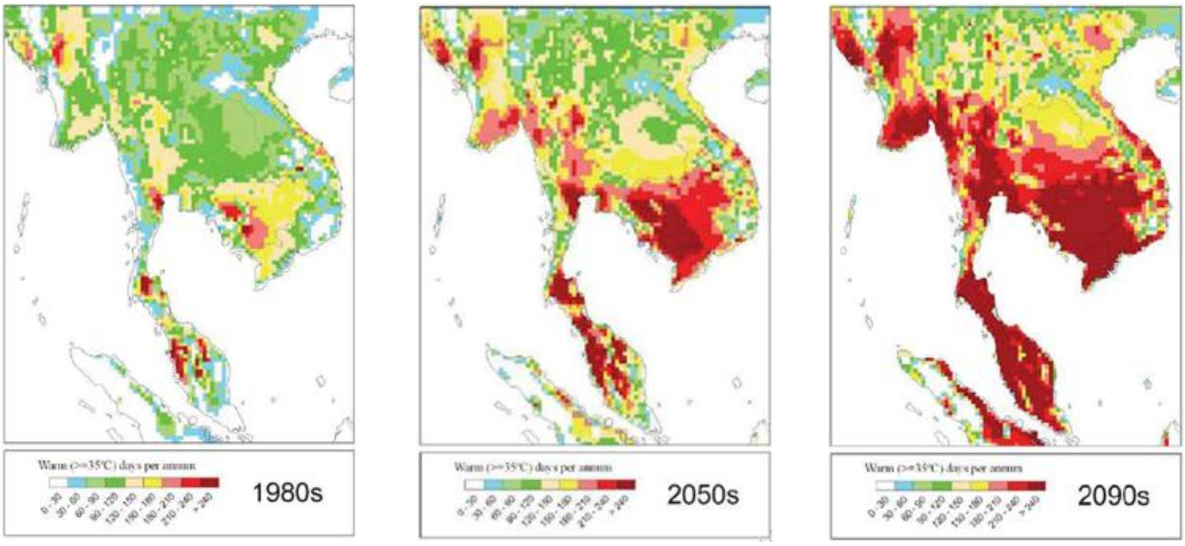


Figure 3.3 Warm periods in Thailand and its vicinity over the 21st century under SRES A2 (Chidthaisong, A., 2011)

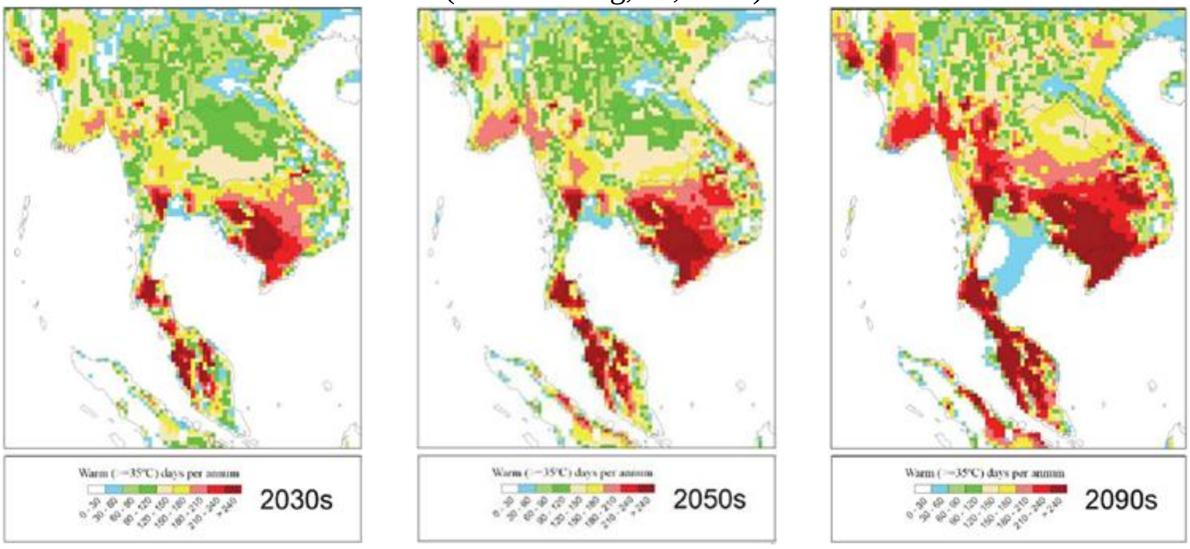


Figure 3.4 Warm periods in Thailand and its vicinity over the 21st century under SRES B2 (Chidthaisong, A., 2011

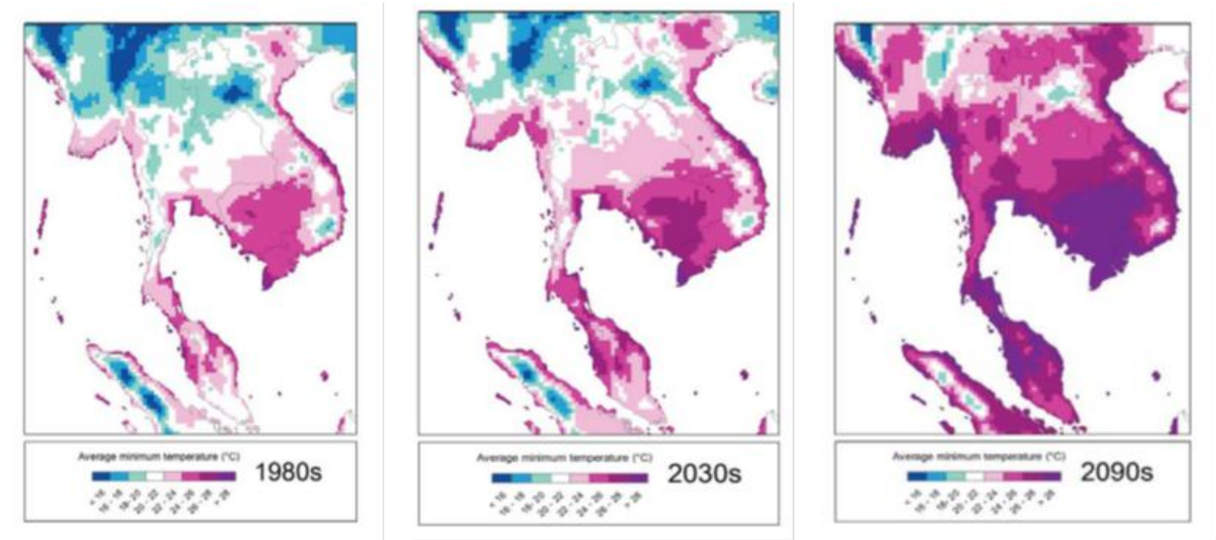


Figure 3.5 Average minimum temperature in Thailand and its vicinity over the 21st century under SRES A2 (Chidthaisong, A., 2011)

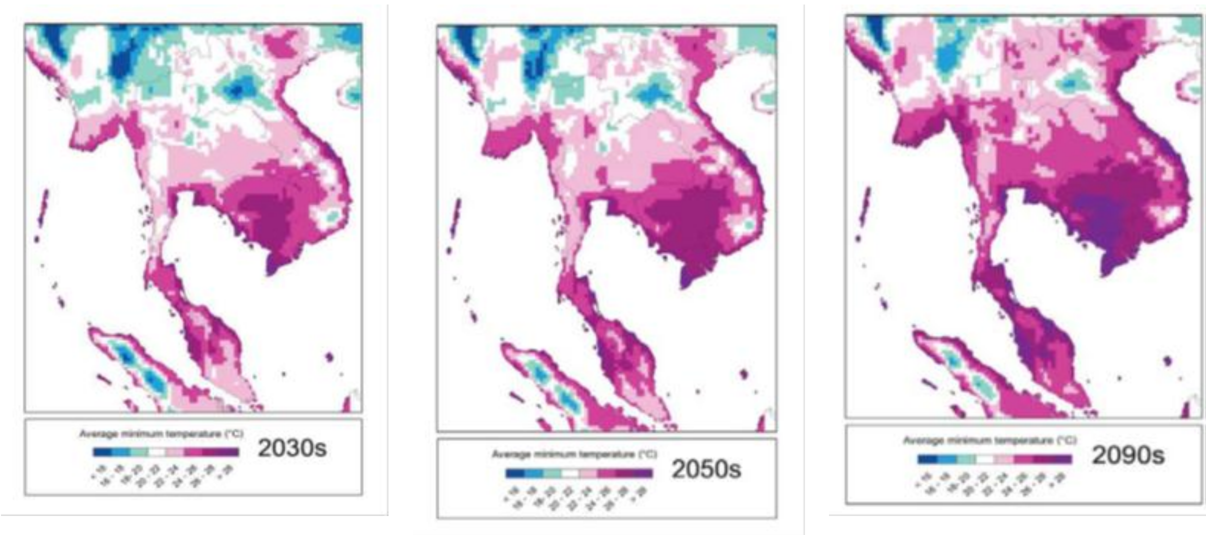


Figure 3.6 Average minimum temperature in Thailand and its vicinity over the 21st century under SRES B2 (Chidthaisong, A., 2011)

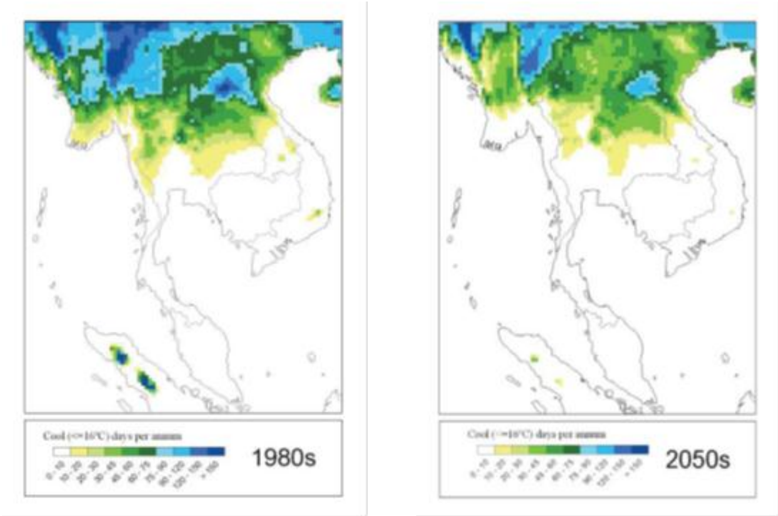


Figure 3.7 Cool periods in Thailand and its vicinity over the 21st century under SRES A2 (Chidthaisong, A., 2011)

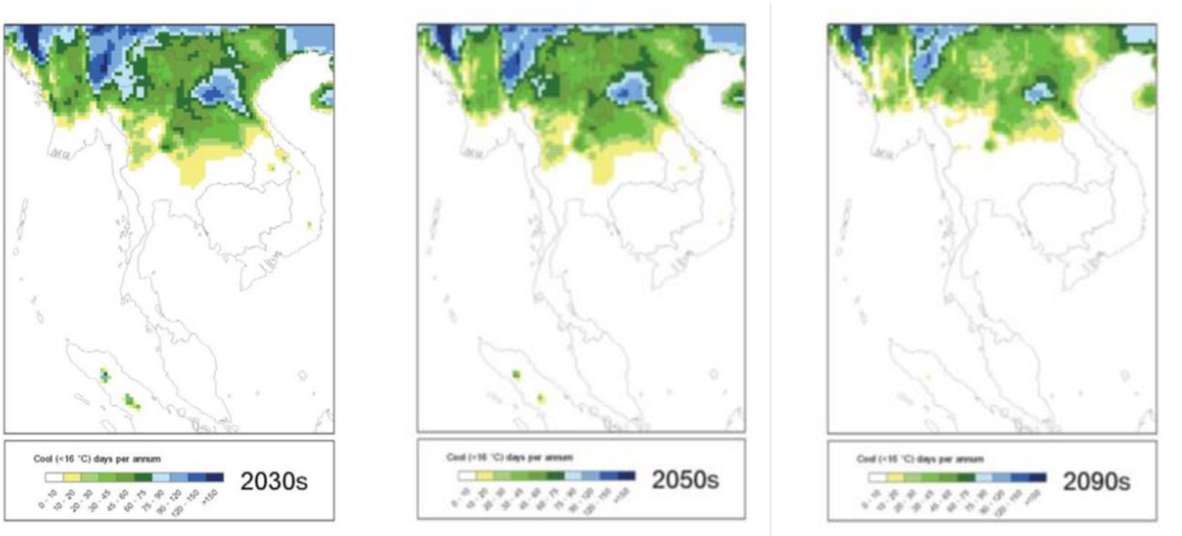


Figure 3.8 Cool periods in Thailand and its vicinity over the 21st century under SRES B2 (Chidthaisong, A., 2011)

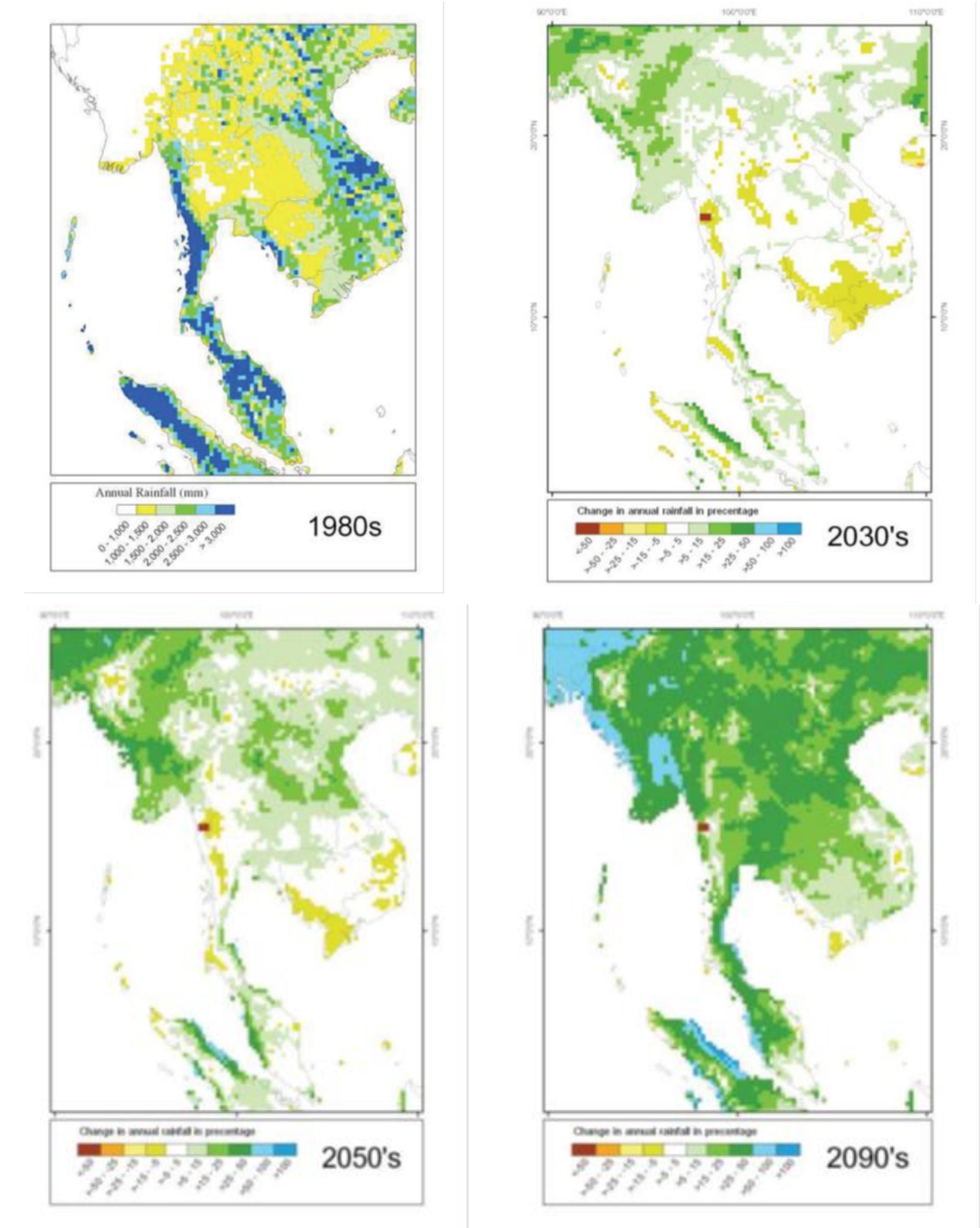


Figure 3.9 Annual rainfall in 1980's decade and change of annual rainfall (%) over the 21st century under SRES A2 (Chidthaisong, A., 2011)

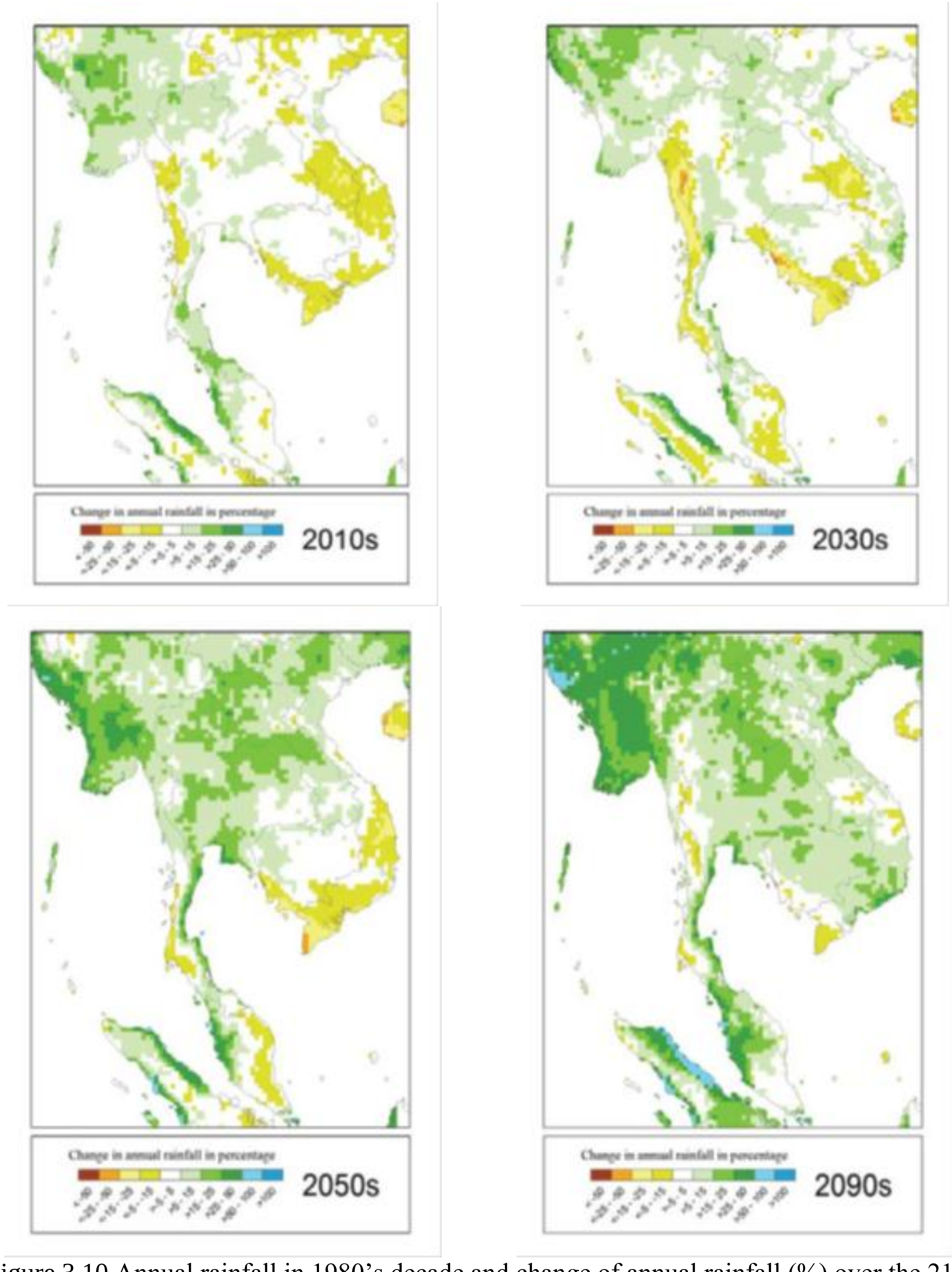


Figure 3.10 Annual rainfall in 1980's decade and change of annual rainfall (%) over the 21st century under SRES B2 (Chidthaisong, A., 2011)

3.2 Thailand Climate Change Scenarios during 2010-2039 by the MM5 Regional Climate Model

Climate change scenarios in Thailand by MM5 model provide a brief summary of climate change in Thailand from 1970 to 1990 and in the next 30 years during 2010-2039 based on key analysis variables including average maximum temperature and rainfall changes. Two GHG emission scenarios – scenario A1B and A2 were simulated underlying greenhouse effect phenomenon following A1B economic and social development approach, and then it was found that average maximum temperature in Thailand in the beginning of the 21st century has not generated a greater change over the end of the 20th century. Regarding the maximum temperature conditions in the future under greenhouse effect situation following A2 economic and social development approach, it similarly shows the increasing trend in almost all areas of Thailand (Figure 3.11-3.12).

According to rainfall volumes in rainy season during 2010-2019, 2020-2029, and 2030-2039 under A1B situation, it was found a smaller change of rainfall volumes when compared to the past volumes, except Central and Northeastern regions in which decreasing rainfalls were envisaged; while the Southern part of Thailand was expected to have increasing trend of rainfall intensity. Such trend was similarly found in A2 situation (Figure 3.13-3.14).

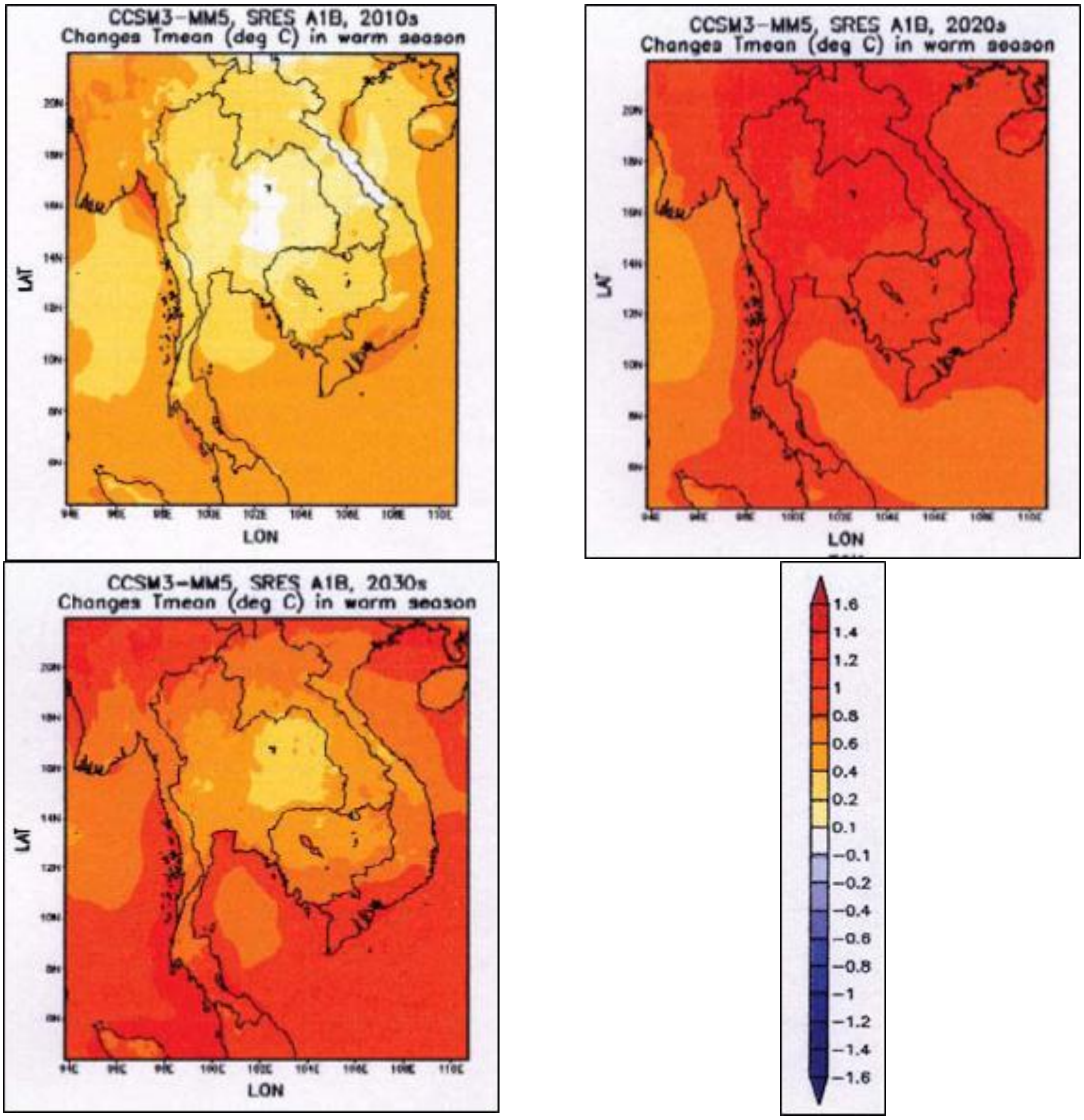


Figure 3.11 Change of average temperature in warm season during the 2010s, 2020s and 2030s compared to 1970-1999 following IPCC SRES A1B (Chidthaisong, A., 2011)

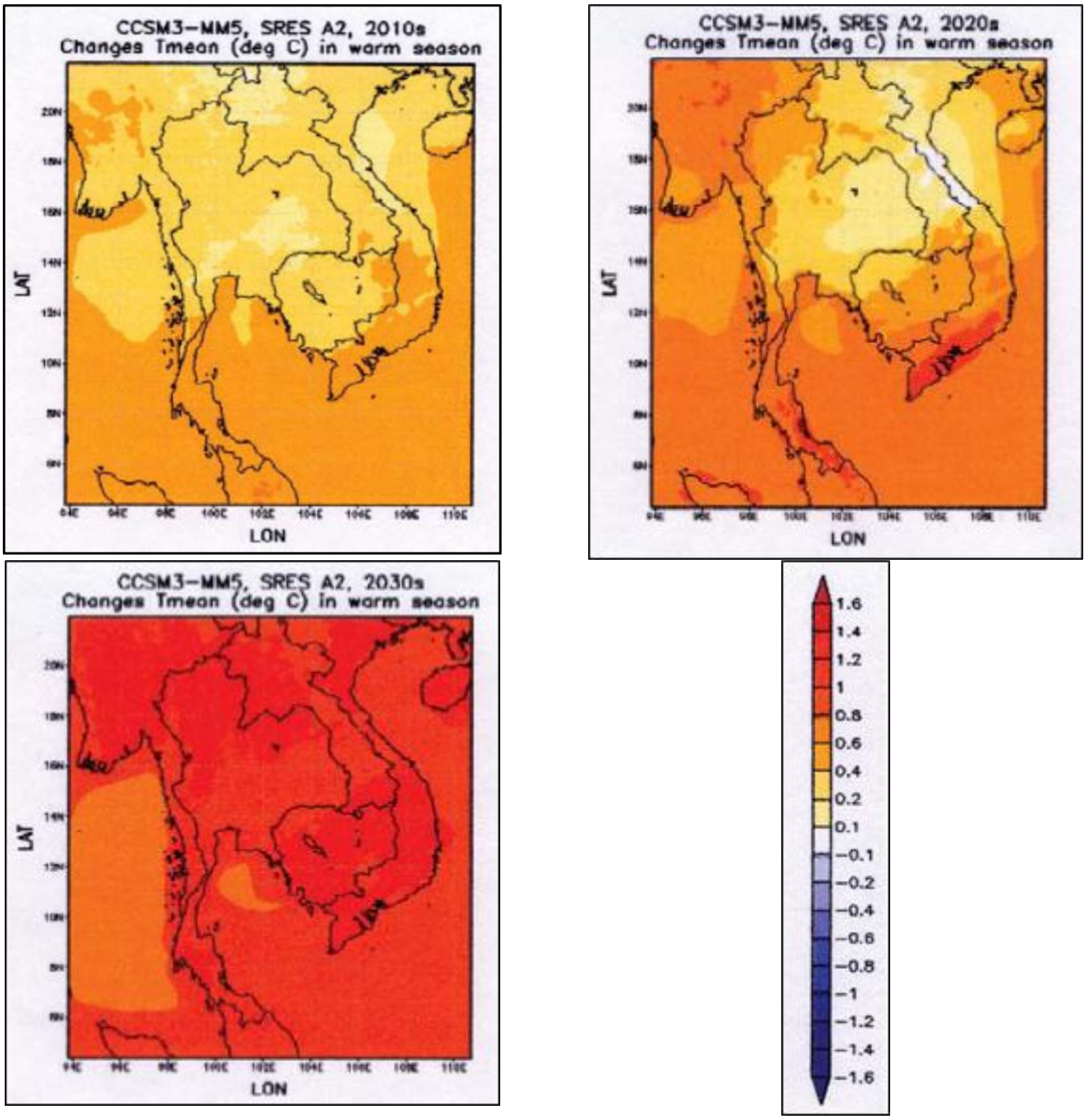


Figure 3.12 Change of average temperature in warm season during the decade of the 2010s, 2020s and 2030s compared to the past from 1970-1999 following IPCC SRES A2 (Chidthaisong, A., 2011)

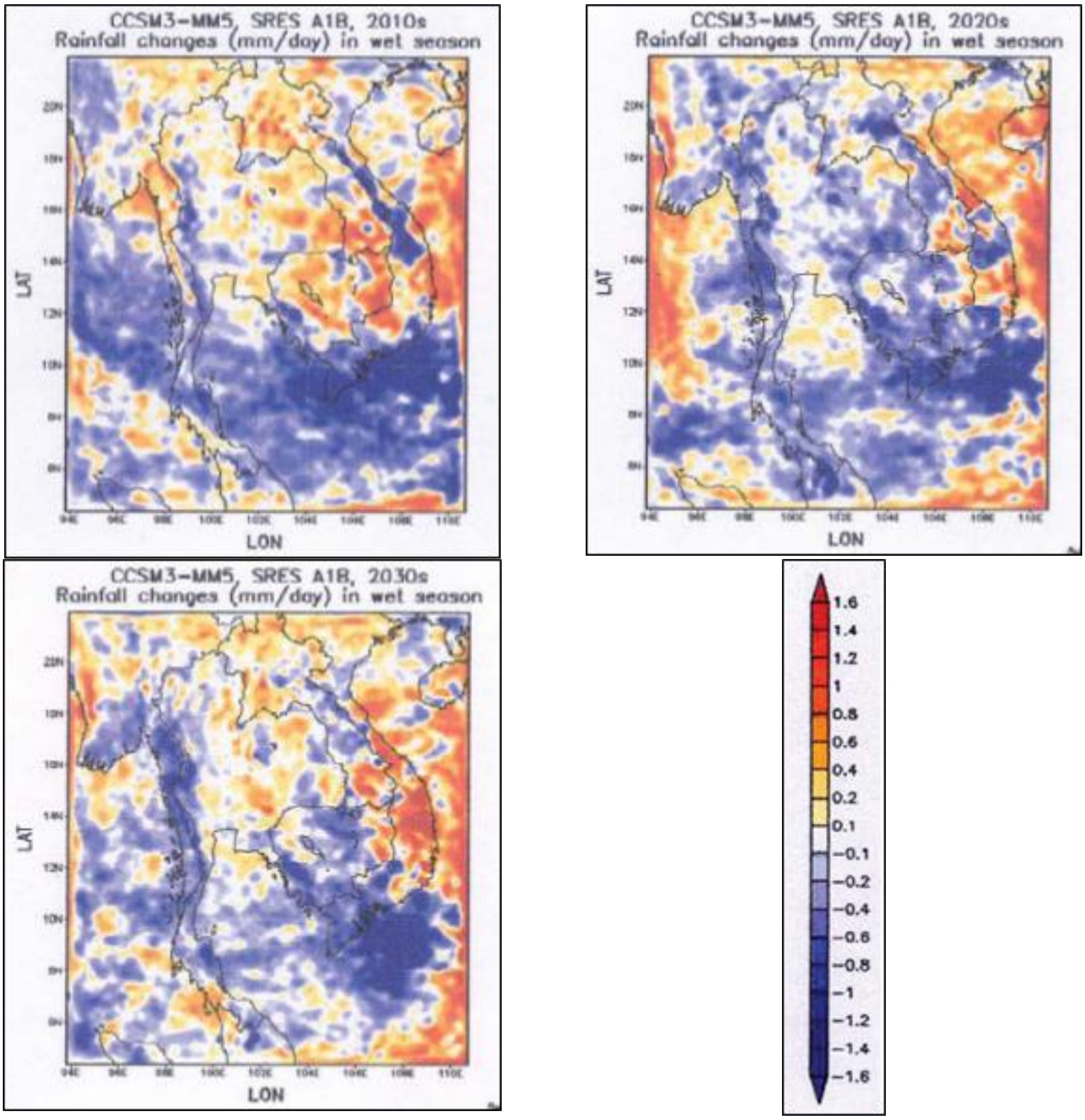


Figure 3.13 Rainfall changes in rainy season during the 2010s, 2020s and 2030s compared to the past from 1970-1999 following IPCC SRES A1B (Chidthaisong, A., 2011)

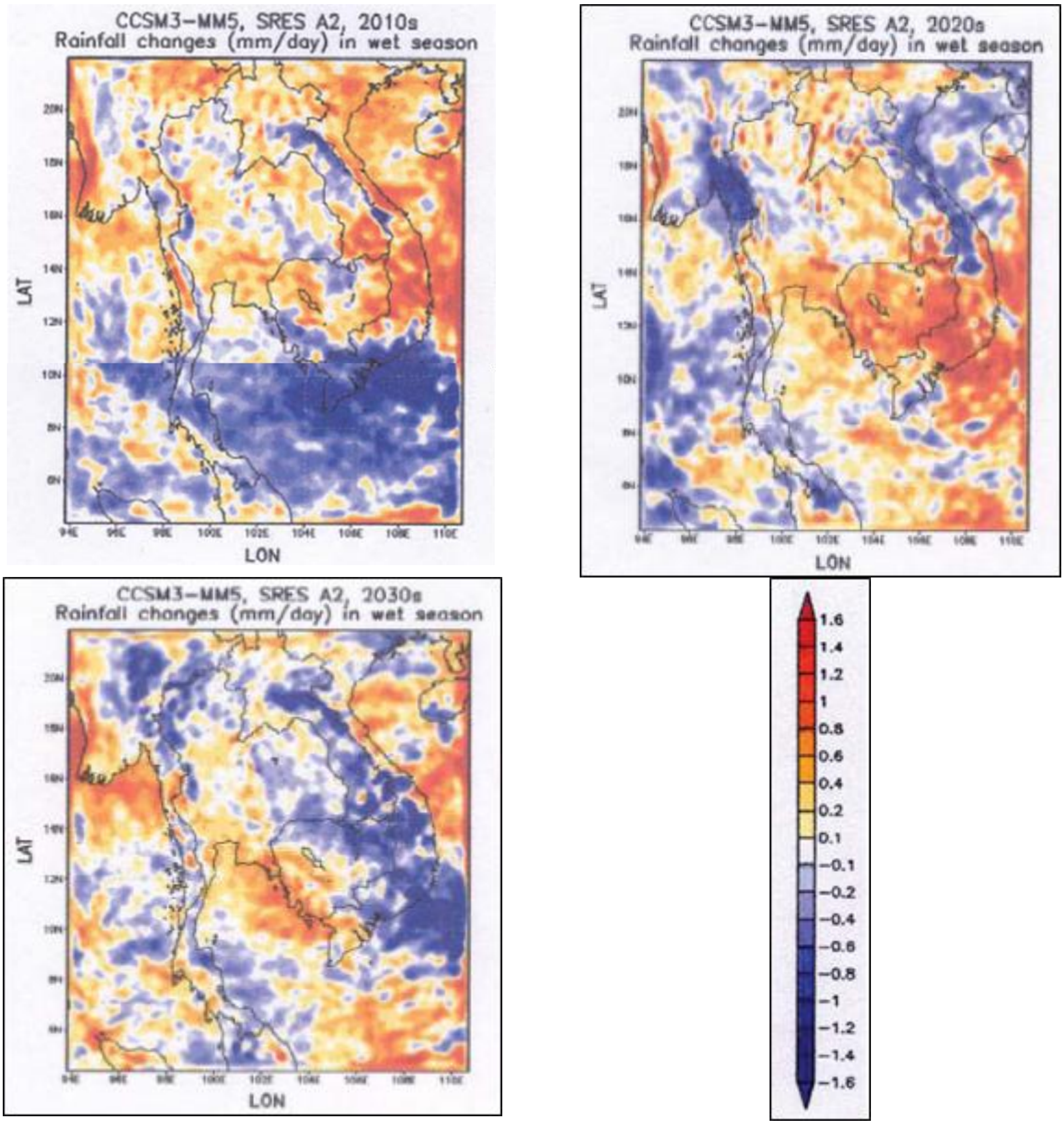


Figure 3.14 Rainfall changes in rainy season in the 2010s, 2020s and 2030s compared to the past from 1970-1999 following IPCC SRES A2 (Chidthaisong, A., 2011)

3.3 Thailand Climate Change Scenarios during 2010-2059 by the GFDL-R30 Global Climate Model

Climate Change Scenarios in Thailand by GFDL-R30 contains a brief summary of climate change in the future 50 years during 2010-2059 covering crucial variables such as average temperature, maximum temperature, minimum temperature, number of days at temperature ≥ 35 degree Celsius, and annual rainfall. Such above variables were used for simulating two-scenarios of GHG emissions including A2 and B2 scenario.

According to average temperature in warm season of two different types of scenario, it becomes apparently increasing in 2019. The SRES A2 scenario shows change in average temperature in warm season over the other years (using series with reference year); whereas SRES B2 illustrates a greater change of average temperature in warm season of the 2059 over the other years, and such year also has a higher change of average temperature than SRES A2 (Figure 3.15-3.16). For change in average maximum temperature in warm season of SRES A2 compared to the base year, the study found that in 2019, it is projected to have the greatest temperature change occurred in the largest number of areas as shown in Figure 3.17; while such phenomenon based on SRES B2 will happen in 2049 (Figure 3.18). With regards to average minimum temperature in warm season of SRES A2 when compared to the base year, the prediction shows the highest change of temperature in 2029 spreading over the most of areas; whereas SERS B2 would demonstrate in the same situation in 2059 (Figure 3.19-3.20).

Regarding change in rainfall volumes in rainy season according to SRES A2, it represents the maximum decreasing in 2029 and most of areas in the nation show a decrease of more than 50 mm rainfall; whereas the change in the case of SRES B2 illustrates a minimum rainfall in 2040 (Figure 3.21-3.22).

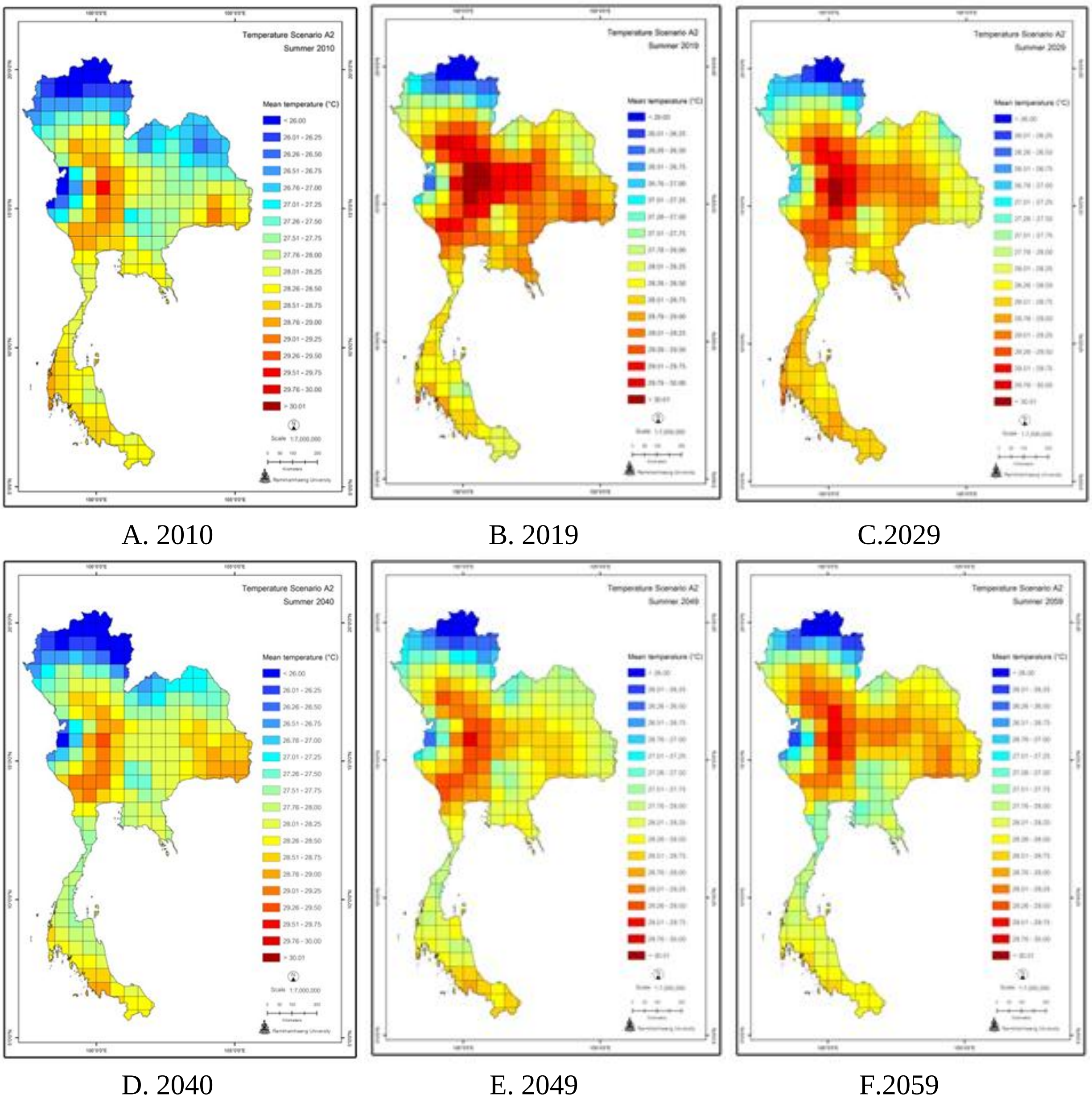
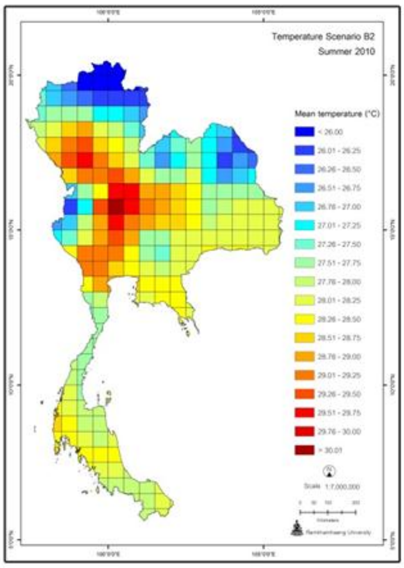
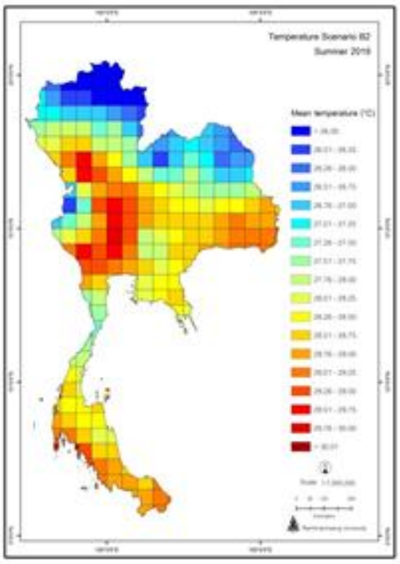


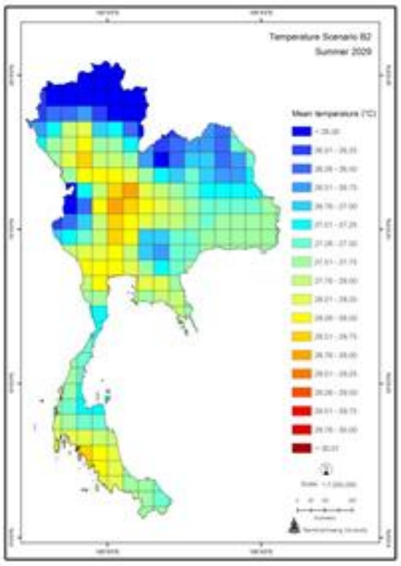
Figure 3.15 Average temperature of Thailand in the 2010s, 2019s, 2029s, 2040s, 2049 s, and 2059s under SRES A2 (Chidthaisong, A., 2011)



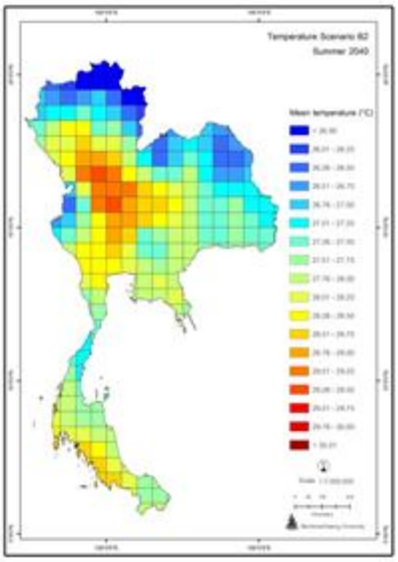
A. 2010



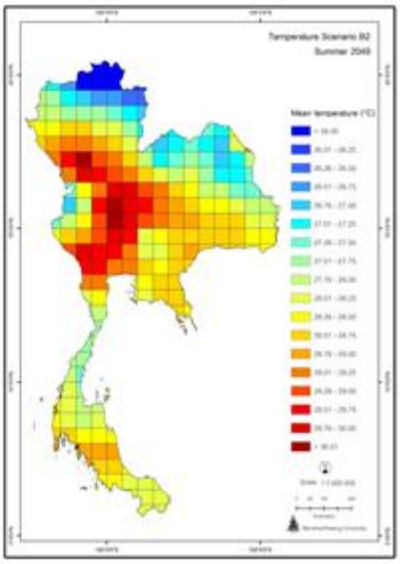
B. 2019



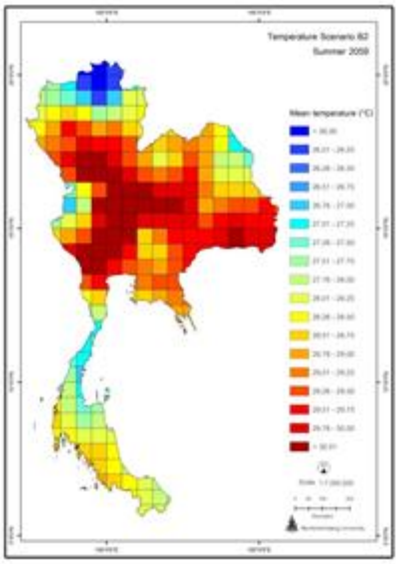
C.2029



D. 2040

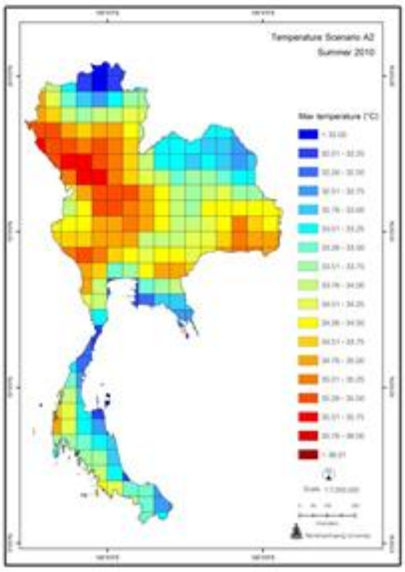


E. 2049

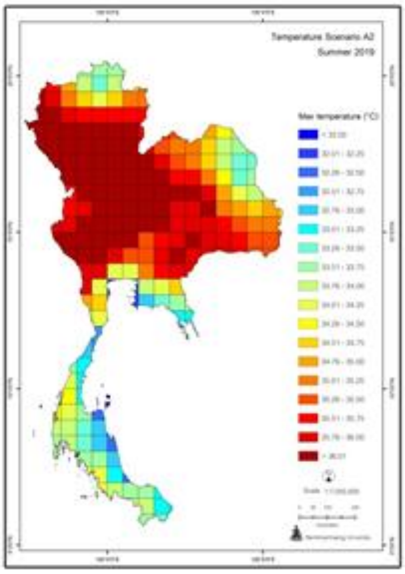


F.2059

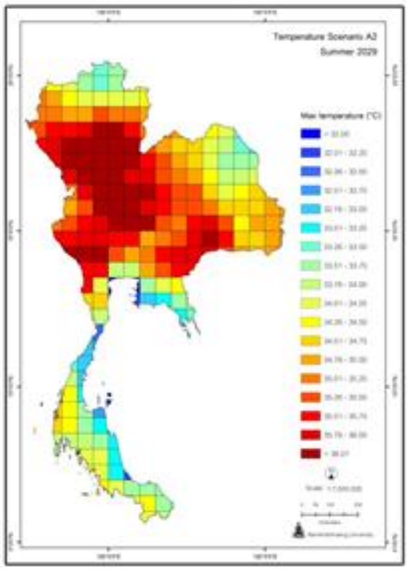
Figure 3.16 Average temperature of Thailand in the 2010s, 2019s, 2029s, 2040s, 2049 s, and 2059s under SRES B2 (Chidthaisong, A., 2011)



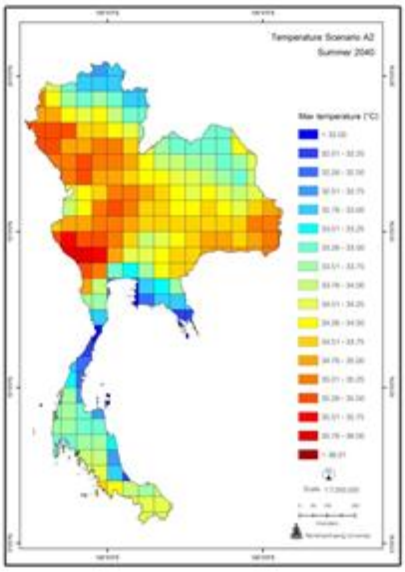
A. 2010



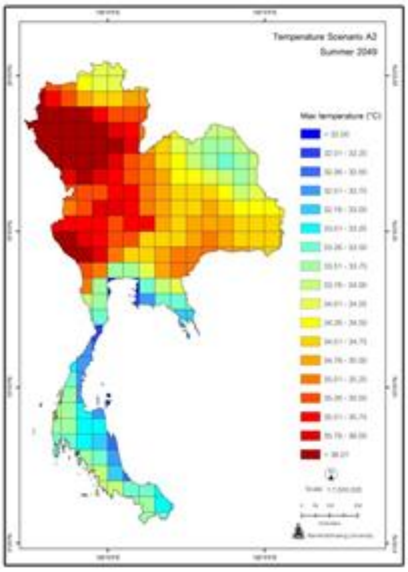
B. 2019



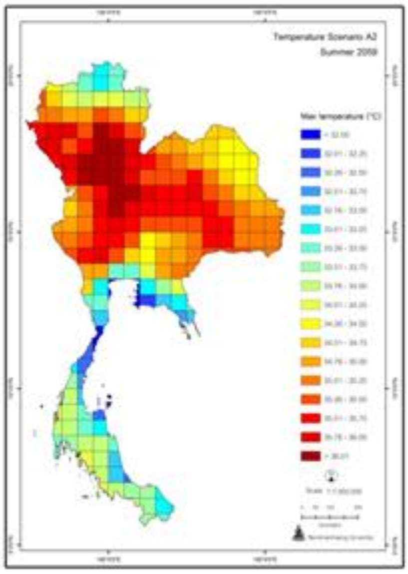
C.2029



D. 2040

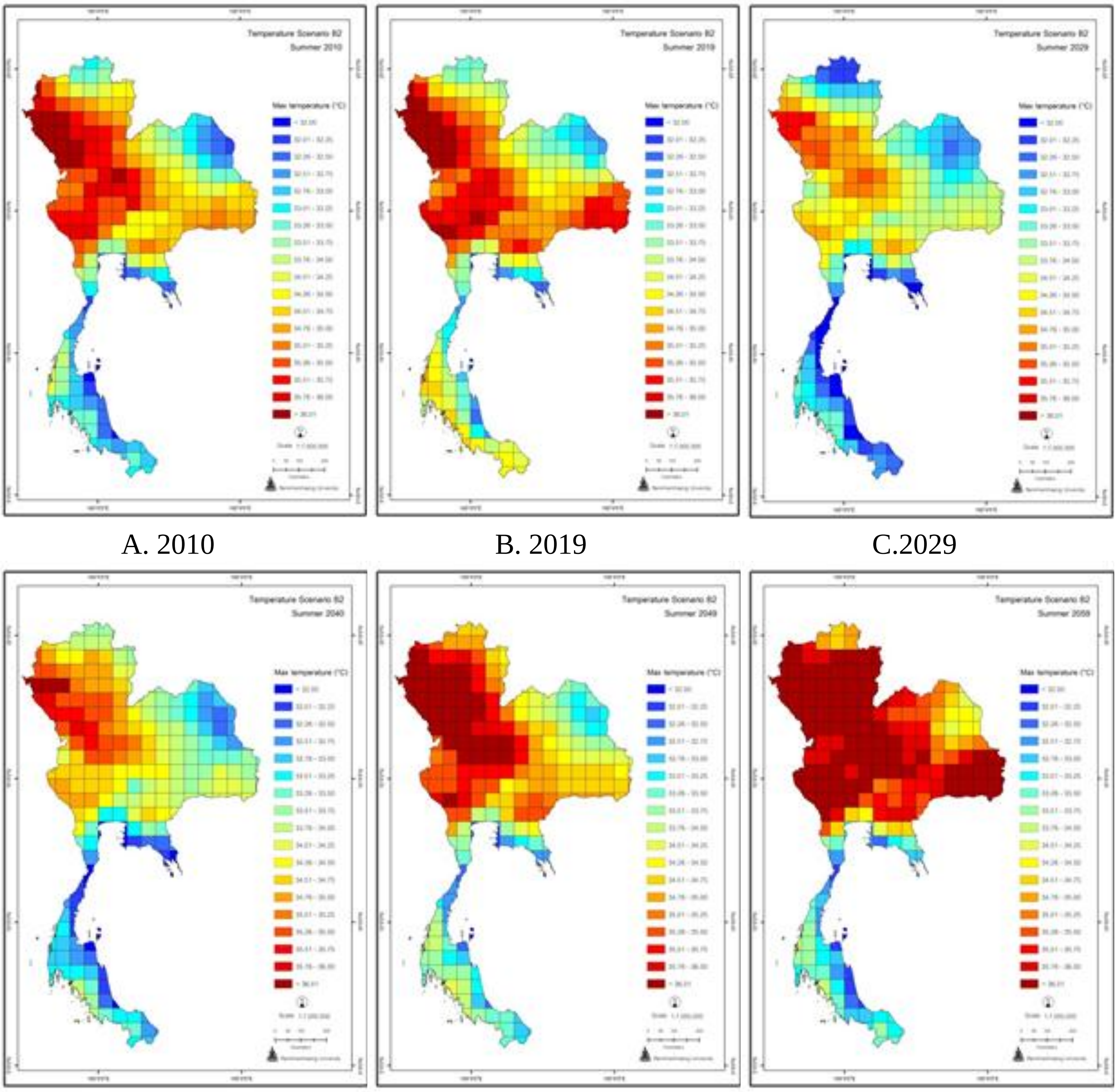


E. 2049



F.2059

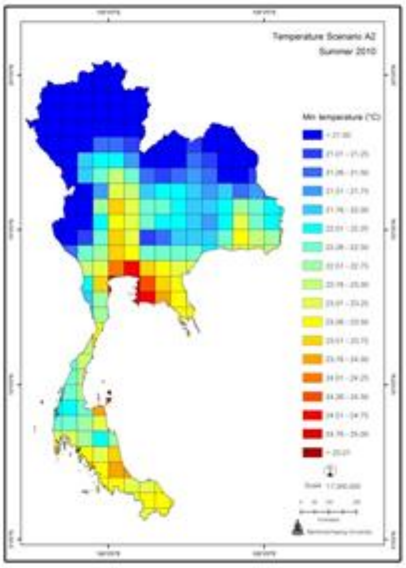
Figure 3.17 A maximum temperature of Thailand in the 2010s, 2019s, 2029s, 2040s, 2049 s, and 2059s under SRES A2 (Chidthaisong, A., 2011)



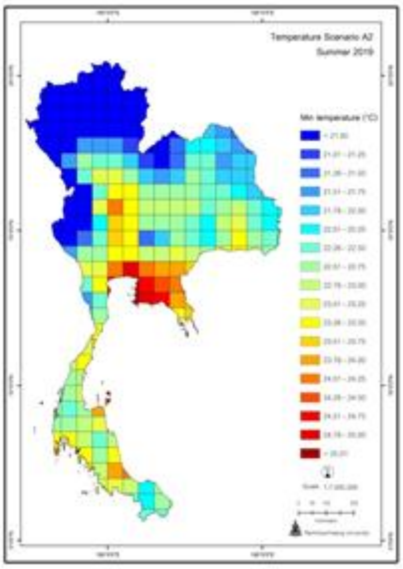
A. 2010 B. 2019 C.2029

D. 2040 E. 2049 F.2059

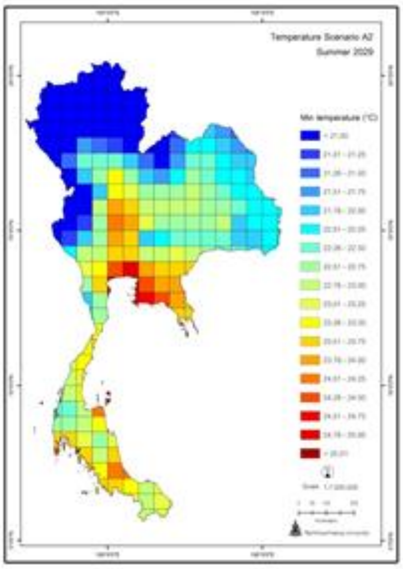
Figure 3.18 A maximum temperature of Thailand in the 2010s, 2019s, 2029s, 2040s, 2049 s, and 2059s under SRES B2 (Chidthaisong, A., 2011)



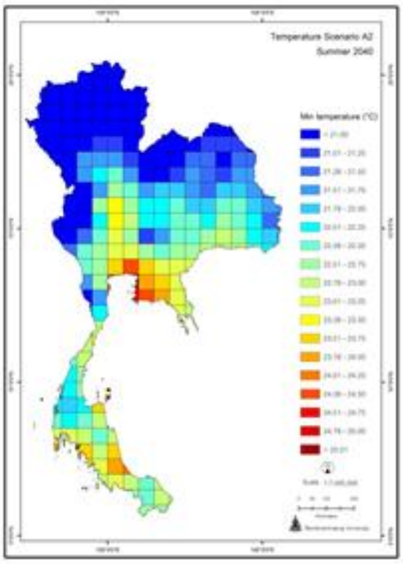
A. 2010



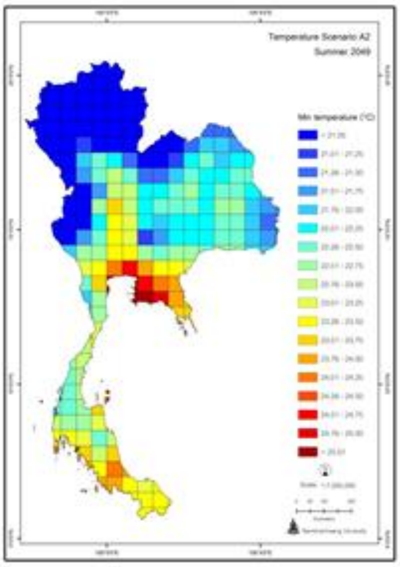
B. 2019



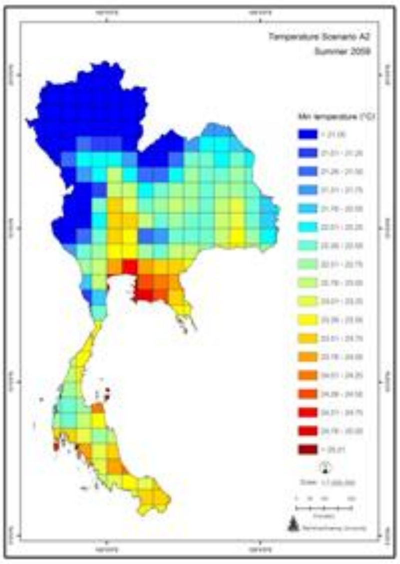
C.2029



D. 2040

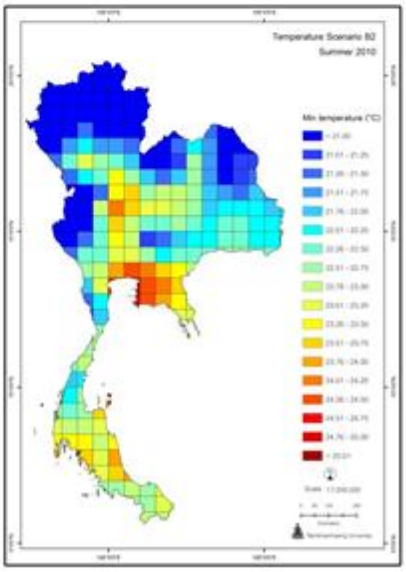


E. 2049

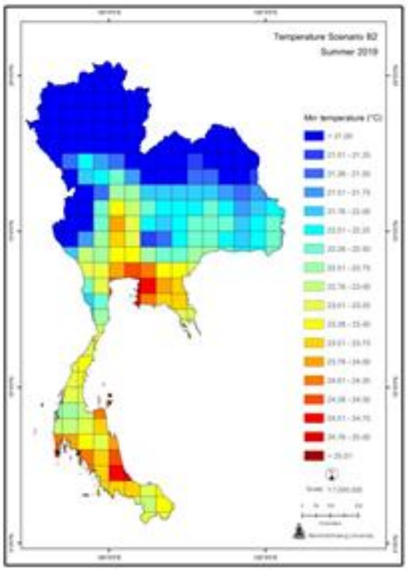


F.2059

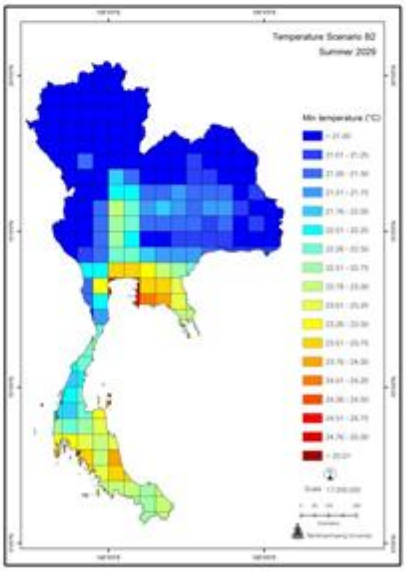
Figure 3.19 A minumum temperature of Thailand in the 2010s, 2019s, 2029s, 2040s, 2049 s, and 2059s under SRES A2 (Chidthaisong, A., 2011)



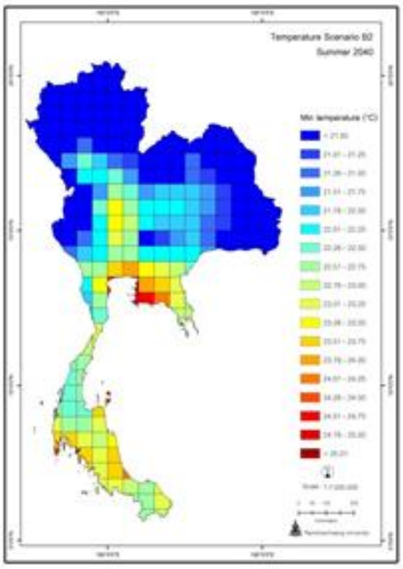
A. 2010



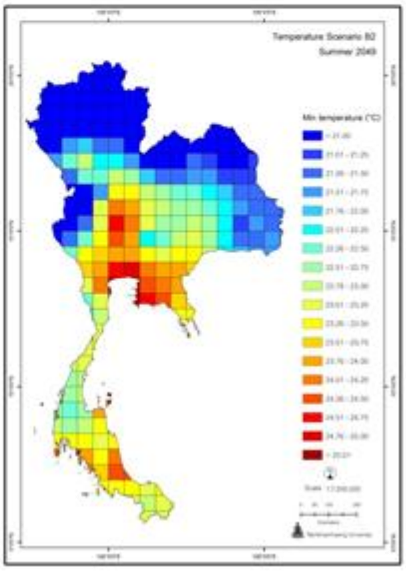
B. 2019



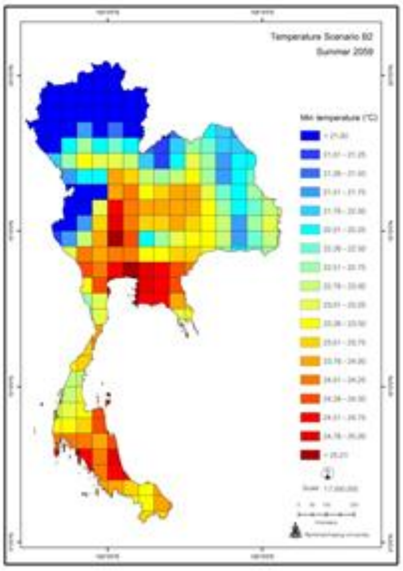
C.2029



D. 2040

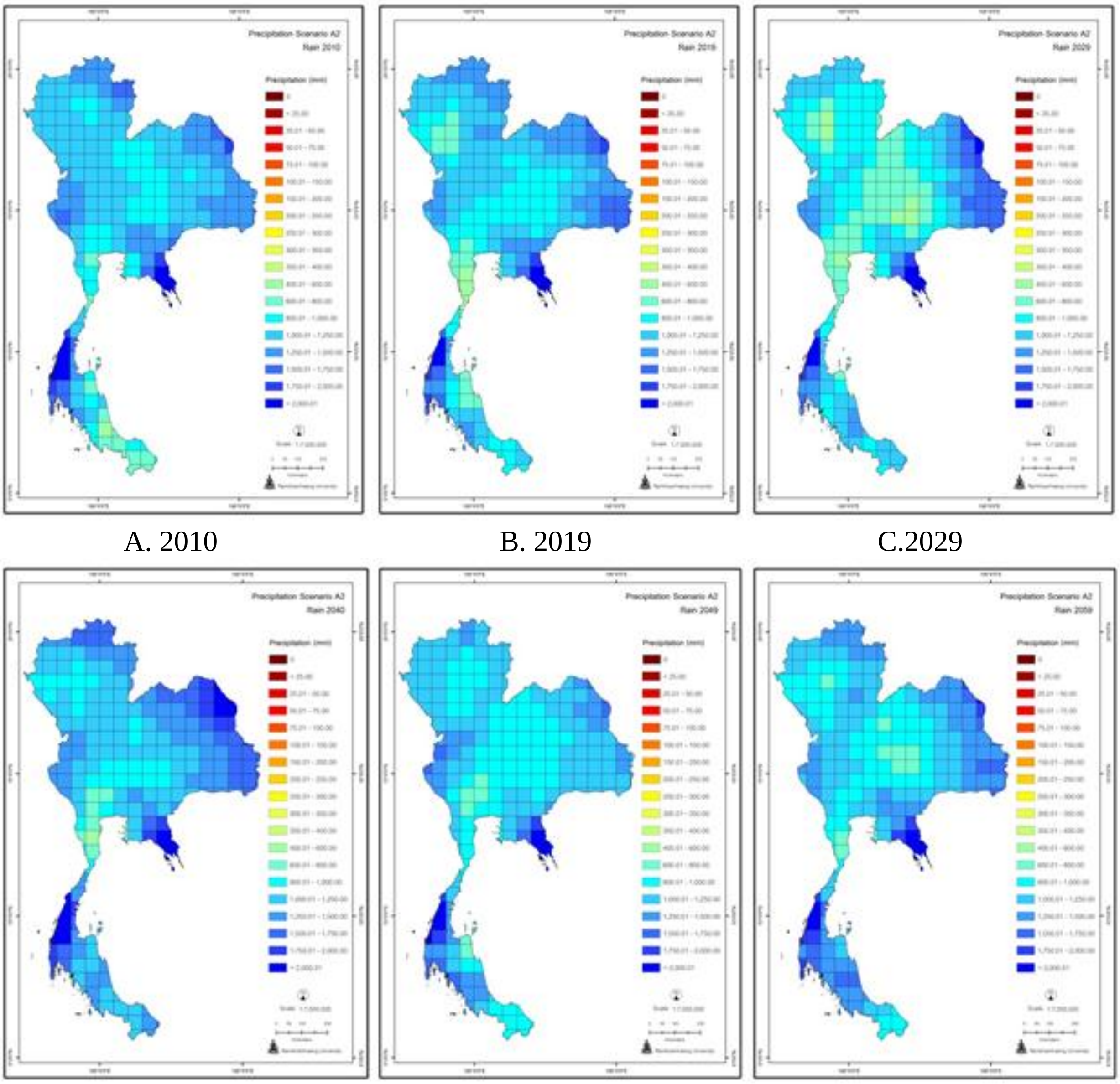


E. 2049



F.2059

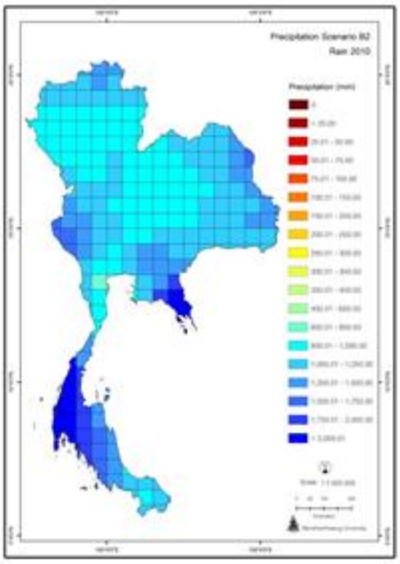
Figure 3.20 A minumum temperature of Thailand in the 2010s, 2019s, 2029s, 2040s, 2049 s, and 2059s under SRES B2 (Chidthaisong, A., 2011)



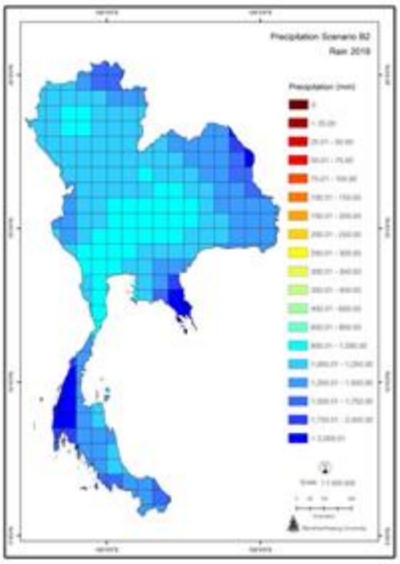
A. 2010 B. 2019 C.2029

D. 2040 E. 2049 F.2059

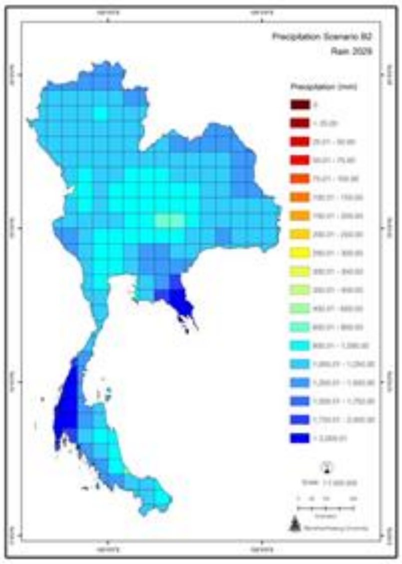
Figure 3.21 Change in rainfall volumes of Thailand in the 2010s, 2019s, 2029s, 2040s, 2049s and 2059s under SRES A2 (Chidthaisong, A., 2011)



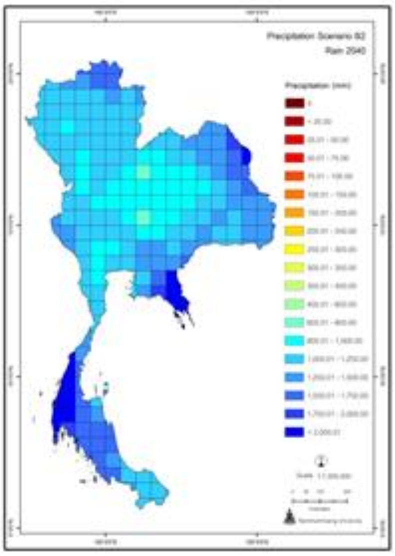
A. 2010



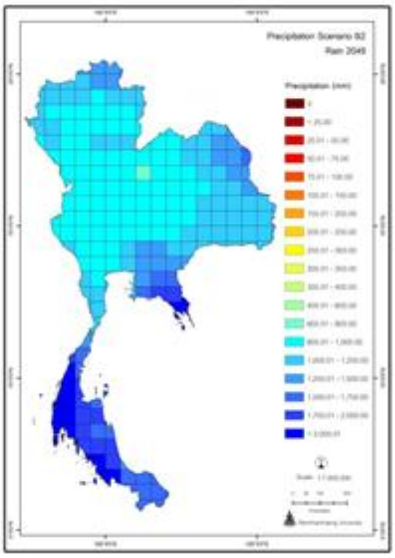
B. 2019



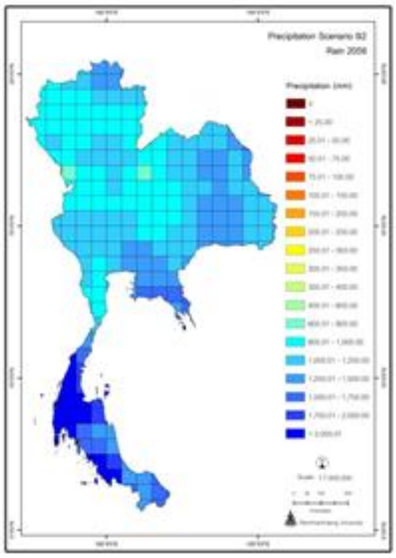
C.2029



D. 2040



E. 2049



F.2059

Figure 3.22 Change in rainfall volumes of Thailand in the 2010s, 2019s, 2029s, 2040s, 2049s and 2059s under SRES B2 (Chidthaisong, A., 2011)

3.4 Summarization of the projection of weather and climate change specific to Thailand

Presently, Thailand has 3 climate models including 1) the PRECIS regional climate model; 2) the MM5 regional climate model; 3) the GFDL-R30 global climate model. The three models contain the same principle by using the significant global simulations to downscale for Thailand area. Each model suggests some differences e.g., variables, scenario, year etc. When considering the assortment of data analyzed by 3 models, it was found that the PRECIS SRES A2 model is the most appropriate for references and analysis based on this study due to the data completion that can predict temperature and rainfall patterns for long periods (present to 2090). Moreover, this model demonstrates greenhouse effect phenomenon following economic and social development approach similar to the current situation in Thailand; while the other two models (MM5 and GFDL-R30) can be executed for the short-term analysis.

For the three models as above, they can only be used for analyzing 2 types of weather conditions including temperature and rainfall, so the analysis of number of storms and increasing/decreasing sea level cannot be predicted by these models. Therefore, this research selects key variables associated with change in temperature and rainfall for further conducting survey opinion including:

Temperature variables

- Change in maximum temperature in warm season (degree Celsius)
- Change in warmest days or days at temperature>35 degree Celsius (days per year)

Rainfall variables

- 30% increase in flood severity from the experienced extreme flood severity due to change in annual rainfall (mm./year) and the severity of future storms
- Change in number of rainy days (days per year)

Each variable exhibits some differences in each region of Thailand as shown in Figure 3.23-3.26 and Table 3.1-3.4

a. Change in average maximum temperature in warm season (degree Celsius)

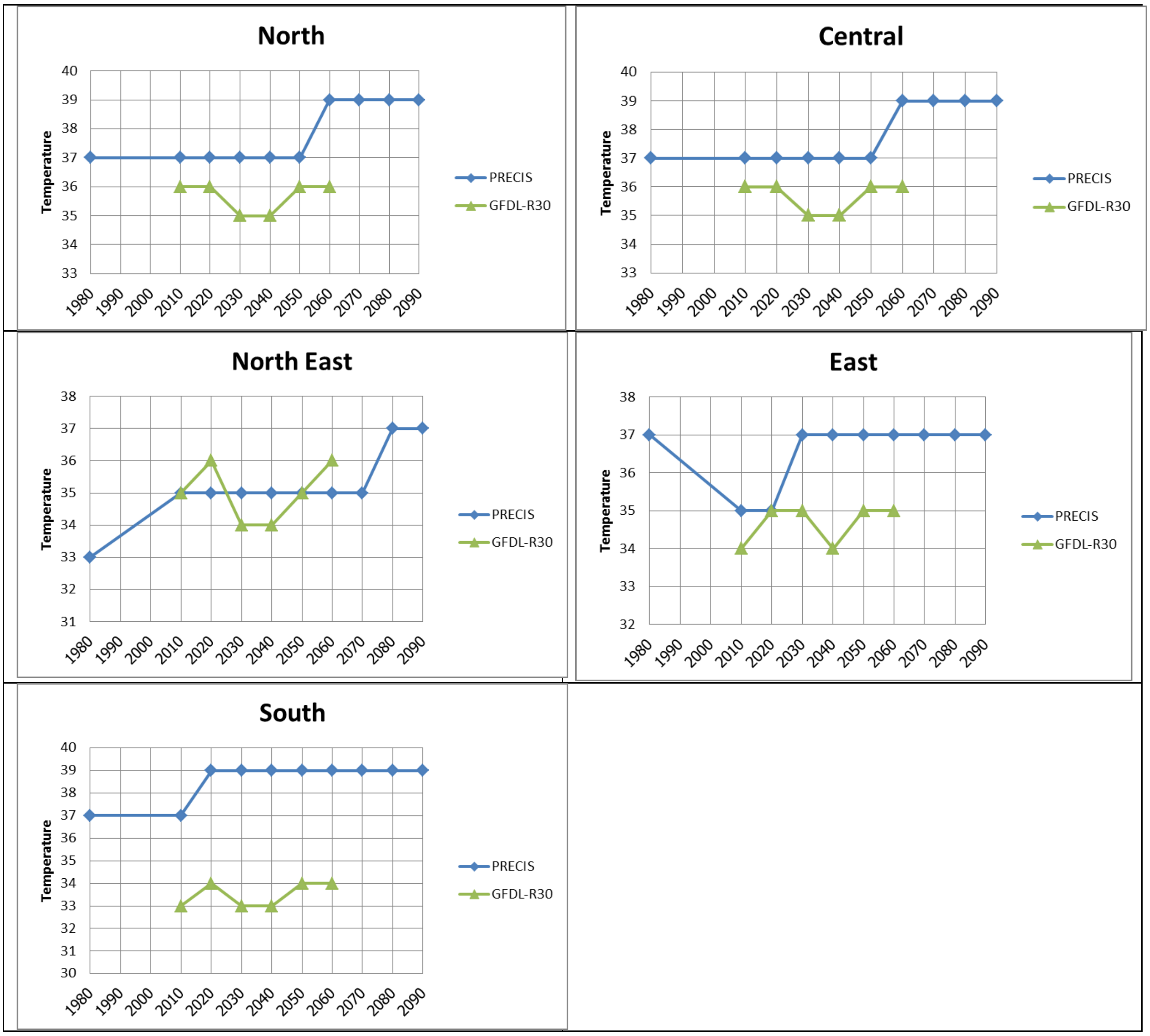


Figure 3.23 Change in average maximum temperature in warm season (degree Celsius)

Table 3.1 Change in average maximum temperature in warm season (degree Celsius)

Region	Change during the 80-year period
Northern	2 ºC
Central	>2 ºC
Northeastern	2 ºC
Eastern	4 ºC
Southern	>2 ºC

* Note: Temperature at 4 ºC was used in opinion survey in all regions of Thailand.

b. Change in warmest days or days at temperature>35 degree Celsius (days per year)

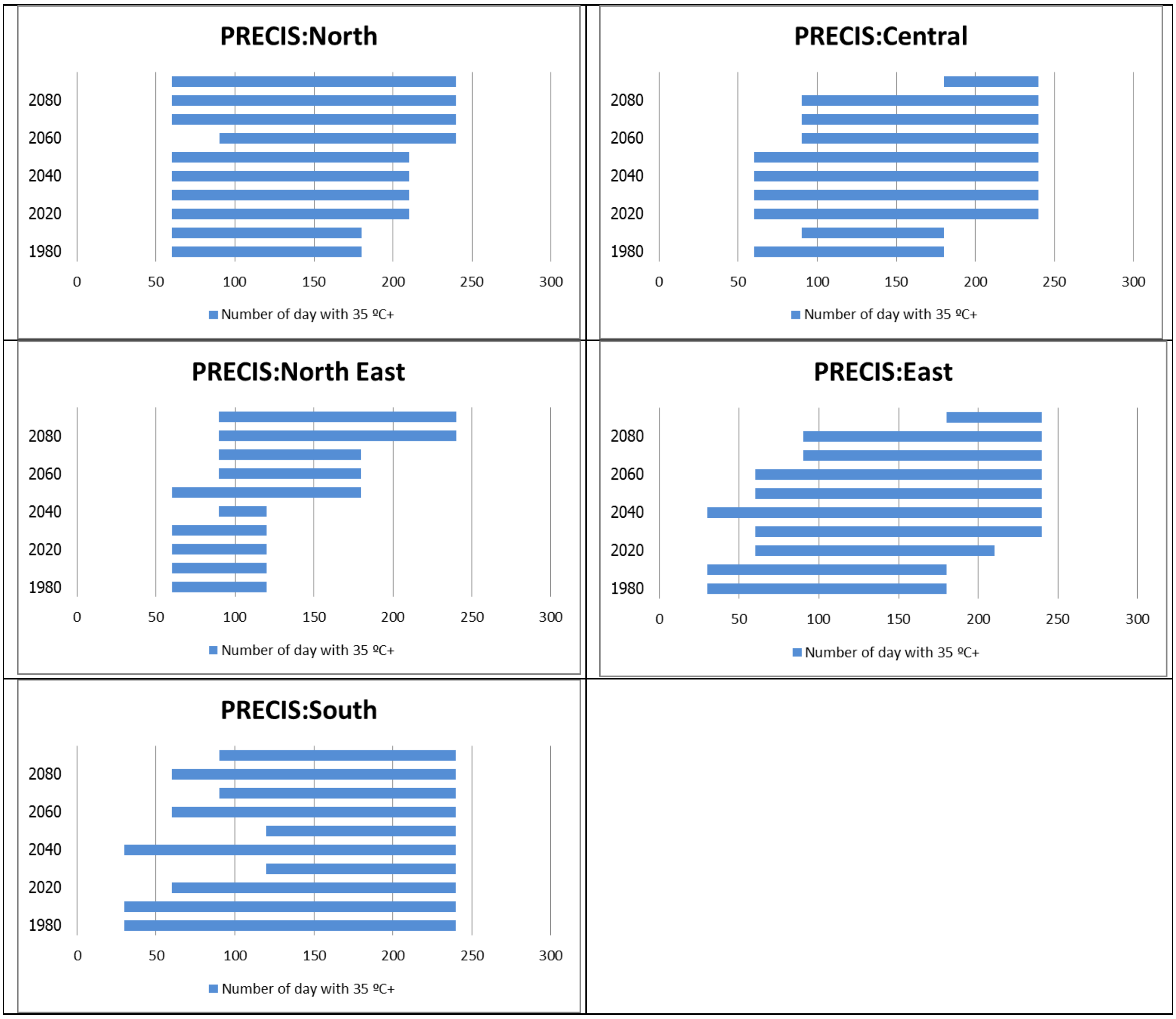


Figure 3.24 Change in number of day with temperature higher than 35 ºC (days per year)

Table 3.2 Change in warmest days or days at temperature>35 degree Celsius (days per year)

Region	Change during the 80-year period
Northern	increase > 2 months
Central	increase > 1 months
Northeastern	increase 3 months
Eastern	increase > 2 months
Southern	increase > 2 months

c. 30% increase in flood severity from the experienced extreme flood severity due to change in annual rainfall (mm./year) and the severity of future storms

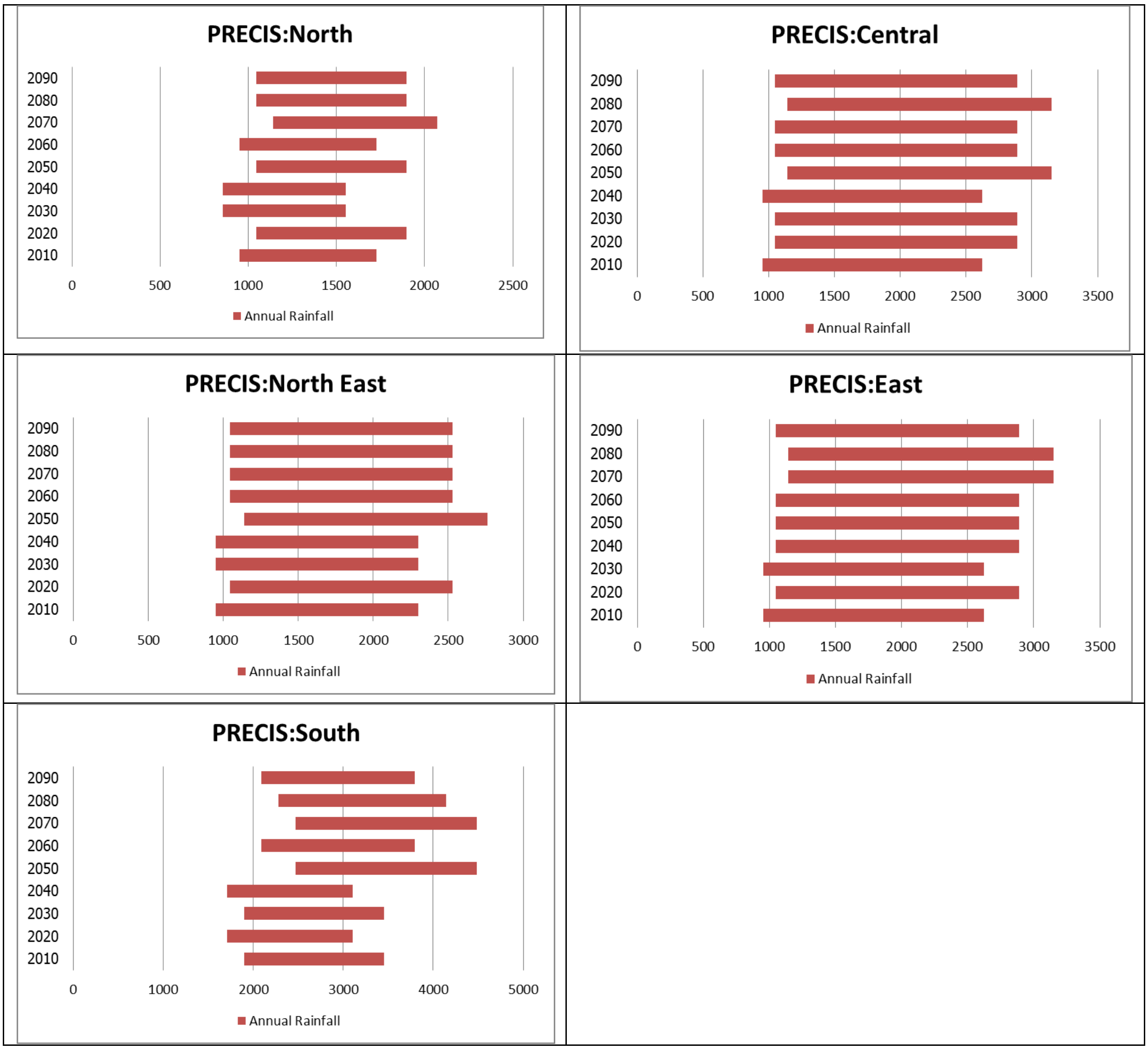


Figure 3.25 Change in annual rainfall (mm./year)

Table 3.3 30% increase in flood severity from the experienced extreme flood severity

Region	Change during the 80-year period	Flood severity
Northern	increase 20%	increase 30%
Central	increase 10%	increase 30%
Northeastern	increase 40%	increase 30%
Eastern	increase 40%	increase 30%
Southern	increase 30%	increase 30%

* Note: A level of 30% was used in opinion survey in all regions of Thailand.

d. Change in number of rainy days (days per year)

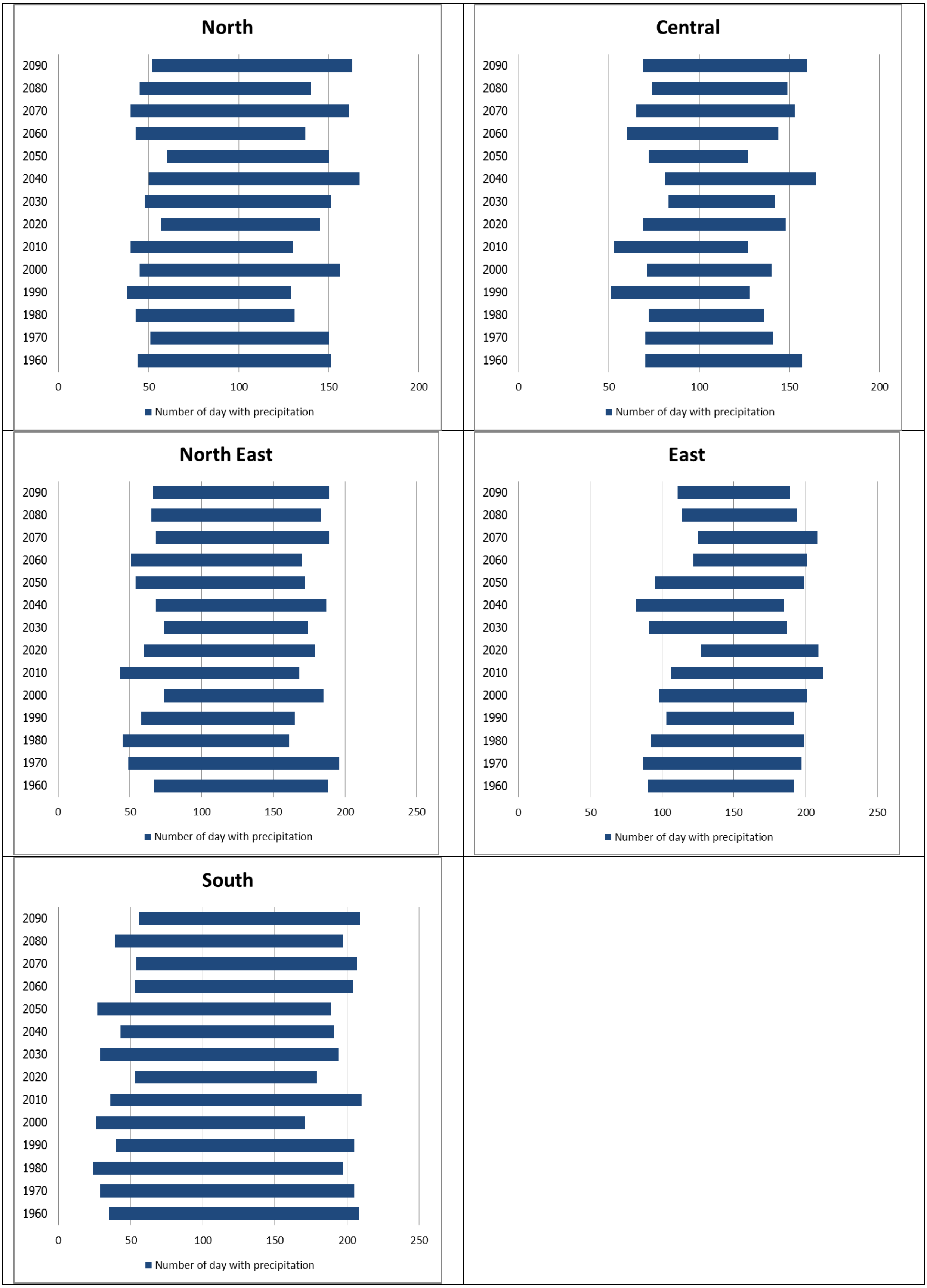


Figure 3.26 Change in number of rainy days (days per year)

Table 3.4 Change in number of rainy days (days per year)

Region	Change during the 80-year period
Northern	increase 14 days
Central	increase 17 days
Northeastern	increase 7 days
Eastern	No change
Southern	increase 30 days

Chapter 4
Expected impacts of climate change to transportation systems

4.1 Introduction

The results from future climate change in Thailand (Chapter 3) were adopted by researcher team to comprehensively develop the questionnaire being used for studying the expected impacts of climate change to transportation system. Four issues were discussed including:

1. Change in average maximum temperature in warm seasons (degree Celsius)
2. Change in the warmest days or days at temperature>35 degree Celsius (days per year)
3. 30% increase in flood severity from the experienced extreme flood severity
4. Change in number of rainy days (days per year)

In this study, research team conducted the questionnaire survey to ask for expected impacts of traffic and land transportation stakeholders in different regions of Thailand. Climate change data of 5 regions including northern, central, northeastern, eastern, and southern Thailand were comprehensively exemplified (details of expected impacts in each region as discussed in Chapter 3)

Questionnaires were designed to be easily understood by using a simple open-ended question with the specific group of respondents as follows:

- In the future, if the maximum temperature during the summer rises by $X_{1,r}$ degrees Celsius compared to the last year, how will it affect your travel?
- In the future, if the number of hottest days in a year (Temperature above 35 degrees Celsius) increases by $X_{2,r}$ days (or 2 months) from the current conditions, how will it affect your travel?
- In the future, if the flood severity increases by $X_{3,r}$ % based on the extreme flood that you have experienced, how will it affect your travel?
- In the future, if the number of rainy days increases by $X_{4,r}$ days / year from the current year, how will it affect your travel?

(note that $X_{1,r}$, $X_{2,r}$, $X_{3,r}$, $X_{4,r}$ vary by region r, depending on the model results discussed in Chapter 3)

The sample groups of this study comprise different agency officials from government agencies and private sectors as well as road users that can be categorized into 4 main groups as follow;

- Government officials responsible for infrastructures. (DOH DOR SRT MRTA).
- Drivers from both public and private sectors. (SRT, BMTA, BTS, MRTA)
- Traffic police and EMS officials (traffic police and EMS).
- Public (road users, transit riders, motorcyclists, bicyclists, pedestrians)

In this study, data were collected from the first three sample groups (as mentioned earlier) by post. Details of data sent and returned through postal survey are illustrated in Table 4.1.

Whereas, the last sample group (road users) were asked to rate the questionnaires and had direct interviews. The number of samples collected is shown in Table 4.2.

Table 4.1 the number of samples sent to different organizations and the number of questionnaires returned by post

Group	Organization	No. of sample	No. of Returned Questionnaire
Government officials responsible for infrastructure	DOH DOR SRT MRTA BTS EXAT	70 46 12 6 6 8	38 18 3 2 7 5
Drivers from both public and private	SRT MRTA BTS Transport company BMTA	10 12 12 14 26	4 5 3 13 9
traffic police and EMS officials	Traffic police EMS officials	20 6	10 0
Total		**248**	**117**

Table 4.2 the samples of road users based on interviews in each region

Group	Number of sample
Central	750
Southern	744
Northern	754
North Eastern	650
East	750
Total	**3,648**

4.2 Expected impacts of climate change to transportation system

4.2.1 Impacts to transportation system in the views of experts from different agencies

Summary of opinions of related stakeholders from different agencies (Government officials responsible for infrastructure, drivers from both public and private sectors, and traffic polices and EMS officials) in the issue of impacts of climate change to transportation system can be classified as following:

a) Temperature

Impacts due to the increase in temperature by 4 ºC in all regions of Thailand and increase in the warmest days or days with temperature>35 degree Celsius (30-90 days per year) are concluded as follows.

- **Government officials responsible for infrastructure**
  - Authorities of highway networks: DOH, DOR, EXAT
  - infrastructure
    - Pavement failure from prolonged high temperatures;
    - Damage to surface structures due to hotter and drier summers;
    - Expansion and contraction of materials.
    - Deterioration of traffic control devices, and rubber parts of the bridge;
    - Increase in grass fire risk;
  - Traffic Operation
    - Increase in road accidents;
    - More delays and less convenient due to poor pavement;
  - Construction
    - Loss of water content of the mixture;
    - Storage of materials;
    - Delays;
    - Decrease in structural performance of the road;
    - Decrease in worker performance;
    - Decrease in lifetime of construction equipment and machine;

  - Authorities of rail networks: SRT, MRTA, BTS
  - Infrastructure
    - Expansion and contraction of steel structures, steel sleepers, rail anchors;
  - Traffic Operation
    - Delays due to slowed down train;
    - No effect on security. If the security is not ensured, the train will stop;
  - Construction
    - Impacts of materials storage;
    - Material Damages;
    - Delays of construction;

- **Drivers from both public and private sectors (SRT, MRTA, BTS, Transport companies, BMTA);**
- Vehicle impacts
  - Acceleration of engine damage due to a hard working engine resulting in higher heat;
  - Car color might be changed quicker than usual i.e., turning pale or loose color;
  - More fuel and electricity consumption
  - Reduction of vehicle age

    - Making lower equipment efficiency i.e., air-conditioning system, braking system, etc.
- Service user impacts
    - Reduction in number of passengers
    - Effect to the emotions of service users i.e., irritation, frustration, etc.
    - Passengers may faint while waiting for the bus in the warmer weather, especially elderly people
    - Increase in the number of cars as well as car parking at station
- Station/sign/bus stop impacts
    - The heat might make travel more difficult;
    - Some roofs cannot protect heat efficiently. Moreover, some bus stops have no roofs and seats/low roofs;
    - If train services run on time, passengers can design a fixed time to reach the station without waiting time. If not, the rest/waiting areas should be provided at station;
    - Materials might have the faster degradation.

- **Traffic polices and EMS officials**
    - Road user impacts
        - Getting more car engine troubles, traffic congestion and accidents caused by cars and drivers who have the direct impacts;
        - Increase in fuel consumption due to higher use of air-conditioner;
        - Causing more stress on the use of roads/ reducing generosity of road users
    - Operational impacts
        - Effect on heath, eyesight and skin;
        - According to increase in the number of car troubles and accidents, crash risks are more likely occur due to repeated accidents
        - Getting involved in stopping car accident case might cause traffic congestion in case of negotiation failure;
        - Traffic polices must have more patience in warmer weather. They are expected to get excessive stress and more likely to have debate when arresting car users for a traffic violation.

b) Rain and flood

Impacts due to the increase in flood severity from the experienced extreme flood severity (by 30%) and increase in number of rainy days (1-30 days per year) are as follows:

- **Government officials responsible for infrastructure**
    - Authorities of highway networks: DOH, DOR, EXAT
        - infrastructure
            - Roughness of draining through shallow channel caused by sediments and sands ;
            - Lack of drainage system capacity and flooding of the network

- Damage to pavement surface layers from flood and more intense rainfall;
- Subsidence and heave on the highway from flood and more intense rainfall;
- Scour and damage to structures as a result of stronger winds and more storminess;
- Structural damage of bridge joints;

• Traffic Operation
- Increase in road accidents;
- Inconvenient and delayed transportation during flood;
- In case of high flood levels, staff are unable to get into work

• Construction
- Halting and delaying construction or hampering the regular work;
- Manufacturing facilities and materials and equipment transportation will be hampered resulting in lack of construction materials
- Increasing complexity in construction process
- Storage of materials or equipment might be damaged by flooding such as cement, steel bar, etc.
- Difficulty of bringing construction materials or equipment into the areas, equipment failure, and obstructing operation during flood;
- In flooding, all construction activities must stop because flooded road making access to the area more difficult, except for additional construction works related to flood remedy/ protection

- Authorities of rail networks: SRT, MRTA, BTS

• Infrastructure
- Railway ballasts might be carried away by flowing water and the problems of bending rail due to material stuck blocking the flow

• Traffic Operation
- Inconvenient and delayed transportation during flood;
- In case of high flood levels, staff are unable to get into work
- Delays due to slowed down train;

• Construction
- Impacts of materials storage;
- Material Damages;
- Delays of construction;

- **Drivers from both public and private** (SRT; MRTA; BTS; Transport company; BMTA);

• Vehicle impacts
- Quicker damage of vehicle body and its color;
- Damage to engines and air compressors;
- Unsafe drive system and braking system;
- Leaking of water into fuel tank;

  - Wheel bearings expired sooner;
  - Paying more engine maintenance expenses;
  - Trains with electrical drive system are unable to run across the flooded railway;
  - Metro services cannot operate if flooding over distribution system
- Service user impacts
  - Difficulty to access bus stops/stations and spending longer time travel that need to set more extra time to reach the destination;
  - Might have lower or no passenger number because no one wants to go through the flood;
  - Changing in passengers' travel behaviors to use boats, or no travel during flood
  - Bus users might be increased because buses can go through flooded roads (not high flood levels);
  - Reducing rail passengers because people cannot access the stations/ rail services stop
- Station/sign/bus stop impacts
  - Roof structures decay and small roof leaks that cannot protect passengers from rain;
  - Leakages in building joints at station;
  - Unsafe sidewalk surface conditions;
  - Inconvenience of service users due to getting wet

- **Traffic police and EMS officials**
  - Road user impacts
    - Increase in the number of accidents caused by slippery road conditions and unclear visibility
    - On rainy days, it is more likely to increase traffic congestion due to slow drivers, car engine or equipment failure and crashes;
    - More energy consumption than usual
    - Increase in broken traffic lights;
    - If high flood levels occur, travel may not be possible;
    - If high flood levels occur, it will cause more road damages and accident risks;
    - If high flood levels occur, travel can be inconvenient and slow;
    - If high flood levels occur, more road damages will cause slow-moving traffic. After a flood, a road repair can also affect imbalance between number of vehicles and number of roads;
    - If high flood levels occur, many cars might be parked in expressway areas resulting in inconvenient travel and less safety from property crimes
  - Operational impacts
    - Difficulty to travel with long time spending, even with a short distance;
    - Inefficient operation in terms of crime/accident prevention and traffic services;
    - Have to stand all day at work and no time to relax resulting in health impacts;
    - Must provide parking arrangement to relieve the blockage for people who need help or rescue;

- If high flood levels occur, traffic operation could be impossible due to no roads for cars running;
- If high flood levels occur, traffic polices must be replaced by water patrol officers/cops for boating;
- Receiving more complaints from road users

4.2.2 Impacts on people's travel

a) General information

In this study, 3,648 samples of road users were collected from five large provinces as representative provinces in each region of Thailand including Bangkok, Nakhon Ratchasima, Chiang Mai, Chonburi, and Nakhon Sri Thammarat Provinces. Users' characteristics can be described as follows:

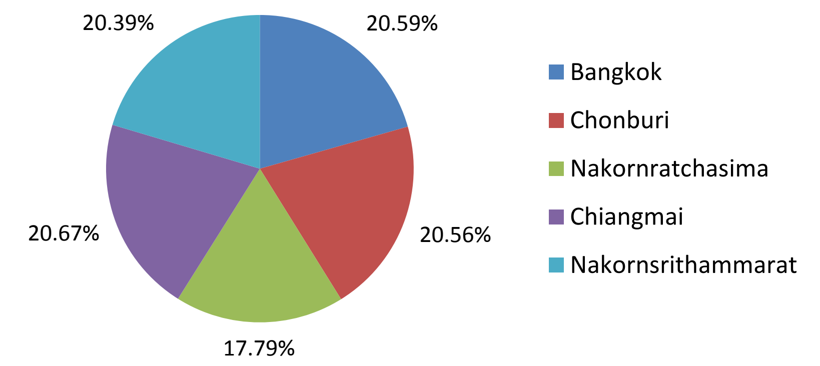


Figure 1 Percentage of a sample of road user groups in overall country classified by regions

According to Figure 1, the study found that the percentages of a representative sample of road user groups in overall country derived from Bangkok, Nakhon Ratchasima, Chiang Mai, Chonburi, and Nakhon Sri Thammarat Provinces are 20.59, 17.79, 20.67, 20.56 and 20.39, respectively.

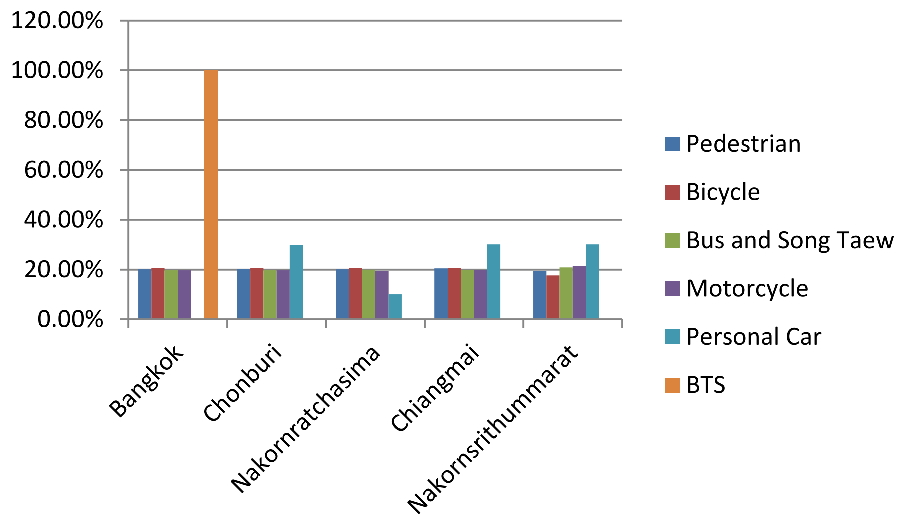


Figure 2 Sample distribution of road user groups in overall country classified by regions

Regarding Figure 2, road user groups in overall country were categorized into 6 groups including: (1) pedestrians; (2) bicycle users; (3) bus and song-taew users; (4) motorcycle users; (5) car users; and (6) BTS users. In each province, distribution of a sample of road user groups is quite similar, except for Bangkok where people would take the BTS and no car use were found.

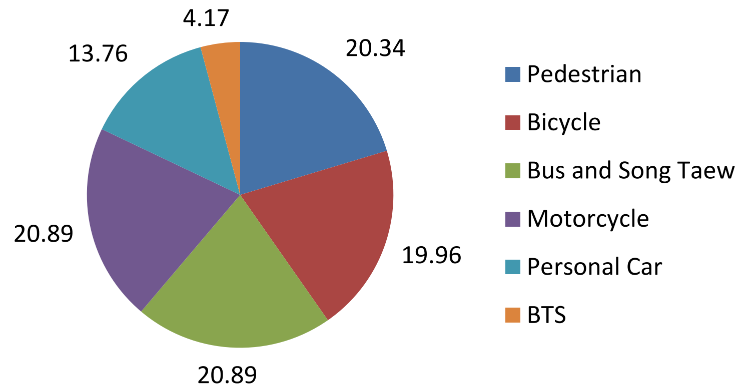


Figure 3 A sample of road user groups in overall country classified by travel behaviors

Based on Figure 3, the study found that the two largest road user groups are bus and song-taew and motorcycle groups with 20.89 percent of a total sample of road user groups in overall country, following by pedestrians (20.34%) and bicycle users (19.96%). While, the study found the number of people who behaviorally commute by BTS is of 4.17 percent as the lowest number of a total sample of road user groups in overall country.

b) Impacts of global warming on travel behaviors

1) Impacts of global warming classified by cases

Overall results from analysis of impacts of global warming on travel behaviors in Thailand classified by case questions can be described as follows:

Table 1 Impacts of global warming on travel behaviors in overall country

Questions	Travel Behaviors	Impacts				
		Used as the same	Decrease	Increase	Used as the same and change behavior	Total
Q1	Pedestrian	25.90%	**49.10%**	2.20%	22.90%	100.00%
	Bicycle	20.70%	**53.60%**	2.20%	23.50%	100.00%
	Bus and Song Taew	23.00%	**31.50%**	16.30%	29.20%	100.00%
	Motorcycle	25.90%	**41.90%**	3.30%	29.00%	100.00%
	Personal Car	**33.50%**	22.90%	18.50%	25.10%	100.00%
	BTS	**69.10%**	19.10%	3.30%	8.60%	100.00%
Q2	Pedestrian	14.40%	**67.10%**	1.20%	17.30%	100.00%
	Bicycle	8.80%	**69.20%**	2.10%	19.90%	100.00%
	Bus and Song Taew	16.00%	**39.50%**	14.60%	29.90%	100.00%
	Motorcycle	15.40%	**58.50%**	2.50%	23.60%	100.00%
	Personal Car	21.10%	**30.50%**	19.10%	29.30%	100.00%
	BTS	**80.30%**	11.80%	1.30%	6.60%	100.00%
Q3	Pedestrian	16.60%	**70.70%**	1.90%	10.80%	100.00%

	Bicycle	10.60%	**74.70%**	3.30%	11.40%	100.00%
	Bus and Song Taew	10.60%	**62.70%**	11.70%	15.00%	100.00%
	Motorcycle	15.20%	**67.50%**	2.00%	15.20%	100.00%
	Personal Car	14.50%	**55.60%**	7.00%	22.90%	100.00%
	BTS	**90.10%**	8.60%	0.70%	0.70%	100.00%
Q4	Pedestrian	13.50%	**70.90%**	1.30%	14.30%	100.00%
	Bicycle	4.60%	**79.10%**	2.50%	13.80%	100.00%
	Bus and Song Taew	12.50%	**53.90%**	12.90%	20.70%	100.00%
	Motorcycle	13.50%	**64.20%**	1.90%	20.50%	100.00%
	Personal Car	22.50%	26.70%	18.50%	**32.30%**	100.00%
	BTS	**80.30%**	8.60%	2.60%	8.60%	100.00%

- Case question 1#: In future, if maximum daily temperature in summer increases by 4 degrees Celsius from the present year, how will it affect your travel?

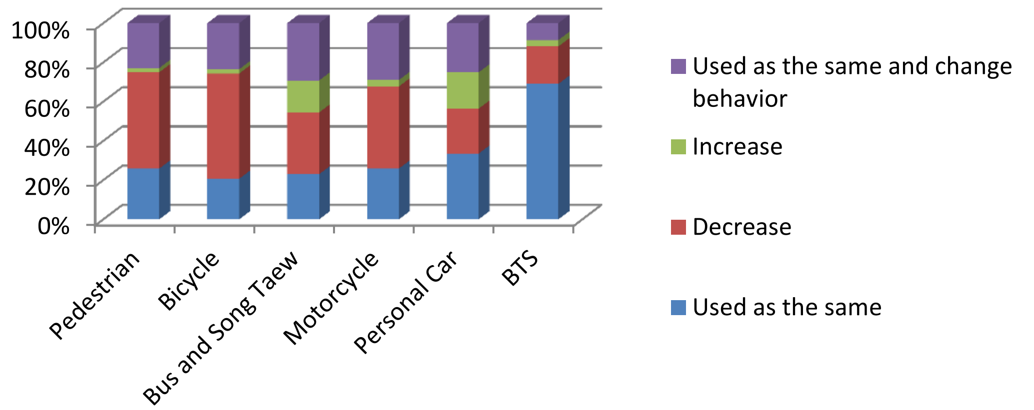


Figure 9 Percentage of impacts on a sample of road users in each group from overall country regarding a case of increase in maximum temperature in summer

According to Table 1 and Figure 9, the impacts on road users in each type from overall country based on case question 1 involve reduction of the percentage of pedestrians (49.10%), bicycle users (53.60%), bus and song-taew users (31.50%), and motorcycle users (41.90%). On the other hand, the percentage of people who are used to commute by cars and BTS are still the same with 33.50 and 69.10, respectively.

- Case question 2#: In the future, if the number of the hottest days in a year (Temperature above 35 degrees Celsius) increases by 30-90 days (1-3 months) from the current conditions, how will it affect your travel?

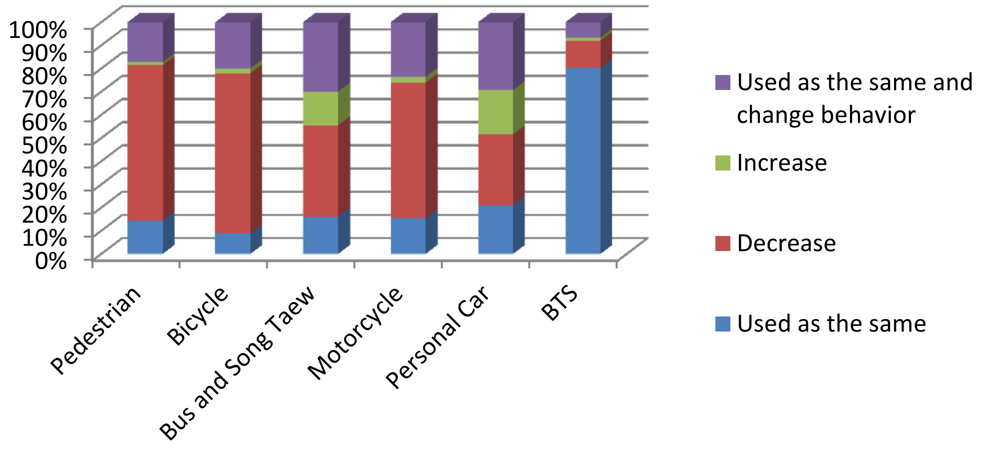


Figure 10 Percentage of impacts on a sample of road users in each group from overall country regarding a case of increase in the number of hottest days (temperature>35 degrees Celsius)

From Table 1 and Figure 10, the findings related to impacts of road users in each type of overall country by case question 2 indicates the lower percentage of pedestrians (67.10%), bicycle users (69.20%), bus and song-taew users (39.50%), motorcycle users (58.50%) and car users (30.50%). In case of the group of BTS commuters, it presented the same percentage (80.30%).

- Case question 3#: In the future, if the flood severity increases by 30% based on the extreme flood that you have experienced, how will it affect your travel?

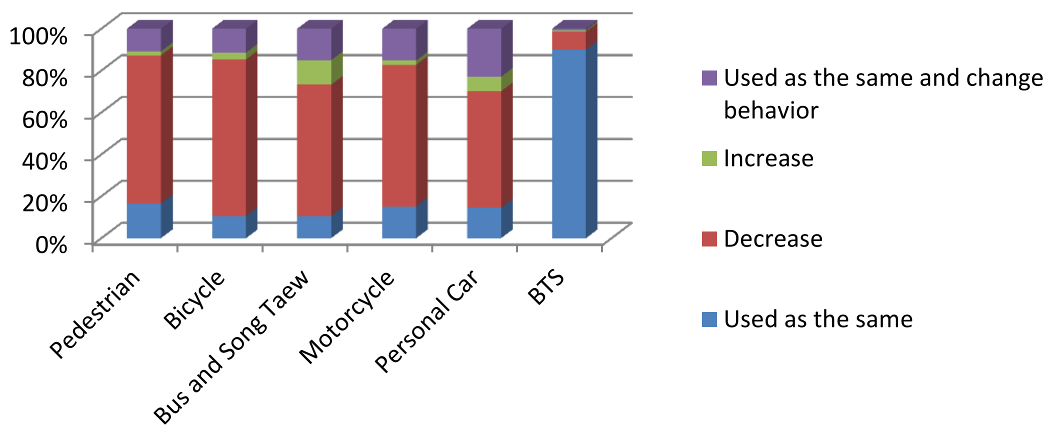


Figure 11 Percentage of impacts on a sample of road users in each group from overall country regarding a case of increase in flood severity

From the results of Table 1 and Figure 11, the potential impacts on road users in each type from overall country based on case question 3 were found in relation to the lower percentage of pedestrians (70.70%), bicycle users (74.70%), bus and song-taew users (62.70%), motorcycle users (67.50%) and car users (55.60%). While, the regular BTS users prefers to travel the same mode (90.10%).

- Case question 4#: In the future, if the number of rainy days increases by 1-30 days / year from the current year, how will it affect your travel?

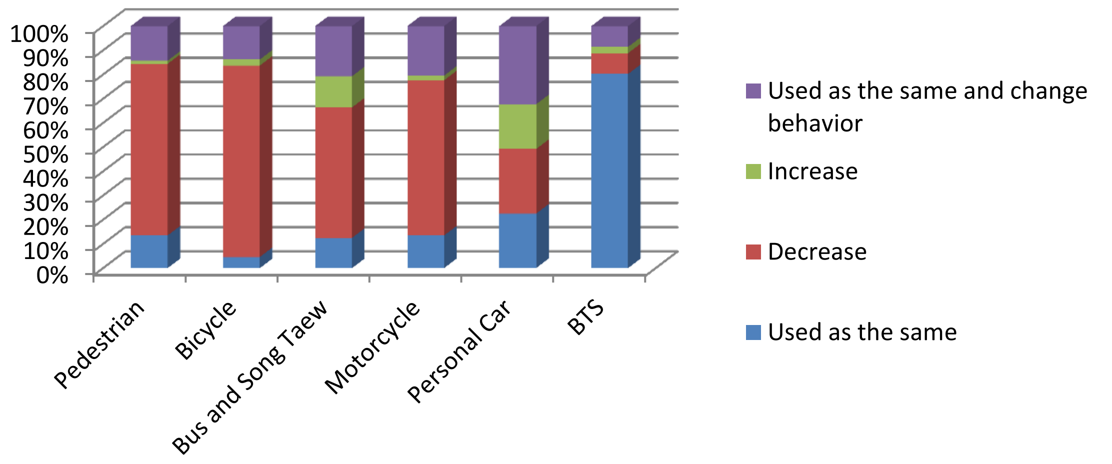


Figure 12 Percentage of impacts on a sample of road users in each group from overall country regarding a case of increase in the number of rainy days

Table 1 and Figure 2 indicated major impacts of road users in each type of overall country based on the case question 4 that involve the reduction in percentage of pedestrians (70.90%), bicycle users (79.10%), bus and song-taew users (53.90%) and bus users (64.20%). From the study, the percentage of people who use cars regularly is still the same, but adapting their individual travel behaviors (32.30%); while BTS commuters choose the same travel (80.30%).

2) Impacts of global warming classified by travel behaviors of a sample group

- Pedestrian group

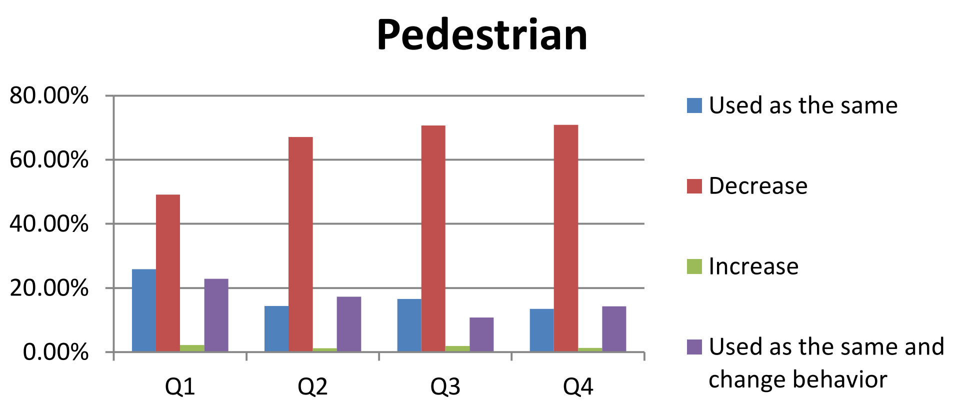


Figure 13 Percentage of impacts by a sample group of pedestrians in overall country

According to Table 1 and Figure 13, the findings illustrated that global warming impacts based on 4 questions will reduce the number of pedestrians in overall country, especially the results of question 4, 3 and 2 (70.90%, 70.70% and 67.10%, respectively)

- Bicycle user group

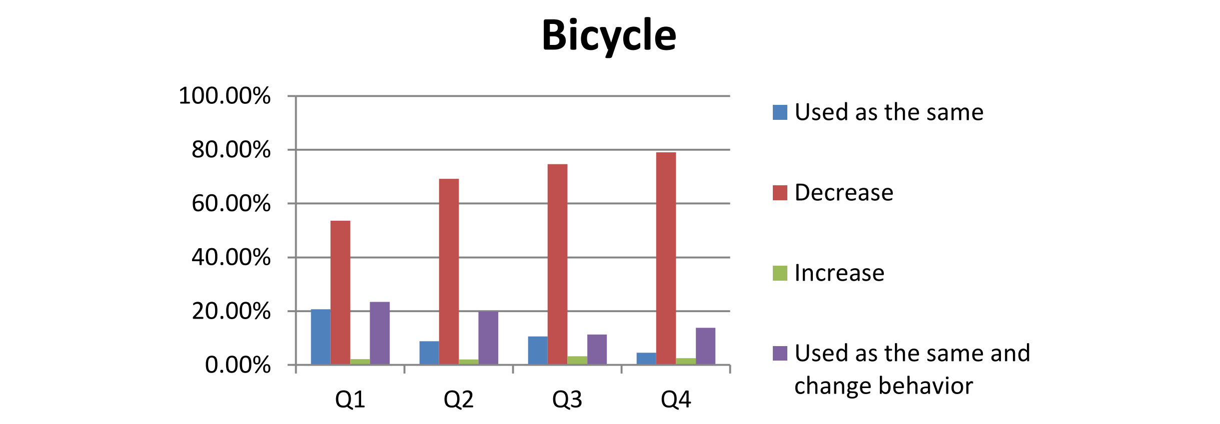


Figure 14 Percentage of impacts by a sample group of bicycle users in overall country

Simultaneously, the results of Table1 and Figure 14 relating to global warming based on the questions showed the lower percentage of bicycling group, especially issues of question 4, 3 and 2 (79.10%, 74.70% and 69.20%, respectively).

- Bus and song-taew user group

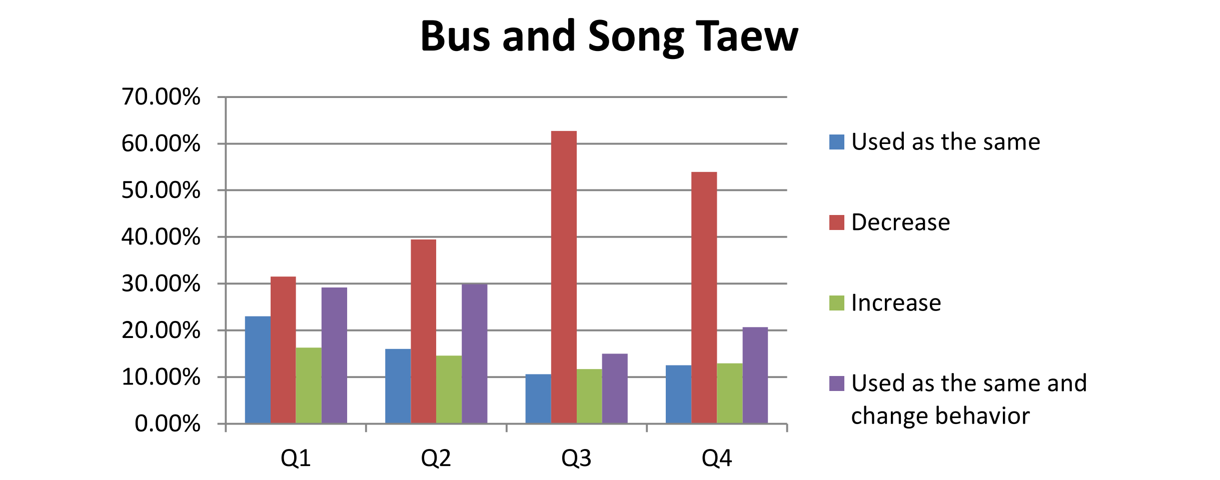


Figure 15 Percentage of impacts by a sample group of bus and song-taew users in overall country

Based on Table 1 and Figure 15, the findings according to 4 questions indicated that global warming would have an effect on reducing the use of buses and song-taews. While the results regarding questions 1 and 2 illustrated that bus and son-taew users do not change travel mode, they adjust their behaviors at relatively high rates (30%).

- Motorcycle user group

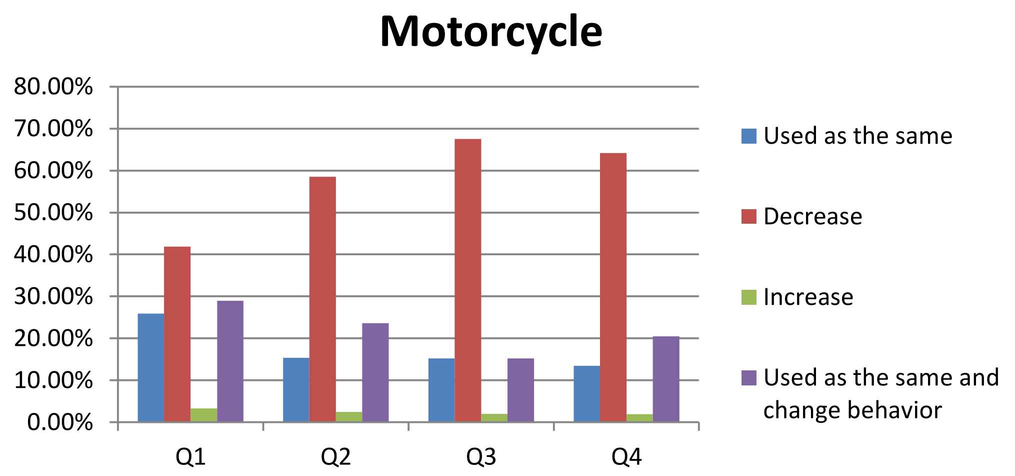


Figure 16 Percentage of impacts by a sample group of motorcycle users in overall country

Table 1 and Figure 16 indicated the reduction of number of motorcycle users in overall country due to global warming based on 4 case questions, especially questions 3, 4 and 2 (67.50%, 64.20% and 58.50%, respectively). In case of question 1, the percentage of the use of motorcycles are still the same, with behavior change (more than 30%).

- Car user group

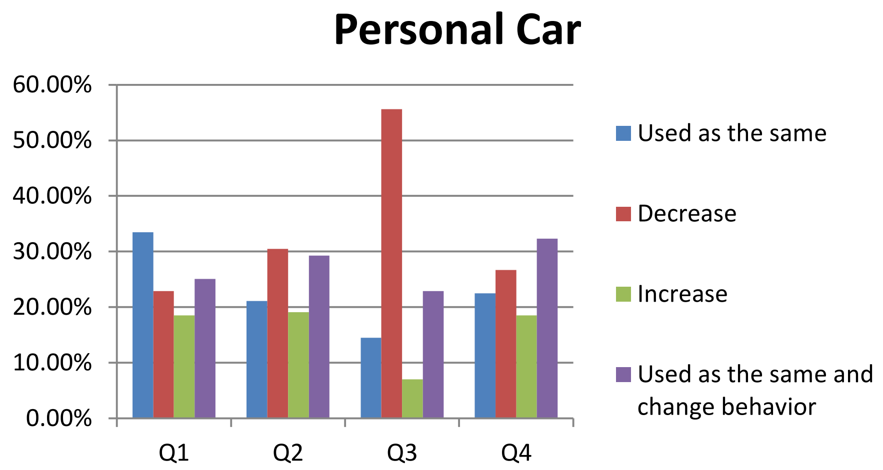


Figure 17 Percentage of impacts by a sample group of car users in overall country

According to Table 1 and Figure 17, the global warming impacts derived from questions 3 and 2 result in the reduction of a number of car user group in the overall country with 55.60% and 30.50%, respectively. It can be obviously seen that in the case question 1, the majority of the sample group still use the same mode. While the results based on question 4 illustrated that most of them prefer to use the same mode, they change behaviors.

- BTS user group

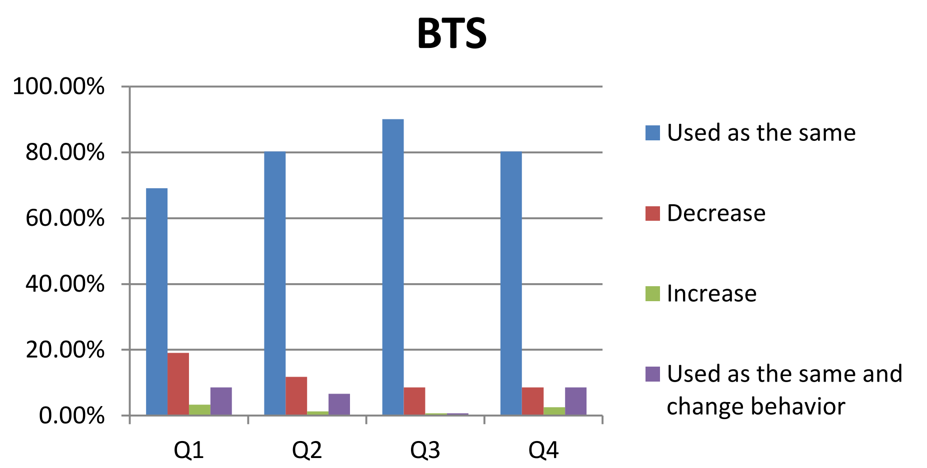


Figure 18 Percentage of impacts by a sample group of BTS users in overall country

Regarding Table 1 and Figure 18, impacts of global warming do not change the mode selection of BTS users, according to which the same percentage of the sample group based on questions 1-4 are illustrated as 69.10%, 80.30%, 90.10% and 80.30%, respectively.

4.3 Recommendation

Besides the study of expected impacts of climate change to transportation system in section 2.2, one part of the questionnaire was essentially captured on adaptations and suggestions from related traffic and transportation authorities' staff together with road users regarded as the public sector. The details can be described as following;

4.3.1 Recommendation from traffic and transportation authorities' staff

- Case question 1# and 2#: Change in maximum temperature in warm season (degree Celsius) and Change in the warmest days or days at temperature>35 degree Celsius (days per year)

The results from questionnaire survey relating to adaptations and suggestions from traffic and transportation authorities' staff can be summarized as follows;

- **Government officials responsible for infrastructure**
  - Infrastructure aspect
    - Considering a mixture design or identifying material properties used for new road construction, i.e. reduction of asphalt in road surfaces, use of asphalt cement to be appropriate for higher temperatures, determination of asphalt with setting greater values of softening point, etc.
    - Conducting the supporting researches to find materials with wider tolerance of climate variability, i.e. different types of fibers that can increase the structural flexibility.
    - Adjusting new regulation standards by considering factors related to the future climate change, i.e. selection of the use of high quality of thermoplastic materials.
    - Replacing the old roads to concrete roads, especially at intersection where long periods of tramping on road usually occur, together with creating a design of steel reinforcement of new concrete surfaces.
    - Considering the modification of bridge joints and deflections.
    - Use of drought stressed grass species or raising awareness by making grass cutting along roadsides to prevent fires during dry season.
    - Efficiently Improving transportation system maintenance plan by increasing inspections of road maintenance and operation more closely and regularly than usual.
    - Need to improve equipment qualification and machines to be suitable for higher temperature.
    - If conducting a big road project, trees should be planted along roadsides with great care.
    - Increasing a wide range of road, ballasts in street and closed inspection.
    - Installing rail expansion joint to reduce excessive forces being existed within railway track and prevent its cracks through a new calculation of spacing of railway head along with maximum increase in rail temperature, and using zero longitudinal restraint which allows expansion of the rails following the long-side direction.
  - Traffic aspect

- Reviewing a new design of traffic control system, i.e. arrangement of traffic management with clearly setting lane dividers at U-turn, installation of traffic sign and traffic light, etc.
- Increasing rest areas/ car parks to be appropriate with land conditions
- Promoting the use of public transportation i.e., buses, metros, etc.
- Improving hazardous locations on roadways
- Reducing vehicle overloading

o During construction
  - Improving design or specification of material characteristics to deliver the construction which meets purpose of road form under higher temperature
  - Keeping the regular maintenance and repairing of equipment
  - Improving a new strategy of construction work or construction period i.e. beginning the work in early mornings while weather is cool, increasing work hours during evening-night periods, and making a nighttime transportation service, etc.
  - Must regularly check the humidity levels of materials
  - Putting water to construction materials thus ensuring temperature reduction or spraying water in the road surfaces before laying the concrete
  - Changing transportation technique and using easy way to keep materials for operation that is suitable for higher temperature
  - A good ventilation system must exist in buildings
  - Keeping materials in good order/ in installed garages or buildings
  - To make rail alignment and install rail restraint, rail temperature should be considered as the major priority. As well, the operation should be conducted in the correct procedure.
  - Providing the operation plan in associated with temperatures and weather conditions. Water or ice might be used to reduce the rail temperature to bending rails in case of emergency that cannot wait until lower temperatures are taken place.
  - Engineers responsible for controlling the construction work must deeply keep an eye on the tasks.

o Other aspects
  - Improving the appropriate car design to serve high temperatures, especially tires.
  - Reviewing the levels of light intensity that allows the UV light to penetrate into the car with sun film
  - Creating helmet design making help to release heat
  - Providing campaign for related stakeholders of all agencies to make the potential solutions for the specific problems, i.e., tree planting campaign.
  - Improving environmental conditions along roadsides, i.e., making a pleasant shade tree/ rest areas to reduce emotional stresses.
  - Launching campaign to reduce the use of automobile and increase in mass transit access through providing more buses and facilities to attract people to use the service.

- **Drivers from both public and private**

o Vehicle aspect
  - Installing solar film and curtains to prevent heat

- Providing regular check and maintenance following required period conditions, especially cooling and wheel systems
- Arranging a new bus route system with more efficiency
- Promoting the use of alternative energy, i.e., installation of NGV system, etc.
- Adjusting a new strategy for bus routes in consort with the way that are appropriate and beneficial for the existing situations
- Providing suggestions for the use of alternative fuels rather than the other fuels
- Planting trees at bus terminals to reduce heat
- Building shelters for locomotives or buses
- Installing more cooling systems, i.e. fan fogger , into transmission systems
- Adjusting the temperature levels within metros
- Using good quality car care products that can prevent warm weather and UV light
- Changing painting to putting sticker/ using UV reflectance color
- Using energy conservation technologies
- Setting temperature levels which are suitable for time periods and the number of passengers

- Service user aspect
    - Must arrange a new travel system along with the expected environmental conditions through adjusting a new travel timetable
    - Providing efficient traffic management/ releasing vehicles at intersection
    - Increasing the number of air buses/ changing the old buses to air buses
    - Scheduling routes to reach the destination on time with appropriate line processions
    - Setting lower temperature inside the train
    - Making a plan in a way of being appropriate with the number of passengers
    - Bringing the aspirator
    - Increasing tree planting campaigns
- Station/ sign / bus stop
    - Improving passenger waiting rooms by installing more fan foggers or air-conditioners with proper temperature.
    - Improving a signal roof with durability and good heat release.
    - Improving landscapes, increasing stations and having mutual cooperation event for tree planting to provide natural cooling.
    - Should have more staff who can be responsible for campaigns
    - Shady trees should be planted inside the rail station
    - Improving passenger waiting areas by installing electric lighting system, grass cutting, providing enough bench seat, and having convenient and safe water coolers for passengers
    - At bus stops, medium-sized trees should be planted to reduce heat
- Other
    - Providing campaigns in cooperation with different agencies to promote tree planting and raise awareness of natural protection

- **Traffic police and EMS officials**
    - Road users aspect

- Increasing efficient public transport system with good connectivity, i.e. metros, intercity trains and all busses with air-conditioning.
- Limiting the number of vehicles per household. If it is beyond the occupancy limit, penalty taxes should be required that would reduce unnecessary burden of new vehicle registration.
- Enhancing people for mutual energy-saving and tree-planting
- Providing campaign activities to give related knowledge as a key to raise awareness of people

o Operation aspect

- Providing campaign activities to encourage the rigorous and substantial participation within agency
- Improving police uniforms in association with the working conditions and environment, and providing work equipment and convenient facilities to the police.
- Giving policies to all operating staff by focusing on service mind.
- Proving convenient facilities and comfortable residences
- Using modern equipment to control traffic, i.e. using CCTV together with traffic signal and car counter at the intersection point with requirement of a simultaneous coordination with the next intersection.
- Providing regular health-check for operating staff

- Case question 3# and 4#: 30% increase in flood severity from the experienced extreme flood severity and change in number of rainy days (days per year)
  - **Government officials responsible for infrastructure**
    - o Infrastructure aspect
      - Improving water resource management through expert advices to alleviate flood severity
      - Improving road/ bridge design to balance with the dynamic situations. It might need both the dike roads (in some areas) and the roads which allow water to flow in (in some areas).
      - Applying GIS system to some specific areas where urban planning is enforced.
      - Preparing emergency, short-term and long-term prevention and remedy plans
      - Conducting survey and audit for efficient diverting water flow system and improving design of new road construction projects in association with the old roads that faced flooding.
      - Readily preparing for cleanliness of canals, drainage
      - Improving the structural design of drainage to serve the increase in water volumes and providing drainage system with potential draining and reducing waterlogging
      - Monitoring the roads that are cut off by landslides or erosions, removing laid stones on railroad track in case of emergency, and conducting survey of routes after flooding. In addition, it should consider the improvement of railways which always face high-floods by building 'Hopewell' and a cooperation with related agencies to construct a long-term flood prevention system to reduce disaster impacts.
      - Making soil cutting on laid road in advance and providing an erosion control and prevention system as well as monitoring key red areas

- Providing appropriate infrastructure repair and improvement
- Opening adequate water channel and considering the building of a low bridge in flood areas to prevent a waterway from railway obstruction.
- Conducting waterproof electrical equipment along roadways and using manual operation for bus services
- Providing appropriate and adequate drainage system
- Improving design for new road construction by taking water direction as a key consideration
- Choosing concrete materials for road surfaces
- Providing the construction quality control following the requirements in terms of materials and techniques
- Checking the equipment regularly
- Limiting traffic volumes, by which trucks are required to avoid the use of flooded roads
- Changing to use materials which are non-susceptible for a change in weather conditions
- In changing to water and heat resistant materials, both quality and cost must be increased.
- Increasing lighting efficiency or reflection of electric lights, traffic lights, traffic signs, and road surface markings.
- Providing efficient and accurate solutions in all steps of the construction process
- Providing maintenance to keep equipment well-functioned and testing waterproof system comprising rubber materials or a plastic cover to prevent leakage.
- Clearing weeds and grass, removing trees and grubbing stumps to prevent the plants from growing disorderly that will cause visual impacts, especially areas of level crossings.

- Traffic aspect
  - Providing traffic discipline campaign and raising awareness
  - Making a plan and promoting transportation systems which have the lowest impacts during flood situation such as metros.
  - Improving structural form, upgrading roads and drainage system, and clearing canals to serve an increase of water volumes.
  - Determining road corridors and road surfaces with clearly noticeable when flood occurs.
  - Using water transportation as a mode choice
  - Putting warning signs and suggesting functional routes as well as arranging staff to assist service users
  - Reserving materials required for emergency responses (i.e. ballast and big stone), providing material sources from nearby area that are ready to deliver, coordinating with related agencies which can support vehicles and materials in case of emergency, Cutting soil at dead-end road earlier, providing erosion prevention system and monitoring road cut-off and landslides at risk locations, opening channel to carry adequate water flows, surveying road conditions after flooding, Considering a construction of low bridge in flood areas to keep waterway from railway obstruction, and having cooperative with related agencies to provide long-term flood prevention system for reducing adverse impacts.

- Coordinating with local organizations for vehicle provisions, improving transport connectivity, providing and improving locomotives that should get ready for flood situation, developing railway infrastructure in readiness for unexpected situations and preparing the service for critical conditions.
- Improving areas where accidental risk locations are expected to exist through testing the slip resistance of road surfaces.
- Being more careful and rigorously complying with the traffic rules and highway standards / using appropriate speeds for slip roads.
- Increasing the lighting efficiency or reflection of electric lights, traffic signals/signs, and road surface markings.
- Requiring soil cutting of laid road, providing erosion prevention system on slopes and monitoring extraordinary circumstances or landslides at risk locations, opening channel to carry adequate water flows, increasing road condition survey during heavy rainfalls for a long period.
- Keeping maintenance of equipment in well-function and testing waterproof system comprising rubber materials or a plastic cover to prevent leakage.
- Clearing weeds and grass, removing trees and grubbing stumps to prevent the plants from growing disorderly that will cause visual impacts, especially areas of level crossings.

o During construction
  - Temporarily breaking construction until water level is reduced, except for the construction of flood protection and remedy project
  - Providing construction planning and with a clear and concise task requirement to reimburse the loss of working hours from rainy/ flood days, and improving construction plan in consort with situations and seasonal changes.
  - Must have the special provisions for traffic management during construction.
  - Finding appropriate transportation routes/ production factory at a new location, preparing the plan for quantity of material stocks/ keeping materials in high places, and bringing pontoons/floats with a well-organized and sailcloth wraps.
  - Issuing fee exemption and reduction measures, expanding construction contract and organizing a purchase for contract partner.
  - Tracking the future forecast and making construction planning along with the situations
  - Providing water protection system, preparing rickshaws or vehicles which can be used for carrying or moving equipment as well as places to keep materials and equipment
  - Conducting quality control while pouring concrete, especially protecting fresh-poured concrete from rain and making construction plan in dry season.
  - Making a cooperative plan with related agencies for providing potential solutions
  - Closely and continually monitoring and evaluating construction outcomes along with designing the responsible staff to keep an eye on the work until its completion.

- **Drivers from both public and private**
  - Vehicle aspect
    - Conducting flood preparedness plan
    - Providing maintenance, repair and improvement system following the situations
    - Improving car structures and colors
    - Increasing the efficiency of maintenance audits and checking all related systems
    - Making rush-proof
    - Increasing vehicle speed control standards
    - Upgrading higher-level railways to allow trains passing through during flood situation
    - Having post-flood repair
  - Service user aspect
    - Government agency should appropriately provide bus or boat services to serve passengers during high flood levels
    - Temporarily moving ticket center and office
    - Adjusting bus routes and schedules
    - Finding solutions related to oil and gas procurement
    - Creating media campaigns to boost user confidence.
    - Adjusting travel plan following the fluctuating situations, i.e. leaving home early
  - Station/sign/bus stop
    - In concerned areas, coordination among aid agencies should be provided by giving route information to affected people; for example, if passengers need to travel, which agencies should they ask to provide convenience?
    - Expanding time of leaving home to wait passengers
    - Having passenger contact information in case of late arrival, i.e. phone calls to follow them
    - Asking for cooperation with government sector in “From bus to car” or “From car to bus” project
    - Improving bus structures and colors and installing awning or splashboard to protect passengers from rain
    - Having post-flood improvement and repair

- **Traffic police and EMS officials**
  - Road users aspect
    - Making a plan for thorough campaigns about related issues and informing the public about current situations for preparedness and response
    - Providing drainage system in associated with water holding capacity by covering of each region
    - Building higher road layers
    - Using amphibian vehicles
    - Finding efficient flood protection approaches for the areas that have a large number of vehicle use i.e., Bangkok and its vicinities
    - Highlighting rigorous campaigns of expressway parking restriction by means of law enforcement making low impacts to people (although, its

performance is not quite good when compared to what had happened in previous years)
- Efficiently marking road lines with reflected light color with obvious lighting along roadways as well as traffic signals
- Increasing number of rescue staff and squad cars at checkpoints to quickly solve the problems

- Operational aspect
  - Sparing time for operation and planning in advance
  - Designing a new road structure with many layers
  - Increasing warning lights in the locations where accidents always occur.
  - Efficiently painting road lines with reflected light color with obvious lighting along roadways as well as traffic signals
  - Must provide training and raising service-minded awareness for staff responsible for road user services
  - Considering and improving inefficient operations resulting in traffic impacts on public
  - Must arrange the parking with clear of any obstructions together with helping people
  - Asking for the help of volunteers and government sector
  - Supporting the use of modern equipment to reduce labor force in finding information on future disaster
  - Providing media campaign to suggest people in avoiding flooded or traffic routes
  - Encouraging more carefulness
  - Having equipment and vehicles that can support travel during floods i.e., rainy clothes with reflected light objects
  - Preparing boats to rescue people and training police to help them on waterways

4.3.2 Adaptations of people's travel behaviors to global warming

Regarding analysis of adaptions of people's travel behaviors to global warming at the national level, the overall results are classified into 4 question issues following global warming impacts as following;

- Case question1# : In future, if maximum daily temperature in summer increases by 4 degrees Celsius from the present year

According to the analysis of a case of increase in maximum daily temperature in summer, adaptations of sample groups of each road user type in overall country were found that;

- Majority of pedestrian group adapted their travel behaviors to other aspects i.e., using umbrella, putting sun block lotion, wearing long-sleeve shirt, etc. (43.80 %), following by taking air bus/song taew/van (17.50%)
- The largest percentage of bicycling group changed their travel behaviors to other aspects i.e., using umbrella, putting sun block lotion, wearing long-sleeve shirt, etc. (32.40%), while some of them do not change the behaviors (18.50%)

- For the bus/song-taew user groups, the majority adjusted their travel behaviors to other aspects i.e., using umbrella, putting sun block lotion, wearing long-sleeve shirt, etc. (37.70%), following by using air bus/van (17.50%)
- Majority of people who usually commuted by motorcycles adapted their travel behaviors to other aspects i.e., using umbrella, putting sun block lotion, wearing long-sleeve shirt, etc. (39.80%), proceeding by not changing the behaviors (20.10%)
- The largest samples of car users adapted their behaviors to other aspects i.e., using umbrella, putting sun block lotion, wearing long-sleeve shirt, etc. (34.10%), following by not changing the behaviors (30.90%)
- There was no change in the majority of BTS passengers' travel behaviors (69.50%)

- Case question 2#: In future, if the number of hottest days (temperatures greater than 35 degrees Celsius) increases by 30-90 days (1-3 months) yearly differing from the current condition.

Regarding the analysis of a case of increase in number of the hottest days (> 35 degrees Celsius), adaptations of sample groups of each road user type in overall country were found that:

- Most of pedestrian groups adapted their travel behaviors to other aspects i.e., using umbrella, putting sun block lotion, wearing long-sleeve shirt, etc. (35.40%), following by using air bus/song-taew/van (26.10%).
- For bicycling group, most of them changed their travel behaviors to other aspects i.e., using air bus/song-taew/van (26.10%), proceeding by using umbrella, putting sun block lotion, wearing long-sleeve shirt, etc. (25.80%)
- Most samples of bus and song-taew commuters adapted themselves to other aspects i.e., using umbrella, putting sun block lotion, wearing long-sleeve shirt, etc. (36.50%), following by using air bus/ van (18.60%)
- Most of people who usually commuted by motorcycles adapted the behaviors to other aspects i.e., using umbrella, putting sun block lotion, wearing long-sleeve shirt, etc. (32.80%), proceeding by using air bus/ van (18.80%)
- For car user groups, most of them adapted their travel behaviors to other aspects i.e., using umbrella, putting sun block lotion, wearing long-sleeve shirt, etc. (37.10%), whereas some of them do not change the behaviors (27.70%)
- The majority of BTS passengers do not change their travel behaviors (81.20%).

- Case question 3#: Based on the biggest flood that you have experienced, if in the future, the flood severity increases by 30%

Regarding the analysis of a case of increase in flood severity, adaptations of sample groups of each road user type in overall country were found that:

- The majority of pedestrian group adapted their travel behaviors to other aspects i.e., wearing boots, avoiding floods, migrating, etc. (25.30%), following by having less travel/ no travel and taking boat (16.80% and 15.20%, respectively)
- The largest percentage of bicycling group changed their travel behaviors to other aspects i.e., wearing boots, avoiding floods, migrating, etc. (20.10%), while some of them change the behaviors to use air bus/song-taew/van, have less travel/no travel, and go by boat(18.00%, 13.00% and 13.00%, respectively)

- Most samples of bus and song-taew commuters adapted themselves to other aspects, i.e. wearing boots, avoiding floods, migrating, etc. (28.50%), following by having less travel/ no travel and taking boat (22.70% and 14.40%, respectively)
- The largest percentage of motorcycle commuters changed their behaviors to other aspects i.e., wearing boots, avoiding floods, migrating, etc. (25.30%), following by not changing the behaviors (18.60%)
- For car user groups, most of them adapted their travel behaviors to other aspects i.e., wearing boots, avoiding floods, migrating, etc. (33.90%), following by not changing the behaviors (21.30%)
- Most of BTS passengers do not change their travel behaviors (91.10%).

- Case question 4#: In future, if the number of rainy days increases yearly by 1-30 days differing from the current situation

Regarding the analysis of a case of increase in rainy days, adaptations of sample groups of each road user type in overall country were found that:

- The majority of pedestrian group adapted their travel behaviors to other aspects i.e., using umbrella, wearing rain coat, avoiding waterlogging areas, etc. (31.30%), following by using air bus/song-taew/van (21.30%).
- The largest percentage of bicycling group changed their travel behaviors to other aspects, i.e. using umbrella, wearing rain coat, avoiding waterlogging areas, etc. (24.50%), while some of them change the behaviors to use cars i.e., relative/friend cars (21.50%)
- Most of samples of bus and song-taew commuters adapted themselves to other aspects, i.e. using umbrella, wearing rain coat, avoiding waterlogging areas, etc. (34.90%), following by using cars i.e., relative's/ friend's cars (22.50%)
- The largest percentage of motorcycle commuters changed their behaviors to other aspects i.e., using umbrella, wearing rain coat, avoiding waterlogging areas, etc. (33.60%), proceeding by using cars i.e., relative's/ friend's cars (18.50%)
- For car user groups, most of them adapted their travel behaviors to other aspects i.e., using umbrella, wearing rain coat, avoiding waterlogging areas, etc. (47.80%), following by not changing the behaviors (28.70%)
- Most of BTS passengers do not change their travel behaviors (80.00%).

4.3.3 Suggestions to government/municipalities from public sector

- Transportation systems management
  - Improving traffic management more efficiently
  - Increasing the number of roadside pavilions (for pedestrians/bicycle/motorcycle users)
  - Providing good quality sidewalks, increasing sidewalk width, conducting bridges with roofs, and determining sale or merchandise prohibited in sidewalk areas
  - Promoting the use of public transportation i.e., expanding metro lines and providing 24 hours service stations/ increasing number of bogies / reducing BTS ticket prices/ providing free BTS tickets for students/ elderly people/ monks / increasing number of song-taews/vans/buses/air buses with good condition and/or reducing ticket prices
  - Reducing expressway tolls
  - Issuing laws for controlling motorcycle taxi stations
  - Determining 'car-free road' or 'car free day'

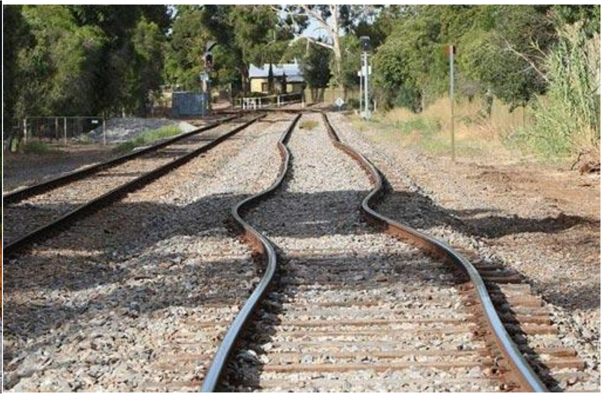
  - Expanding roads/sois width with good quality
  - Conducting bicycle/motorcycle lanes
- Global warming management
  - Providing deforestation campaigns
  - Increasingly planting trees on road shoulder
  - Increasing the number of parks
- Flood severity management
  - Conducting flood protection measures i.e., building/cleaning drainage pipes, building flood tunnels/ the Monkey Cheeks project (Kaem Ling)/ dams for water reserve.
  - Providing more public boats together with rescue center to adequately give food, water and medicines during a flood.
  - Improving public relations during a crisis.
- Other
  - Increasing taxes for import cars and reducing taxes for domestic cars
  - Reducing oil prices
  - Increasing gas stations

Chapter 5
The transport knowledge
that match the expected climate change

5.1 Introduction

Transportation system obtained "Temperature Effect" and "Precipitation and Flood Effect" under climate change phenomenon. Transportation Engineer and planners should be aware of these impact and propose appropriate adaptation planning framework for transport authorities to maintain the transportation system under climate change circumstances.
The element of transportation systems involved climate change phenomenon as follow:

1. Infrastructure
2. Vehicle
3. Road Users
4. Traffic and Transport
5. Construction
6. Operation

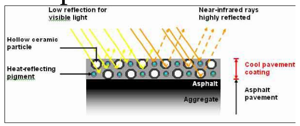



The adaptation knowledge are gather from theories, standards, practices, researches and expert in various related field (e.g transportation , civil and environment). These knowledge will develop to adaptation planning framework and method for Thailand transport authorities implementation.

5.2 Infrastructure

Transportation infrastructure is significant fundamental of transportation system. The impact of High temperature and Precipitation or Flood to infrastructure is decline. The detail of adaptation options and knowledge as follow:
:

<table>
<tr><th>Potential Climate Change</th><th>Infrastructure Impact</th><th>Adaptation options</th><th>Method/Knowledge</th></tr>
<tr><td colspan="4">Land Transport</td></tr>
<tr><td rowspan="2">Temperature increases</td><td rowspan="2">T1 : Asphalt Pavement: Crack, Rutting, etc.
</td><td>T1.1 : Improved/ Enhanced Asphalt property</td><td>– Adjust more high Softening Point
– Applied Hot Rolled Asphalt Surf 40/60 standard
– Hot Rolled Asphalt standard 910 at low volume road and 911, 943 for more risk area
– Applied bond coats to reduce voids at layer
– Applied Cool pavement technology
– Add anti-oxidation in asphalt mix
– Used porous asphalt and asphalt-rubber

– Used coating above pavement

– Applied polymer Substances in pavement mixture to avoid rutting</td></tr>
<tr><td>T1.2 : Enhanced New Design Standard</td><td>– Select high quality thermoplastic Substances in pavement mixture
– Applied MEPDG or Mechanistic-Empirical Pavement Design Guide and created Enhanced Integrated Climate Model (EICM) to predict temperature and climate change situation</td></tr>
</table>

Potential Climate Change	Infrastructure Impact	Adaptation options	Method/Knowledge
Land Transport			
Temperature increases	**T1 : Asphalt Pavement: Crack, Rutting, etc.** 	T1.3 : Research and study for new technology and method	– Polymer Substances research – Created Enhanced Integrated Climate Model (EICM) and predict cost/benefit of adaptation options – Alternative Materials study
		T1.4 : Convert to concrete pavement	– Convert to concrete pavement at intersection area – Redesign reinforcement of concrete pavement
		T1.5 : developed and Enhanced maintenance plan	– Increased the maintenance routine and performance – Developed maintenance plan assessment – Developed the maintenance report related to weather factors
	T2 : Concrete joint expansion 	T 2.1 : Developed and Enhanced concrete joint material property	– The Ply-Krete® Bridge Joints – Bridge Elastomeric expansion joint  
		T2.2 : Enhanced concrete pavement design standard	– Sustainable Concrete Pavements Technique

Potential Climate Change	Infrastructure Impact	Adaptation options	Method/Knowledge
Land Transport			
Temperature increases	**T3 : Life time of traffic control device decreased**	T3.1 : Developed and Enhanced material property	
		T3.2 : Enhanced the Ventilation	– Increase number of ventilation and system
	T4 : Life time of Rubber bearing decreased	T4.1 : Enhanced the material property	– E.g. High Damping Rubber Bearing (HDR) for Bridge 
	T5 : Vegetation growth and wildfire problem	T5.1 : Selection of suitable vegetation	
		T5.2 : Increased maintenance activities	
		T5.3 : Increase mow schedule activities	
	T6 : Rail-track deformities 	T6.1 : Widening rail track	
		T6.2 : provided rail expansion Joint material	– Calculate track and gap related to new temperature average and used Zero Longitudinal Restraint for maintain rail joint
		T6.3 : Enhanced systems and technology	– Technology e.g. sensor system – Signals improvement

Potential Climate Change	Infrastructure Impact	Adaptation options	Method/Knowledge
Land Transport			
Temperature increases	**T6 : Rail-track deformities**	T6.4 : Enhanced and improved maintenance procedures	– Enhanced rail track damage indicators standard – Developed temperature maps
		T6.5 : Enhanced rail track material and technique	– Continuous welded method 
		T6.6 : Developed temperatures monitoring system	– To avoid impact to track and reduce deformities effect e.g. limit load during high temperature period
		T6.7 : Development of new, heat-resistant materials	
		T6.8 : Enhanced operation management procedure	– E.g . setting operation and management plan under speed limit condition
	T7 : Insufficient shading at bus stop and terminal /no roof at bus stop	T7.1 : More shading at bus stop/terminal	
		T7.2 : Enhanced the bus stop design	 – New structure design – Installation of fans and air condition – increased number of Ventilations at bus stop

Potential Climate Change	Infrastructure Impact	Adaptation options	Method/Knowledge
Land Transport			
Temperature increases	**T7 : Insufficient shading at bus stop and terminal /no roof at bus stop**	T7.3 : Increased ventilation system performance at terminal	– Applied Green roof technology (white color)  http://www.nicholas.duke.edu/thegreengrok/whiteroofs-revisited
	T8 : Public Transport Facilities damaged/ lifetime decreased	T8.1: Development of new, heat-resistant materials	
		T8.2 : More planting, shading	
Precipitation and Flood	**P1 : More flooding on road and tunnel**	P1.1 : Developed alternative routes and protect vulnerable areas	
		P1.2 : Created "Flood maps"	– Create Blue Spot Model – Developed Geographical Information Systems (GIS)
		P1.3 : Enhanced drainage systems	– Increased frequent clearing of ditches and culverts – increase water drainage infrastructure – Paving ditches to reduce erosion – Developed new drainage capacity standard
		P1.4 : Increased drainage culvert sizing	– Increased the dimension about 20% at least
		P1.5 : Increased pumping at tunnel	
		P1.6 : Increase more lighting/traffic control device reflex efficiency	

Potential Climate Change	Infrastructure Impact	Adaptation options	Method/Knowledge
Land Transport			
Precipitation and Flood	**P2 : More debris in ditches and culverts which decrease drainage performance**	P2.1 : More frequent clearing of ditches and culverts activities	
		P2.2 : Paving ditches	
		P2.3 : Cutting grass and vegetation frequently	
	P3 : drainage system are overloaded	P3.1 : Enhanced drainage infrastructure	– Resizing drainage systems – Reviewing the drainage requirements and audit regularly
		P3.2 : Increasing standard of drainage capacity improvement	– Increasing capacity about 20% – Enhanced pumping – Improve flood plain management
		P3.3 : protect the importance infrastructure	
	P4 : Subgrade material degraded more rapidly, loosing road strength and bearing capacity	P4.1 : Enhanced drainage infrastructure performance to reduce subgrade absorption	
		P4.2 : More frequent maintenance	
		P4.3 : Subgrade material Monitoring, especially during storm or flooding situation	
		P4.4 : developed subgrade material qualification and standard	

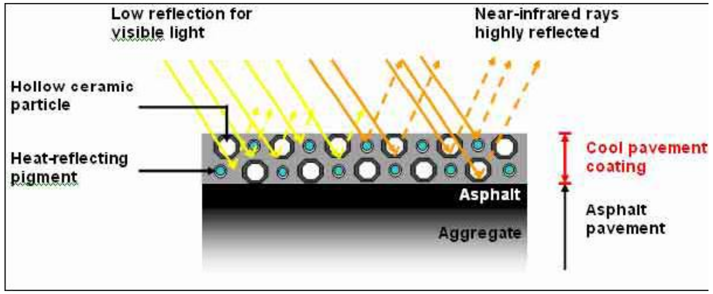
Potential Climate Change	Infrastructure Impact	Adaptation options	Method/Knowledge
Land Transport			
Precipitation and Flood	**P5 : Road infrastructure more erosion, life time deceased**	P5.1 : Monitoring system and technology development	– Inspecting infrastructure before and after flooding events – Install monitoring system at risk area – Install monitoring system at bridge piers and abutments
		P5.2 Construction materials standard development	– Revising design
		P5.3 : More frequent maintenance	
		P5.4 : protect importance infrastructure	– Bridge piers and abutments protective 
	P6 : Bridge joint degraded more rapidly	P6.1 : Monitoring system and technology development	– Monitoring water resistant equipment at bridge joint
		P6.2 : Construction materials standard and qualification development	
		P6.3 : More frequent maintenance	
	P7 : Road damages due to erosion, landslides	P7.1 : Cutting back the side slope to a shallower angle	
		P7.2 : Construct slope retention	 slope retention

Potential Climate Change	Infrastructure Impact	Adaptation options	Method/Knowledge
Land Transport			
Precipitation and Flood	**P7 : Road damages due to erosion, landslides**	P7.3 : Increased sub-surface drainage capacity and roadside drainage performance	
		P7.4 : Created new monitoring method	- Create Mapping landslide - Flood map real time monitoring system - Restrict developments in high-risk areas - Preparing Emergency planning and evacuation routes in high-risk areas
	P8 : Traffic control device and road infrastructure damaged and shorter life time	P8.1: Protect traffic control device and lighting system	
		P8.2: Modified the material and equipment of devices to prevent rain/water	- Developed waterproof material/equipment
		P8.3 : More frequent maintenance	
	P9 : Lost of Track ballast and rail track damaged due to flood event	P9.1 : Construction overpass track at frequently flooding area	
		P9.2 : Rail track protective	
		P9.3 : Reserve track maintenance material , especially on heavy raining and storm occur	
		P9.4 : Monitoring and technology development	- Erosion monitoring system at risk area

Potential Climate Change	Infrastructure Impact	Adaptation options	Method/Knowledge
Land Transport			
Precipitation and Flood	**P10 : Rail track damaged, out of service**	P10.1 : Construction overpass track at frequent flooding area	
		P10.2: Monitoring and technology development	– Erosion monitoring system at risk area – Preparing the maintenance plan and operation e.g. operators , equipment and material , especially on heavy raining and storm occur
		P10.3: Reroute (Extreme case)	
	P11 :Obstruction of rail track due to flood/storm	P11.1: Improved the maintenance plan and operation , especially on heavy raining and storm occur	– e.g. operators , equipment and material
		P11.2: Provide adequate equipment to remove obstruction from track	
		P11.3: Temporary change mode of transport	
	P12 :More risk of emergency evacuation	P12.1: Prepare the emergency evacuation plan at risk area	
		P12.2: Evacuation route protective	
	P13 : Roof of bus stop insufficient to protect public transport users	P13.1 : Enhanced , redesign the structure and roof of bus stop	
	P14 : Footpath unsafe	P14.1 : Extend footpath paving friction	
	P15 : Public transport users Difficulty access to bus stop/terminal	P15.1 : Enhanced the design of bus stop /terminal	
		P15.2 : More shading	

Potential Climate Change	Infrastructure Impact	Adaptation options	Method/Knowledge
Water Transport			
Temperature increases	**T9 : Affect to water transport due to level of water decreased**	T9.1: Reroute /convert to another transport mode	
		T9.2 : Increased port, raise level of port and facilities	
		T9.3 : Provided new port	
Precipitation and Flood	**P16: Grout cumulative, affect to depth of waterway and navigation**	P16.1 : Raise level of bridge and relate structure	
		P16.2 : Dredging waterway	
		P16.3 : Reroute / covert to another transport mode	
		P16.3 : Provided new port	
	P17: Gap between vessel and bridge decreased due to level of water	P17.1 : Raise level of bridge and relate structures	
		P17.2 : Dredging waterway	
		P17.3 : Provided new port	
	P18: Infrastructure and facilities degraded more rapidly, life time decreased	P18.1 : protect port infrastructure from flood/ waves	- Raise level of bridge and relate structures - Construct the jetties and wall to protect port  Jetties
		P18.2 : Enhanced , redesign the standard of infrastructure	
		P18.3 : Strengthen port structure to protect storm surge and waves	
		P18.4 : Established structure which protect terminal/cargo	

Potential Climate Change	Infrastructure Impact	Adaptation options	Method/Knowledge
Water Transport			
Precipitation and Flood	**P19: Port and infrastructure damaged**	P19.1 : Strengthen port structure to protect storm surge and waves	- Raise level of bridge and relate structures - Construct the jetties and wall to protect port  Jetties
		P19.2 : Established structure which protect terminal and cargo	
Air Transport			
Temperature increases	**T10: Runway Concrete Pavement joint expansion**	T10.1 : material standard development	- Delastic® Preformed Pavement Seals  
	T11: High temperature in Aircraft Storage	T11.1 : Construction material improvement	
		T11.2 : Enhanced ventilation system / Increasing fans	
		T11.3 : Enhanced roof design	- Green Roof design technology  

Potential Climate Change	Infrastructure Impact	Adaptation options	Method/Knowledge
Air Transport			
Temperature increases	**T12: Deflection of Runway asphalt pavement and concrete**	T12.1 : Enhanced pavement material property	– Provide coating pavement to reflect light  – Adding anti-oxidation in asphalt
		T12.2 : Developed new standard and technology	– Cool pavement technology – Sustainable Concrete Pavements Technique
	T13 : Aircraft need more length of runway due to high temperature effect	T13.1 : Runway length extension	– More High temperature will reduce air density affect to aircraft performance
		T13.2 : Weight limit restrict	
		T13.3 : Prepared/enhanced aircraft which more engine power performance	

Potential Climate Change	Infrastructure Impact	Adaptation options	Method/Knowledge
Air Transport			
Precipitation and Flood	**P20 : Flooding on runway**	P20.1 : Raise runway level	
		P20.2 : Increased sub-surface drainage capacity and roadside drainage performance	
	P21 : The terminal and facilities damaged	P21.1 : Increased the capacity of drainage	
		P21.2 : Strengthen the terminal and other structure	
	P22 : Drainage system inadequate, system are overloaded	P22.1 : Increased the capacity of drainage	
		P22.2 : Runway drainage performance development	

5.3 Vehicle

Vehicle is the one significant fundamental of transportation system. The impact of High temperature and Precipitation or Flood to vehicle is decline every various area in Thailand. The detail of adaptation options and knowledge as follow :

Potential Climate Change	Vehicle Impact	Adaptation options	Method/Knowledge
Temperature increases	**T14 : vehicle (car) degraded more rapidly, life time decreased** due to high temperate effect related to heat of engine	T14.1 : More frequent maintenance ,especially cooling system and wheel	
		T14.2 : Developed the vehicle which high temperature resistant , especially vehicle tire	
		T14.3 : Improving the window vehicle film standard relate to light intensity	
	T15 : Color of vehicle degraded more rapidly, life time decreased	T15.1 : Developed new color product	– Convert to sticker in some cases – Product which more reflect UV property
		T15.2 : Applied product which protect color of vehicle	
	T16 : Wasted more fuel/energy	T16.1 : The management strategy improvement	– Improving service time table – Maintain air condition temperature relate to time period and passengers
		T16.2 : Developed new technology to saving energy	– Alternate energy/fuel
	T17: Train degraded more rapidly, life time decreased	T17.1 : Vehicle storage improvement	– E.g. improving roof of storage building
		T17.2 : Public transport vehicle e.g. Bus, train design improvement	– The aerodynamic design of train Exterior – Improved Air Filtering – Improved Exterior equipment – More window film to reflect UV

Potential Climate Change	Vehicle Impact	Adaptation options	Method/Knowledge
Precipitation and Flood	**P23 : Structure of vehicle degraded more rapidly, life time decreased**	P23.1 : Undercoating	
		P23.2 : More frequent maintenance	
	P24 : Vehicle parts degraded more rapidly, life time decreased	P24.1 : More frequent maintenance relate to flood situation	
	P25 : Break system and power system performance decreased	P25.1 : More frequent maintenance relate to flood situation	
		P25.2 developed emergency maintenance help center	
	P26 : Waste more maintenance cost due to flood situation	P26.1 Flood Emergency planning and evacuation routes at high-risk areas	
		P26.2 published information during flooding situation	

5.4 Road Users

The impact of High temperature and Precipitation or Flood to infrastructure is decline and affect to all groups of road users including private car users, public transport users and pedestrian. The detail of adaptation options and knowledge to developed the management and strategy related to road users as follow :

Potential Climate Change	Road users Impact	Adaptation options	Method/Knowledge
Public transport users			
Temperature increases	**T18 : Public transport users decreased**	T18.1 Public transport and network development	
		T18.12 : Infrastructure and facilities improvement	– Green building design – Green roof and roof design technology
	T19 : Users feel uncomfortable due to heat wave /affect to Users healthy	T19.1 : Install air condition in public transport vehicle and terminal	
		T19.2 : Improved ventilation system and shading	– Plants trees at bus stop ,terminal and walk way – Shading at bus stop and walk way
		T19.3 : Provided specific bus lane	
	T20 : Public transport users convert to used car due to uncomfortable	T20.1 : Private car limit policy	– Limit new private car license policy – Tax policy
		E T20.2 : Encourage and promote alternate transport mode e.g. bicycle	– Provided bicycle way and infrastructure
		T20.3 : Public education , campaign the alternate mode e.g. bus, train, bicycle (city)	
		T20.4 : Public transport ticket policy	– Integrated ticketing – Price policy

Potential Climate Change	Road users Impact	Adaptation options	Method/Knowledge
Public transport users			
Precipitation and Flood	**P27 : Users feel uncomfortable due to raining/flooding and users decreased**	P27.1 : Changing time table relate to situation	
		P27.2 : Reroute	
		P27.3 : Published information to users	
	P28 : Public transport users convert to used alternate transport mode due to flood situation	P28.1 : Changing time table relate to situation	
		P28.2 : Reroute	
		P28.3 : Published information to users	
	P29 : Public transport users increased during flood	P29.1 : Increasing bus/train and operators relate to situation	
		P29.2 : Extend service time and increased round trip	
	P30 : Insufficient public transport fuel (during flood)	P30.1 : fuel transport reroute relate to situation	
		P30.2 : Temporary change garage position	

Potential Climate Change	Road users Impact	Adaptation options	Method/Knowledge
Private car users			
Temperature increases	**T_{21} : vehicle failure due to heat affect to traffic and accident**	T_{21}.1 : GPS and TMC systems to represent Real-time traffic information	
		T_{21}.2 : Vehicular Communication to inform incident and travel delay	
		T_{21}.3 : Traffic Sign Recognition	
		T_{21}.4 : Braking and Stability Control Assistance	
	T_{22} : Wasted more fuel/energy	$T_2$2.1 : Saving energy strategy	– Eco-Car – Government campaign – Public transport encourage
	T_{23} : bicycle rider feel uncomfortable due to heat	$T_2$3.1 : Shading at bicycle way	
		$T_2$3.2 : Plant trees	
		$T_2$3.3 : Improving the attractiveness along roadside	
	T24: Private car users feel stress due to heat and traffic	$T_2$4.1 : Increased more stop point and facilities	

Potential Climate Change	Road users Impact	Adaptation options	Method/Knowledge
Private car users			
Precipitation and Flood	**P31 : More incident**	P31.1 : Road marking improvement and increase lighting	
		P31.2 : Increased the emergency service operators	
	P32 : Wasted more fuel/energy	P32.1 : Saving energy strategy	- Eco-Car - Government campaign - Public transport encouragement
	P33 : private car users travel trouble in flood situation	P32.1 : GPS and TMC systems to represent Real-time traffic information	
		P32.2 : Vehicular Communication to inform incident and travel delay	
		P32.3 : Published information to users	
	P34 : Insufficient parking during flood situation	P34.1 : Provide emergency parking area	
		P34.2 : Published information to users	

5.5 Traffic and Transport

The impact of High temperature and Precipitation or Flood to traffic and transport is decline and affect to the operation of and transport via road rail water and air transport mode. The detail of adaptation options and knowledge to developed the management and strategy related to road users are as follow

Potential Climate Change	Traffic and Impact	Adaptation options	Method/Knowledge
Land transport			
Temperature increases	**T25 : More traffic jam and incident**	T25.1 : Public transport encouragement	
		T25.2 **:** Developed the Intelligent Transport System (ITS)	– E.g. Automatic Traffic Control (ATC)
		T25.3 : Provide adequate emergency service operators , facilities	
	T26 : Rail transport more delay	T26.1 : Published information to users	
		T26.2 : The weather information notification improvement	
		T26.3 : Increased round trip	
Water transport			
Temperature increases	**T27 : Affect to water transport due to level of water decreased**	T27.1 : Weight Limit policy	
		T27.2 : Reroute	
		T27.3 : Increased vessels	
		T27.4 : Change mode	
Air transport			
Temperature increases	**T28 : Flight delay due to heat (air transport)**	T28.1 : Limit weight policy	
		T28.2 : Cancelled flight (Extreme case)	

Potential Climate Change	Traffic and Impact	Adaptation options	Method/Knowledge
Land transport			
Precipitation and Flood	**P35 : Transport delay**	P35.1 : Convert to another transport mode	
		P35.2 : Created flood map/ indentify flood pains area	– Create Blue Spot Model – Developed Geographical Information Systems (GIS) 
	P36 : Affect to current maintenance activities and safety	P36.1 : Improving hazardous location	
		P36.2 : Increase more lighting/traffic control device reflex efficiency	
		P36.3 : Cutting back the side slope to a shallower angle	
		P36.4 : Landslide monitoring at risk area	
		P36.5 : Protect traffic control device and lighting system	
		P36.6 : Cutting grass and vegetation frequently	
		P36.7 : Increased the capacity of drainage	– Increased frequent clearing of ditches and culverts – increase water drainage infrastructure – Paving ditches to reduce erosion – Increased the dimension of culvert about 20% at least
		P36.8 : More frequent maintenance and monitoring	

Potential Climate Change	Traffic and Impact	Adaptation options	Method/Knowledge
Land transport			
Precipitation and Flood	**P37 : Flooding affect to rail transport**	P37.1 : Provide structure to protect rail track	
		P37.2 : Published information to users	
Water transport			
Precipitation and Flood	**P38: Grout cumulative, affect to depth of waterway and navigation**	P38.1 : Limit weight of shipping	
		P38.2 : Dredging water way	
		P38.3 : Reroute / covert to another transport mode	
Air transport			
Precipitation and Flood	**P39 : Out of service**	P39.1 : Created emergency flooding plan	
		P39.2 : Published information to users	
		P39.3 : Provided facilities at airport for users during situation	
	P40 : Affect to current maintenance activities and safety	P40.1 : Increased maintenance schedule activities and operators , especially heavy rain and flooding	
		P40.2 : Published information to users	
		P40.3 : Improving the Information notification system	
		P40.4 : Created/improved emergency plan	

5.6 Construction

Construction procedure obtain the impact of High temperature and Precipitation or Flood including schedule of construction , method of construction and material transport to construction site. The detail of adaptation options and knowledge related to Construction procedure are as follow

Potential Climate Change	Construction Impact	Adaptation options	Method/Knowledge
Temperature increases	**T29 : The mixture loosing water due to heat**	T29.1 : Developed the mixture property or material specification relate to temperature	
		T29.2 : Monitoring Moisture level of mixture	
		T29.3 : Spray water to construction material and subsurface before concrete pavement construction procedure	
	T30: Performance of pavement structure decreased	T30.1 : Mixture property or material specification Development relate to temperature	
		T30.2 : Improving construction procedure and method	
	T31 : Worker performance decreased due to heat affect to health	T31.1: shifting periods of construction activity	- Improving Schedule work to avoid peak daytime - Shift schedule of transport construction material on nighttime
	T32 : Construction material and equipment lifetime decreased	T32.1: Provide storage or building	

Potential Climate Change	Construction Impact	Adaptation options	Method/Knowledge
Temperature increases	**T33 : Affect to material and equipment storage**	T33.1: Reduce stock	– Balance stock and construction activity – Logistics /Supply chain knowledge 
		T33.2: ventilation system / Increasing fans at storage	
	T34 : Construction delay (rail track)	T34.1: Improving construction plan relate to weather and temperature	
		T34.2: Obtain water/ice to reduce temperature of track during construction	
		T34.3: Install track relate to current temperature	
Precipitation and Flood	**P41 : Construction process delay or stop (extreme case)**	P41.1 : construction plan Improvement	– Extend construction period, consider raining and flooding occur – Improving construction plan relate to weather and temperature
		P41.2 : The construction material transport reroute / new plant or sources	
		P41.3 : Protect construction material/lift up during heavy rain/flooding situation	

Potential Climate Change	Construction Impact	Adaptation options	Method/Knowledge
Precipitation and Flood	**P41 : Construction process delay or stop (extreme case)**	P41.4 : Extend period of construction contract	
		P41.5 : Modulate penalty policy	
		P41.6 : Monitoring weather forecast , improve the construction planning	
	P42: Insufficient material due to manufacture and transport affect from flooding/ unable to deliver	P42.1 : Improving construction plan relate to weather and temperature condition	
		P42.2 : The construction material transport reroute / new plant or sources	
		P42.3 : Balance stock and construction activity	- Logistics /Supply chain knowledge
		P42.4 : Protect construction material/lift up during heavy rain/flooding situation	
		P42.5 : Modulate penalty policy under flooding situation	
	P43 : Complicated Construction procedure at raining weather	P43.1 : Applied construction method	- e.g. Modular construction
		P43.2 : Avoid the construction on raining season	

Potential Climate Change	Construction Impact	Adaptation options	Method/Knowledge
Precipitation and Flood	**P44: Material and equipment storage damaged due to flooding**	P44.1 : Provided building/storage to protect Material and equipment	
		P44.2 : Provided truck /vehicle to move Material and equipment , especially on heavy raining or flooding	
		P44.3 : Provided reserve storage	

5.7 Operation

The impact of High temperature and Precipitation or Flood affect to transport operation. including routine operation of operators , operators performance, operator's health and safety. The detail of adaptation options and knowledge related to Construction procedure are as follow

Potential Climate Change	Operation Impact	Adaptation options	Method/Knowledge
Temperature increases	**T35 : Affect to health of traffic police due to heat wave**	T35.1 : Provided facilities and rest location for operators	
		T35.2 : Improving traffic police uniform relate to weather	
		T35.3 : Enhanced transport technology to reduce traffic police responsibility	– Intelligent Transport System (ITS) – Automatic Traffic Control (ATC)
Precipitation and Flood	**P45 : Performance of operator decreased /operator get stress**	P45.1 : Increased operators during flooding	
		P45.2 : Provided adequate equipment	
	P46 : More mission	P46.1 : Increased operators during flooding	
		P46.2 : Establish call center	
		P46.3 : Establish operator training program for flooding situation	

5.8 Expert comment and recommendation

The adaptation knowledge which gather from theories, standards, practices, researches are represent to expert in various related field in Thailand. As the evidence of current climate change Phenomenon the experts are agree with the Initiated transport adaptation in Thailand. The expert are examine the conclusion of adaptation options and gave additional suggestion in 3 section of transport, there are land transport water transport and air transport. The detail are as follow:

5.8.1 Land Transport

Authorities Management and road users issues

- Thailand transport authorities should developed the public transport system and infrastructure. The travel time of public transport must consistent and especially users safety concern.
- Public transport infrastructure and facilities should mostly comfortable attract users , for instance created bus lane and applied the ITS privilege to public transport users
- Public transport reroute and improve time table
- Widening rail track and improving train
- Limit private car restrict policy
- Increase lighting and improved reflex property of traffic control device at frequently heavy raining area/ flooding
- Improved construction method and schedule relate to situation concern (e.g. heat, raining season, flooding)
- Increased the emergency service operators at risk area
- Developed flooding and emergency evacuation plan
- Increased Public relations and public education

Technology and energy issues

- Create “flood map” and developed blue spot model
- Create GPS and TMC systems to represent Real-time traffic information
- Create Vehicular Communication system to inform incident and travel delay
- Create Traffic Sign Recognition system
- Create Braking and Stability Control Assistance system
- Encourage energy saving options (e.g. eco car)
- Applied ITS technology
- Developed heat resistant material and infrastructure facilities

Freight transport issues

- Shift from road transport to rail /water transport
- Created cargo distribution center
- Widening rail track and improving train
- Improving rail transport infrastructure

5.8.2 Water Transport

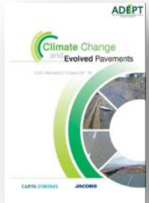
- Dredging waterway
- Embankment paving
- In case of depth of waterway and navigation are vary by Grout cumulative, operators/users should shift to another transport mode (extreme case)

5.8.3 Air Transport

- Improved standard of limit weight relate to temperature concern
- Extend runway length (extreme case)

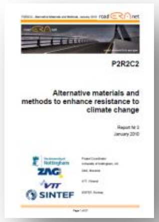
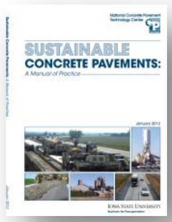
5.9 Adaptation options and sources of knowledge

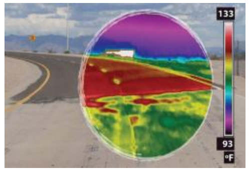
The suggestion of experts can clarify the adaptation options which suitable to implement for developed the transport adaptation framework and suggested to Thailand transport authorities. Furthermore, there are adaptation options and sources of knowledge, the detail in as follow:

Transportation System effect	Adaptation options	method	reference	page
T1 : Asphalt Pavement: Crack, Rutting, etc.	T1.1 : Improve Asphalt property	– Hot Rolled Asphalt Surf 40/60 standard	Climate Change and Evolved Pavements, ADEPT 	97
		– Thin pavement construction method	Best Practice Guide for Durability of Asphalt pavements, TRL 	
		– Hot Rolled Asphalt standard 910 at low volume road and 911, 943 for more risk	Manual of Contract Documents for Highway Works Volume 1 Specification for Highway Works Series 900 	7,27

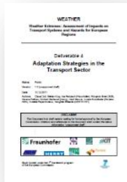
Transportation System effect	Adaptation options	method	reference	page
T1 : Asphalt Pavement: Crack, Rutting, etc.	T1.1 : Improve Asphalt property	– Applied bond coats to reduce voids at layer	Climate Change and Evolved Pavements, ADEPT	98
		– Applied Cool pavement technology		
		– Add anti-oxidation in asphalt mix	Future rehabilitation & cost-benefit study of alternative solution, July 2010 Road research in Europe 	15

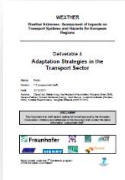
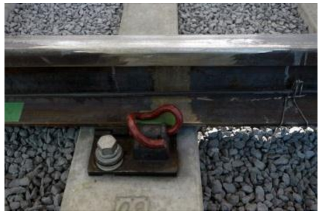
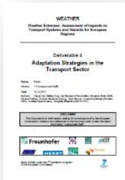
Transportation System effect	Adaptation options	method	reference	page
T1 : Asphalt Pavement: Crack, Rutting, etc.	T1.1 : Improve Asphalt property	– Used porous asphalt and asphalt-rubber	Future rehabilitation & cost-benefit study of alternative solution, July 2010 Road research in Europe	15
		– Used coating above pavement	Future rehabilitation & cost-benefit study of alternative solution, July 2010 Road research in Europe	17
		– Applied polymer Substances in pavement mixture to avoid rutting	Deliverable 4 Adaptation Strategies in the Transport Sector , the European Commission, 2011 	62
	T1.2 : Enhanced New Design Standard	1. Applied MEPDG or Mechanistic-Empirical Pavement Design Guide and created Enhanced Integrated Climate Model (EICM) to predict temperature and climate change situation	The Implications of Climate Change on Pavement Performance and Design, Qiang Li et al 	22-27
			Mechanistic-Empirical Pavement Design Guide, NCHRP 	

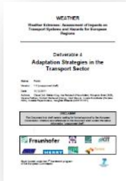
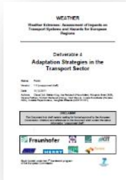
Transportation System effect	Adaptation options	method	reference	page
T1 : Asphalt Pavement: Crack, Rutting, etc.	T1.3 : Research and study for new technology and method	Created Enhanced Integrated Climate Model (EICM) and predict cost/benefit of adaptation options	Pavement Management Roadmap, FHWA, 2010 	
		Alternative materials study	Alternative materials and methods to enhance resistance to climate change, July 2010, Road research in Europe 	17
	T1.4 : Convert to concrete pavement	Convert asphalt pavement to concrete pavement at some area/redesign	Sustainable Concrete Pavements: A Manual of Practice, IOWA State University,2012 	

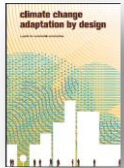
Transportation System effect	Adaptation options	Method/knowledge	Reference	page
T1 : Asphalt Pavement: Crack, Rutting, etc.	T1.4 : Convert to concrete pavement	Concrete pavement are lower temperature than asphalt pavement	Concrete pavement research and technology special report, American Concrete Pavement Association, 2007 	
		Reduced rutting problem	Climate Change Impacts and Adaptation: A Canadian Perspective, Government of Canada, 2004	143
T2 : Concrete joint expansion	**Concrete joint expansion**	Developed and Enhanced concrete joint material property	Deliverable 4 Adaptation Strategies in the Transport Sector , the European Commission, 2011  	67
		Sustainable Concrete Pavements Technique	Sustainable Concrete Pavements: A Manual of Practice, IOWA State University,2012 	

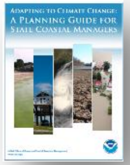
Transportation System effect	Adaptation options	Method/knowledge	Reference	page
T3 : Life time of traffic control device decreased	T3.1 : Developed and Enhanced material property	Enhanced material property	Deliverable 4 Adaptation Strategies in the Transport Sector , the European Commission, 2011 	69
	T3.2 : Enhanced the Ventilation	Increase number of ventilation and system	Deliverable 4 Adaptation Strategies in the Transport Sector , the European Commission, 2011 	69(road),71 (rail)
T4 : Life time of Rubber bearing decreased	T4.1 : Enhanced the material property	High Damping Rubber Bearing (HDR) for Bridge	 http://www.bridgestone.com/products/diversified/antiseismic_rubber/hdr.html	

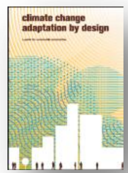
Transportation System effect	Adaptation options	Method/knowledge	Reference	page
T 5 : Vegetation growth and wildfire problem	T5.1 : Selection of suitable vegetation		Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies, UNEP, 1998 	8-37
	T5.2 : Increased maintenance activities		Deliverable 4 Adaptation Strategies in the Transport Sector , the European Commission, 2011 	68
	T5.3 : Increase mow schedule activities		Climate Change Adaptation, ROADEX, 2012 	88

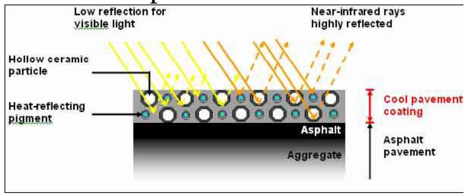
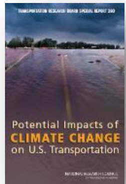
Transportation System effect	Adaptation options	Method/knowledge	Reference	page
T6 : Rail-track deformities	T6.4 : Enhanced and improved maintenance procedures	Enhanced rail track damage indicators standard	Deliverable 4 Adaptation Strategies in the Transport Sector , the European Commission, 2011 	71-
		Developed temperature maps	Adapting Urban Transport to Climate Change, GTZ,2009 	14
	T6.5 : Enhanced rail track material and technique	Continuous welded method 	Deliverable 4 Adaptation Strategies in the Transport Sector , the European Commission, 2011 	71, 79

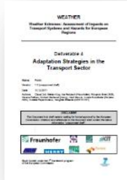
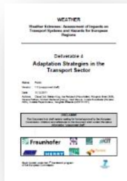
Transportation System effect	Adaptation options	Method/knowledge	Reference	page
T6 : Rail-track deformities	T6.6 : Developed temperatures monitoring system	To avoid impact to track and reduce deformities effect e.g. limit load during high temperature period	Deliverable 4 Adaptation Strategies in the Transport Sector , the European Commission, 2011 	71
	T6.7 : Development of new, heat-resistant materials		Deliverable 4 Adaptation Strategies in the Transport Sector , the European Commission, 2011 	71
	T 6 . 8 : Enhanced operation management procedure	E.g . setting operation and management plan under speed limit condition	Adapting Urban Transport to Climate Change, GTZ,2009 	14

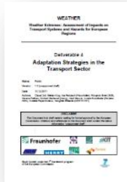
Transportation System effect	Adaptation options	Method/knowledge	Reference	page
T7 : Insufficient shading at bus stop and terminal /no roof at bus stop	T7.2 : Enhanced the bus stop design	New structure design Installation of fans and air condition increased number of Ventilations at bus stop	  Deliverable 4 Adaptation Strategies in the Transport Sector , the European Commission, 2011	57-58
T8 : Public Transport Facilities damaged/ lifetime decreased	T8.1: Development of new, heat-resistant materials		Climate change adaptation by design a guide for sustainable communities, TCPA, 2007 	22
			Adapting to Climate change impact – A good practices guide for sustainable communities, South-East Climate Change Partnership, London Climate Change Partnership, Sustainable Development Round Table for East of England, 2006 	38

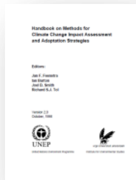
Transportation System effect	Adaptation options	Method/knowledge	Reference	page
T8 : Public Transport Facilities damaged/ lifetime decreased	T8.2 : More planting, shading		London's Commercial Building Stock and Climate Change Adaptation Design, Finance and Legal Implications, London Climate Change Partnership, 2009 	27
T9 : Affect to water transport due to level of water decreased	T9.1: Reroute /convert to another transport mode		Adapting Urban Transport to Climate Change, GTZ,2009 	16
	T9.2 : Increased port, raise level of port and facilities		Adapting to Climate Change: A Planning Guide for State Coastal Managers, NOAA Office of Ocean and Coastal Resource Management, 2010 	51 ,73, 76, 85-93

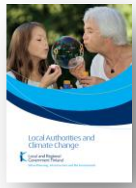
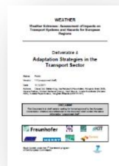
Transportation System effect	**Adaptation options**	**Method/knowledge**	**Reference**	**page**
T11: High temperature in Aircraft Storage	T11.2 : Enhanced ventilation system	Increasing fans	London's Commercial Building Stock and Climate Change Adaptation Design, Finance and Legal Implications, London Climate Change Partnership, 2009 	27
	T11.3 : Enhanced roof design		Climate change Adaptation for Building Designers : An Introduction, EDG, 2011 	5
			Climate change adaptation by design a guide for sustainable communities, TCPA, 2007 	22

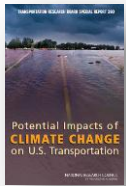
Transportation System effect	Adaptation options	Method/knowledge	Reference	page
T12: Deflection of Runway asphalt pavement and concrete	T12.1 : Enhanced pavement material property	Provide coating pavement to reflect light	Future rehabilitation & cost-benefit study, July 2010 , Road research in Europe 	17
		Adding anti-oxidation in asphalt	Future rehabilitation & cost-benefit study, July 2010 , Road research in Europe 	15
T13 : Aircraft need more length of runway due to high temperature effect	T13.1 : Runway length extension T13.2 : Weight limit restrict T13.3 : Prepared/enhanced aircraft which more engine power performance	More High temperature will reduce air density affect to aircraft performance	Potential Impacts of CLIMATE CHANGE on U.S. Transportation, TRB, 200 	ANNEX 5-1C

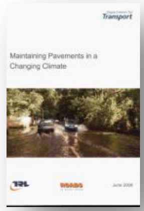
Transportation System effect	Adaptation options	Method/knowledge	Reference	page
T14 : vehicle (car) degraded more rapidly, life time decreased due to high temperate effect related to heat of engine	T14.1 : More frequent maintenance ,especially cooling system and wheel		Deliverable 4 Adaptation Strategies in the Transport Sector , the European Commission, 2011 	131-132
	T14.2 : Developed the vehicle which high temperature resistant , especially vehicle tire		Adapting Urban Transport to Climate Change, GTZ, 2009 	16-18
			Deliverable 4 Adaptation Strategies in the Transport Sector , the European Commission, 2011 	132

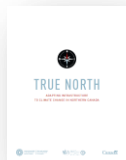
Transportation System effect	Adaptation options	Method/knowledge	Reference	page
T16 : Wasted more fuel/energy	T16.1 : The management strategy improvement	Maintain air condition temperature relate to time period and passengers	Deliverable 4 Adaptation Strategies in the Transport Sector , the European Commission, 2011 	119,130
	T16.2 : Developed new technology to saving energy	Alternate energy/fuel	Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies, UNEP, 1998 	Chapter 11
T17: Train degraded more rapidly, life time decreased	T17.2 : Public transport vehicle e.g. Bus, train design improvement	The aerodynamic design of train Exterior Improved Air Filtering Improved Exterior equipment More window film to reflect UV	Deliverable 4 Adaptation Strategies in the Transport Sector , the European Commission, 2011 	125-127

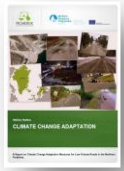
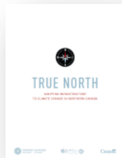
Transportation System effect	Adaptation options	Method/knowledge	Reference	page
T18 : Public transport users decreased	T18.12 : Infrastructure and facilities improvement	Green roof and roof design technology	London's Commercial Building Stock and Climate Change Adaptation Design, Finance and Legal Implications, London Climate Change Partnership, 2009 	27
T19 : Users feel uncomfortable due to heat wave /affect to Users healthy	T19.2 : Improved ventilation system and shading	Plants trees at bus stop ,terminal and walk way Shading at bus stop and walk way	Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies, UNEP, 1998 	10-27
	T19.3 : Provided specific bus lane		Adapting Urban Transport to Climate Change, GTZ, 2009 	16-18

Transportation System effect	Adaptation options	Method/knowledge	Reference	page
T20 : Public transport users convert to used car due to uncomfortable	T20.1 : Private car limit policy	Limit new private car license policy Tax policy	Local Authorities and Climate Change, Local and Regional Government Finland 	13
	T20.3 : Public education	campaign the alternate mode e.g. bus, train, bicycle (city)	Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies, UNEP, 1998 	10-27
T21 : vehicle failure due to heat affect to traffic and accident	T21.1 : GPS and TMC systems to represent Real-time traffic information T21.2 : Vehicular Communication to inform incident and travel delay T21.3 : Traffic Sign Recognition T21.4 : Braking and Stability Control Assistance		Deliverable 4 Adaptation Strategies in the Transport Sector , the European Commission, 2011 	115-119

Transportation System effect	Adaptation options	Method/knowledge	Reference	page
T23 : bicycle rider feel uncomfortable due to heat	T23.1 : Shading at bicycle way		Adapting Urban Transport to Climate Change, GTZ,  2009	18-20
T25 : More traffic jam and incident	T25.1 : Public transport encouragement		Adapting Urban Transport to Climate Change, GTZ, 2009	16-18
T27 : Affect to water transport due to level of water decreased	T27.3 : Increased vessels		Deliverable 4 Adaptation Strategies in the Transport Sector , the European Commission, 2011	175
T28 : Flight delay due to heat (air transport)	T28.1 : Limit weight policy		Potential Impacts of CLIMATE CHANGE on U.S. Transportation, TRB, 200 	ANNEX 5-1C
	T28.2 : Cancelled flight (Extreme case)		Potential Impacts of CLIMATE CHANGE on U.S. Transportation, TRB, 200	ANNEX 5-1C

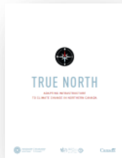
Transportation System effect	Adaptation options	Method/knowledge	Reference	page
T29 : The mixture loosing water due to heat	T29.1 : Developed the mixture property or material specification relate to temperature T29.2 : Monitoring Moisture level of mixture T29.3 : Spray water to construction material and subsurface before concrete pavement construction procedure		Maintaining Pavements in a Changing Climate, Department for Transport , 2008 	42-48
T31 : Worker performance decreased due to heat affect to health	T31.1: shifting periods of construction activity	Improving Schedule work to avoid peak daytime Shift schedule of transport construction material on nighttime	Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies, UNEP, 1998 	10-27
T32 : Construction material and equipment lifetime decreased	T32.1: Provide storage or building		London's Commercial Building Stock and Climate Change Adaptation Design, Finance and Legal Implications, London Climate Change Partnership, 2009	27

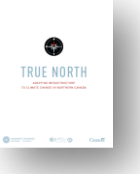
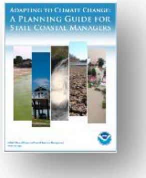
Transportation System effect	Adaptation options	Method/knowledge	Reference	page
P1 : More flooding on road and tunnel	P1.1 : Developed alternative routes and protect vulnerable areas		Adapting Urban Transport to Climate Change, GTZ, 2009	11
	P1.2 : Created "Flood maps"	Create Blue Spot Model Developed Geographical Information Systems (GIS)	Climate Change Adaptation, ROADEX, 2012 	91
	P1.3 : Enhanced drainage systems	Increased frequent clearing of ditches and culverts increase water drainage infrastructure	Adapting Urban Transport to Climate Change, GTZ, 2009	11
		Paving ditches to reduce erosion Developed new drainage capacity standard	Adaptive Infrastructure to Climate Change in Northern Canada, National Round Table on the Environment and the Economy, 2009, 	74
	P1.4 : Increased drainage culvert sizing	Increased the dimension about 20% at least	Deliverable 4 Adaptation Strategies in the Transport Sector , the European Commission, 2011	73

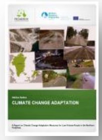
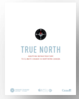
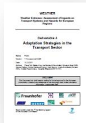
Transportation System effect	Adaptation options	Method/knowledge	Reference	page
P2 : More debris in ditches and culverts which decrease drainage performance	P2.1 : More frequent clearing of ditches and culverts activities P2.2 : Paving ditches P2.3 : Cutting grass and vegetation frequently		Climate Change Adaptation, ROADEX, 2012  Good practice measures (see summary of typical drainage problems and solutions in Appendix 8.4)	91-92
P4 : Subgrade material degraded more rapidly, loosing road strength and bearing capacity	P4.1 : Enhanced drainage infrastructure performance to reduce subgrade absorption P4.2 : More frequent maintenance		Climate Change Adaptation, ROADEX, 2012 Deliverable 4 Adaptation Strategies in the Transport Sector , the European Commission, 2011 Adaptive Infrastructure to Climate Change in Northern Canada, National Round Table on the Environment and the Economy, 2009 	92 73 74

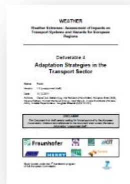
Transportation System effect	Adaptation options	Method/knowledge	Reference	page
P5 : Road infrastructure more erosion, life time deceased	P5.1 : Monitoring system and technology development	Inspecting infrastructure before and after flooding events Install monitoring system at risk area Install monitoring system at bridge piers and abutments	Climate Change Adaptation, ROADEX, 2012 Adapting Urban Transport to Climate Change, GTZ, 2009 Infrastructure, Engineering and Climate Change Adaptation – ensuring services in an uncertain future, The Royal Academy of Engineering, 2011 	92 11
P7 : Road damages **due to erosion, landslides**	P7.4 : Created new monitoring method	Create Mapping landslide Flood map real time monitoring system Restrict developments in high-risk areas Preparing Emergency planning and evacuation routes in high-risk areas	Climate Change Adaptation, ROADEX, 2012 Adapting Urban Transport to Climate Change, GTZ, 2009	93 11

Transportation System effect	Adaptation options	Method/knowledge	Reference	page
P8 : Traffic control device and road infrastructure damaged and shorter life time	P8.2: Modified the material and equipment of devices to prevent rain/water	Developed waterproof material/equipment	Adapting Urban Transport to Climate Change, GTZ, 2009	15
P10 : Rail track damaged, out of service	P10.2: Monitoring and technology development	Erosion monitoring system at risk area Preparing the maintenance plan and operation e.g. operators , equipment and material , especially on heavy raining and storm occur	Adapting Urban Transport to Climate Change, GTZ, 2009 	15
	P10.3: Reroute (Extreme case)		Deliverable 4 Adaptation Strategies in the Transport Sector , the European Commission, 2011	73

Transportation System effect	Adaptation options	Method/knowledge	Reference	page
P11 :Obstruction of rail track due to flood/storm	P11.1: Improved the maintenance plan and operation , especially on heavy raining and storm occur	e.g. operators , equipment and material improvement plan	Deliverable 4 Adaptation Strategies in the Transport Sector , the European Commission, 2011	73
P12 :More risk of emergency evacuation	P12.1: Prepare the emergency evacuation plan at risk area		Adaptive Infrastructure to Climate Change in Northern Canada, National Round Table on the Environment and the Economy, 2009 	74

Transportation System effect	Adaptation options	Method/knowledge	Reference	page
P18: Infrastructure and facilities degraded more rapidly, life time decreased	P18.1 : protect port infrastructure from flood/ waves	Raise level of bridge and relate structures Construct the jetties and wall to protect port  Jetties	Adapting Urban Transport to Climate Change, GTZ, 2009 	11
	P18.2 : Enhanced , redesign the standard of infrastructure		Adaptive Infrastructure to Climate Change in Northern Canada, National Round Table on the Environment and the Economy, 2009  	74
P19: Port and infrastructure damaged	P19.1 : Strengthen port structure to protect storm surge and waves	Raise level of bridge and relate structures Construct the jetties and wall to protect port  Jetties	Adapting to Climate Change: A Planning Guide for State Coastal Managers, NOAA Office of Ocean and Coastal Resource Management, 2010  	75

Transportation System effect	Adaptation options	Method/knowledge	Reference	page
P22 : Drainage system inadequate, system are overloaded	P22.1 : Increased the capacity of drainage		Climate Change Adaptation, ROADEX, 20 	93
			Adapting Urban Transport to Climate Change, GTZ, 2009 	11
	P22.2 : Runway drainage performance development		Adaptive Infrastructure to Climate Change in Northern Canada, National Round Table on the Environment and the Economy, 2009 	74
			Deliverable 4 Adaptation Strategies in the Transport Sector , the European Commission, 2011 	73

Transportation System effect	Adaptation options	Method/knowledge	Reference	page
P26 : Waste more maintenance cost due to flood situation	P26.1 Flood Emergency planning and evacuation routes at high-risk areas		Former Car Garage and Showroom High Street, Williton Flood Evacuation Plan, Aardvark EM Limited , June 2010 	
P29 : Public transport users increased during flood	P29.1 : Increasing bus/train and operators relate to situation P29.2 : Extend service time and increased round trip		Flooded Bus Barns and Buckled Rails: Public Transportation and Climate Change Adaptation , FTA Research, FTA Report No. 0001 	
P33 : private car users travel trouble in flood situation	P32.1 : GPS and TMC systems to represent Real-time traffic information P32.2 : Vehicular Communication to inform incident and travel delay		Deliverable 4 Adaptation Strategies in the Transport Sector , the European Commission, 2011 	115-119

Transportation System effect	Adaptation options	Method/knowledge	Reference	page
P35 : Transport delay	P35.2 : Created flood map/ indentify flood pains area	Create Blue Spot Model Developed Geographical Information Systems (GIS)	Climate Change Adaptation, ROADEX, 2012 Adapting to Climate Change The Public Policy Response Public Infrastructure, James E. Neumann and Jason C. Price, 2009 	91 36
	P36 : Affect to current maintenance activities and safety	Increased frequent clearing of ditches and culverts increase water drainage infrastructure Paving ditches to reduce erosion Increased the dimension of culvert about 20% at least	Adapting Urban Transport to Climate Change, GTZ, 2009 Adaptive Infrastructure to Climate Change in Northern Canada, National Round Table on the Environment and the Economy, 2009, Deliverable 4 Adaptation Strategies in the Transport Sector , the European Commission, 2011	11 74 73
P43 : Complicated Construction procedure at raining weather	P43.1 : Applied construction method	e.g. Modular construction	New Road Construction Concepts , April 2008 	235

Chapter 6
Conclusion

6.1 Introduction

Transportation Infrastructure plays as a key role for national economic development. In 2012, Thailand has about 200,000 km. of highway network, 4,000 km. railroad, 6 international deep sea ports, and 36 airports as summarized in figure 6.1. All transportation infrastructures has been planned, developed and built during past century with a large amounts of investment. Moreover, NESDB, (2012) summarized Thailand's future investment plan for infrastructure development during 2012 -2020 that are USD 72,000 million while 71 percent are invested on tranportation. (see figure 6.2)

Road	National Highway	63,100 km.
	Motorway & Expressway	226 km.
	Rural road	39,254 km.
	Local road	101,845 km.
Water	Total International Deep Sea Port	6
	- Laem Chabang Port	7.7 M TEU/year
Rail	Single Track	3,885 km.
	Double and Third Track	234 km.
Air	Airports	36
	- Suvarnabhumi Airport	45 M ppl/y
	- Don Mueang Airport	36 M ppl/y
	- Phuket Airport	6.5 M ppl/y
	- Chiang Mai Airport	8 M ppl/y

Source: NESBD (2012)

Figure 6.1 Transportation infrastructure of Thailand

Sector	Amount (million USD)	Share (%)
1. Land Transport	46,662	65
2. Air and Marine Transport	4,714	6
3. Energy	15,855	22
4. Telecommunication	1,117	2
5. Utility	3,716	5
Total	72,064	100

Financing source	Amount (million USD)	Share (%)
1. SOEs and Loan	22,905	32
2. PPP	13,124	18
3. Government	36,035	50
Total	72,064	100

Source: NESBD (2012)

Figure 6.2 Investment plan for infrastructure development (2012-2020)

Increasing occurrences of natural disasters as well as change in weather patterns around the globe cause growing concerns on the on-going dreadful climate change phenomenon. Since industrial evolution, the large amount of greenhouse gases (GHGs) has been produced by the human activities. Their impacts would have affected the transport system. IPCC state that "Climate change is a serious and urgent issue" For Thailand evidence, the worst flooding is happened 3 times in 2011. The first flooding began in April 2011 in 10 provinces in southern of Thailand. The damage was severe and wide spread causing the death of 64 people[1]. After that from the end of July 2011 and until mid of January 2012, the second flooding was occurred in the lower Chao Phraya river basin resulting in a total of 884 deaths and 13.6 million people affected. The World Bank has estimated 1,425 billion baht (USD 45.7 Billion) in economic damages and losses due to flooding, as of 1 December 2011[2,3]. And the last occurred in the Southern of Thailand during November and December 2554 causing 10 deaths.[3]

According to AON Benfield report the transportation infrastructure sustained major damage during the floods, with a high number of roads and bridges having been flooded or washed away. The Department of Highways and the Department of Rural Roads reported that parts of 1,700 roads, highways and bridges were damaged or destroyed. The economic cost to roadways alone was listed at THB139.0 billion (USD 4.5 billion). Airports around Thailand were also hit, including in Bangkok. The city's secondary airport (Don Mueang) was forced to close in October 2011 after floodwater crept into the main terminal building and also over the facility's runways. The airport was re-opened to commercial flights in March 2012, after the eastern runway needed repairs. The president of Airports of Thailand reported that approximately THB150.0 million (USD 4.8 million) was necessary to repair the runway. Train services were also disrupted as rail tracks were left submerged or washed away on multiple routes.

The happening above affects the travel of people, transport and logistics system and emergency assistance accessibility during a crisis. From the above events of disaster are reflected up to the level of severity of the problem and unreadiness to face the climate change and its consequences in many aspects such as the level of information and knowledge regarding flood, management plan, the preparation of the response, and the availability of equipment, etc.

However, this is not the first event in Thailand. During 30 years, the lower Chao Phraya River Basin has been flooding many times as shown in Figure 5.1[4]

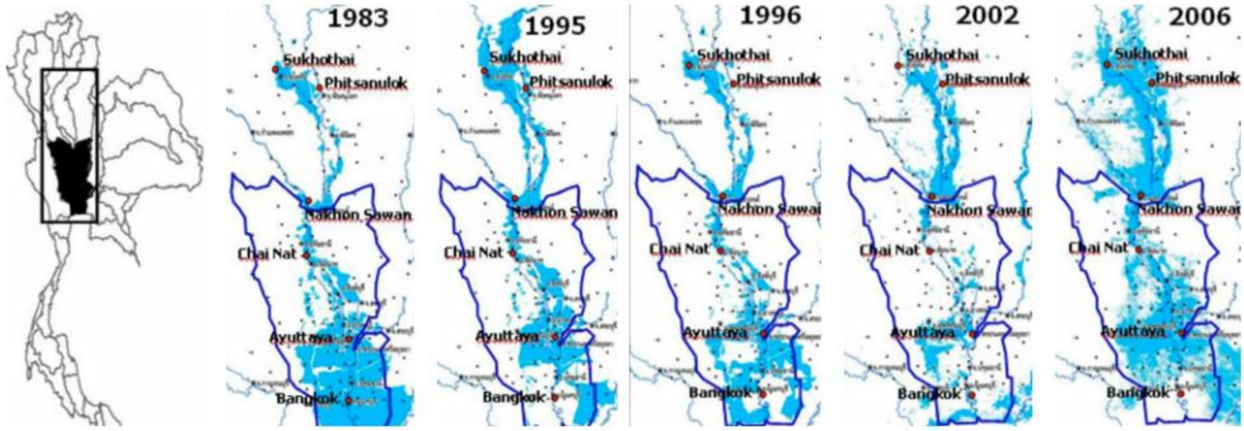
---

[1] Tavida Kamolvej (2011), The local disaster management. manual, King Prajadhipok's Institute (KPI), Thailand.

[2] The World Bank, "The World Bank Supports Thailand's Post-Floods Recovery Effort" 13 December 2011.

[3] AON Benfield (2012). 2011 Thailand Floods Event Recap Report Impact Forecasting - March 2012

[4] Somkiat Prajamwong and Pornsak Suppataratarn (2009). Integrated Flood Mitigation Management in the Lower Chao Phraya River Basin,



Source: AON (2012) adapt from Somkiat (2009)

Figure 6.3: the past severe floods and inundation area in the Chao Phraya river basin

Obviously, the global climate change mitigations are necessary, for example, reducing CO_2 emissions in all sectors, but the adaptation to deal with the current consequences is also indispensable. However, the improvement of existing transportation system is a very difficult process. Particular, it may have a very high cost to improve. Hence, There is need to assess the risk and vulnerability of the existing transportation system. Moreover, it's also need to priority due to resource allocation. In addition, the climate change challenges need to be take into account for the future transport infrastructure development in all over facilitie service life.

According to the study results of weather and climate change specific to Thailand in chapter 3, the expected impacts of climate change to transportation systems in chapter 4, and the current transport knowledge that match the expected climate change, this chapter will summarize all results and develop appropriate adaptation planning framework for transport authorities, in order to plan, design, manage and maintain the transport system under climate change phenomenon

6.2 Climate change specific to Thailand

The expected climate change specific to Thailand can be summarized into 2 main topics as follows,

- Temperature
  - Increase in average maximum temperature;
  - A warm period is longer;
  - A cold period is shorter;
- Rainfall pattern
  - Annual cumulative precipitation in Thailand was decreased slightly in the Central and East region;
  - Annual cumulative precipitation in Thailand was significantly increased in the North and North-East region;

In this study, PRECIS model[5] with SRES A2 scenario is selected for references and analysis based on this study due to the data completion that can predict temperature and rainfall patterns for long periods (present to 2090). 4 Key variables associated with change in temperature and rainfall to Thailand can be summarized as follows:

Temperature variables

- Increase in average maximum temperature in warm season compared to 2010 from 2 to 4 degree Celsius
- Increase in the warmest days (>35 degree Celsius) compared to 2010 from 30-90 days per year

Rainfall pattern variables

- 30% increase in flood severity from the experienced extreme flood severity due to change in annual rainfall (mm./year) and the severity of future storms
- Change in number of rainy days compared to 2010 from 0 to 30 days per year

The full detail of how these clamatic variable change along 80 years period is described in chapter 3. These climatic changes is used for further study conducting impacts of expected climate change to the transport system.

6.3 Impacts of climate change to transportation system

6.3.1 Impacts to transportation system in the views of experts from different agencies

Summary of opinions of related stakeholders from different agencies (Government officials responsible for infrastructure, drivers from both public and private sectors, and traffic polices and EMS officials) in the issue of impacts of climate change to transportation system can be classified as following:

a) Temperature impacts due to the increase in temperature by 4 ºC in all regions of Thailand and increase in the warmest days or days with temperature>35 degree Celsius (30-90 days per year).

b) Rain and flood impacts due to the increase in flood severity from the experienced extreme flood severity (by 30%) and increase in number of rainy days (1-30 days per year).

The expected impact can be classified in to 8 aspects as follows; (Details in chapter 4)

1. Infrastructure
2. Traffic
3. Construction
4. Vehicle
5. Passenger
6. Station/Terminal
7. Road Users
8. Traffic Operation

[5] The Thailand Research Fund’s Research Development and Co-ordination Center for Global Warming and Climate Change (THAI-GLOB)

6.3.2 Impacts on people's travel

According to the analysis result in chapter 4, overall results from analysis of impacts of global warming on travel behaviors in Thailand classified by case questions can be summarized as shown in table 6.1.

Table 6.1 Impacts of global warming on travel behaviors

Travel Behavior	Impact of each factor of climate change (Percent)				
	Q1	**Q2**	**Q3**	**Q4**	**Details**
Pedestrian	⇩49.10	⇩67.10	⇩74.70	⇩70.90	"Decrease in travel demand in 4 road user groups (30-80%)"
Bicycle	⇩53.60	⇩69.20	⇩62.70	⇩79.10	
Bus and Song Taew	⇩31.50	⇩39.50	⇩67.50	⇩53.90	
Motorcycle	⇩41.90	⇩58.50	⇩55.60	⇩64.20	
Personal Car	33.50	⇩30.50	⇩55.60	32.30*	"Decreased in travel demand due to flooding by 55% (Q3)"
BTS	69.10	80.30	90.10	80.30	"Mostly used as the same (>70-90)"

Remark: * = used as the same and change behavior

6.4 The transport knowledge that match the expected climate change

According to impacts of climate change to transportation system, the element of transportation systems related to climate change phenomenon can be classified as follow;

1. Infrastructure
2. Vehicle
3. Road Users
4. Traffic and Transport
5. Construction
6. Operation

The adaptation knowledge are gathered from theories, standards, practices, researches and expert in various related field (e.g transportation , civil and environment). This knowledge will used for transport authorities' implementation.

6.5 Transportation adaptation planning framework on climate change

Adaptation planning for climate change can be successful after completion of the impacts analysis and risk and vulnerability assessments for each vital segment. While there are many different approaches used to develop action and implementation plans. In general, the first step of the framework is identifying who should be involved in adaptation planning and which planning areas will be most severely affected. After that, a long-term vision should be expressed, together with decisions on scale. Next, the team should complete risk and vulnerability assessments in each planning area faced from climate change. Moreover, the adaptation plans should prioritize helping areas that are most vulnerable to climate impacts based on cost-effective principle, along with the continuous evaluation.

To encourage transportation adaptation to climate change in Thailand, a proposed framework for the planning process for transport authorities is shown in figure 6.4;

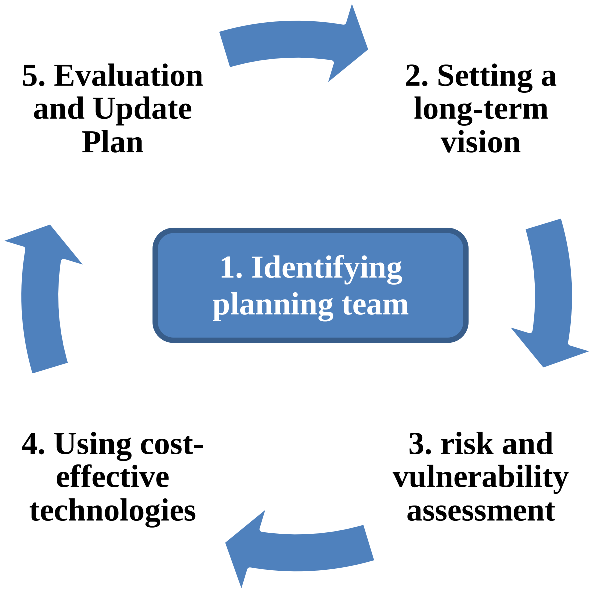


Figure 6.4 Transportation adaptation planning framework

In addition, the long-term investment of transportation system in the future which is always expected to have a higher economic cost, project management have to prudently conduct for maximizing investment values by considering significant factors and possible risks from changes in climatic conditions as well. Adapatation management of this field can be brought in to practice as follows:

1. Providing risk assessment of transportation system investment by both government and local administrative organizations to determine the levels of risk from related aspects depending on regional and locational characteristics
2. Determining construction design measures and using public utilities with a lower risk of climate change impacts corresponding to GHGs mitigation practices
3. Conducting green infrastructure such as tree planting and care, growing new trees along road corridors and other public utilities to provide a pleasant view and reduce thermal radiation releases from roads and "urban heat island" problems as well as enhance carbon storage
4. Promoting green logistics to provide a guideline for long-term transportation development by focusing on improving and increasing rail and marine transportation and reducing car use through cross subsidy between car users and public transport users as well as appropriately applying the road and utility pricing strategies to

increase lifespan of infrastructures and create the new financial source for transportation development

5. Setting a land use control and implementing conservation and plantation along watershed or dam zones to increase discharge areas as well as increasing the potential of irrigation systems, ditches and canals
6. Enhancing the application of eco-design in utility design, location selection and construction to avoid the risk of disaster impacts on new utilitiy structures
7. Identifying the large communities (including government-operatec communities) to establish green transportation facilitating pedestrians and reduce car usage (Transit-Oreinted Development: TOD)

References

Amnat Chidthaisong. (2011) Thailand Climate Change Information, Volume 2: Climate Model and Future Climate, The Thailand Research Fund (TRF), 176 pages.

AON Benfield (2012). 2011 Thailand Floods Event Recap Report Impact Forecasting - March 2012

Bipartisan Policy Center. (2009) Transportation Adaptation to Global Climate Change, by Cambridge Systematics, Inc.

Eddowes M.J., Waller D., Taylor P., Briggs B., Meade T., Ferguson I. (2003). Railway Safety Implications of Weather, Climate and Climate Change: Final Report. United Kingdom.

Federal Highway Administration. (2012). Regional Climate Change Effects: Useful Information for Transportation agencies. U.S. Department of Transportation : United States of America.

Hyman R.C., Potter J.R., Savonis M.J., Burkett V.R., Tump J.E., (2008). Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I. United States of America.

Jaroszweski D., Chapman L., Petts J. (2010). Assessing the potential impact of climate change on transportation: the need for an interdisciplinary approach. Journal of Transport Geography. 18 : 331–335.

Kinsella Y. and McGuire F. (2005). Climate Change Uncertainty and the State Highway Network: A moving target. Transit New Zealand, Auckland : New Zealand.

Kirshen P.H., Ruth M., Anderson W., Lakshmanan T.R.(2004). Infrastructure Systems, Services, and Climate Change: Integrated Impacts and Response Strategiesfor the Boston Metropolitan Area (CLIMB Final Report). U.S. Environmental Protection Agency : Washington, D.C.

Love G., Soares A., Püempel H. (2010) . Climate Change, Climate Variability and Transportation. Procedia Environmental Sciences. 1 : 130–145.

PIANC. (2008) ports and waterways: A review of climate change drivers, impacts, responses and mitigation. BELGIUM.

Regmi M.B. and Hanaoka S. (2011). A survey on impacts of climate change on road transport infrastructure and adaptation strategies in Asia. Environ Econ Policy Stud. 13:21–41.

Somkiat Prajamwong and Pornsak Suppataratarn (2009). Integrated Flood Mitigation Management in the Lower Chao Phraya River Basin.

Sompong Sirisoponsil. (2011) Risk and vulnerability of the economic system: transport and logistics, In: Thailand's First Assessment Report on Climate Change 2011 report: Working Group 2 : Impacts, Vulnerability and Adaptation, The Thailand Research Fund (TRF) [Anon Snidvongs and Amnat Chidthaisong (Editors)].

Tavida Kamolvej (2011), The local disaster management. manual, King Prajadhipok's Institute (KPI), Thailand.

The Royal Academy of Engineering. (2011). Infrastructure, Engineering and Climate Change Adaptation ensuring services in an uncertain future. The Royal Academy of Engineering : United Kingdom.

The Thailand Research Fund (TRF). (2011) Technical Summary, In: Thailand's First Assessment Report on Climate Change 2011 report: Working Group 1 : Scientific Basis of Climate Change, [Atsamon Limsakul, and Amnat Chidthaisong, and Kansri Boonpragob (Editors)].

The World Bank, "The World Bank Supports Thailand's Post-Floods Recovery Effort" 13 December 2011.

Transportation Research Board. (2008). Potential Impacts of CLIMATE CHANGE on U.S. Transportation. Washington, D.C.