ACP ASIAN Co-benefits Partnership

Ministry of the Environment

IGES

Asian Co-benefits Partnership
White Paper 2018

Quantifying Co-benefits in Asia:
Methods and Applications

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Printed in Japan

Acknowledgements

The preparation of this White Paper was overseen by the Institute of Global Environmental Strategies (IGES) in its capacity as secretariat of the Asian Co-benefits Partnership (ACP).

Extensive peer reviews and suggestions from government agencies, research institutions, universities and regional organisations helped to improve earlier drafts of the White Paper. The ACP would like to extend its gratitude to the following people for giving liberally of their time and knowledge to comment on the White Paper, including: Natalie Harms, United Nations Economic and Social Commission for Asia and the Pacific (UN ESCAP); Katsumasa Tanaka, National Institute for Environmental Studies (NIES); Dang Espita, Clean Air Asia (CAA); Li Liping, Policy Research Center for Environment and Economy (PRCEE); Didin Agustian Permadi, Asian Institute of Technology (AIT); Sudarmanto Budi Nugroho, IGES; Supat Wangwongwatana, Regional Resource Center for Asia and the Pacific (RRC.AP).

Every effort was taken to incorporate the technical comments from peer reviewers. However, the authors remain responsible for any inaccuracies or mistakes made therein.

Valuable advice and inputs were received from Katsunori Suzuki, Kanazawa University and other members of the ACP advisory group. This White Paper would not have been possible without their steadying hand and thoughtful feedback over the past two years.

The White Paper was edited by Eric Zusman and So-Young Lee. Emma Fushimi kindly reviewed Chapters 2, 4 and 5. Printing was handled by Match-up Printing Service Co. Ltd. Tomoko Yamashita provided administrative support.

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ACP White Paper 2018

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List of Acronyms

ACP	Asian Co-benefits Partnership
ADB	Asian Development Bank
APCAP	Asia Pacific Clean Air Partnership
ASEAN	Association of Southeast Asian Nations
BRT	Bus Rapid Transit
CCAC	Climate and Clean Air Coalition
CCC	Climate Change Commission
CDM	Carbon Development Mechanism
CIFs	Climate Investment Funds
CLE	Current legislation
CO_2	Carbon dioxide
COP	Conference of Parties
CTCN	Climate Technology Network Centre
DOCs	Diesel oxidation catalysts
DOTr	Department of Transportation
DPFs	Diesel particulate filters
DRR	Disaster Risk Reduction
EC	Elemental carbon
ECLIPSE	Evaluating the climate and air quality impacts of short-lived pollutants
EMEP	European Monitoring and Evaluation Programme
EQS	Environmental quality standard
GAINS	Greenhouse gas–Air pollution Interactions
GBD	Global Burden of Disease
GCF	Green Climate Fund
GEF	Global Environmental Facility
GHG	Greenhouse gas
GIZ	German Development Agency
HFCs	Hydrofluorocarbons
HLPF	High-level political forum
IBAQ	Integrated Better Air Quality
IBC	Integrated Benefits Calculator
IETA	International Emissions Trading Agency
IIASA	International Institute for Applied Systems Analysis
IKI	International Climate Initiative
INDCs	Intended Nationally Determined Contributions
IPCC	Intergovernmental Panel on Climate Change
ITDP	Institute for Transport and Development Policy
JCM	Joint Credit Mechanism
LEAP	Long-range Energy Alternatives Planning system
MOEJ	Ministry of the Environment of Japan
NAMAs	Nationally Appropriate Mitigation Actions
NDCs	Nationally Determined Contributions
NH_3	Ammonia
NMVOC	Non-methane volatile organic compounds
NOx	Nitrogen oxides
OR	Operational regulations
PM	Particulate matter
SDGs	Sustainable Development Goals
SDM	Sustainable Development Mechanism
SEI	Stockholm Environment Institute
SLCP	Short-lived climate pollutants
SNAP	Supporting National Action and Planning on SLCPs
SO_2	Sulphur dioxide
TEEMP	Transport Emissions Evaluation Model for Projects
TMG	Tokyo Metropolitan Government
TMR	Tokyo Metropolitan Region
UNDP	United Nations Development Programme
UNEA	United Nations Environment Assembly
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency International Development
VNRs	Voluntary national reviews
VOC	Volatile organic compound
VTR	Vehicle-type regulations
WHO	World Health Organization

Executive Summary

The Paris Agreement and the 2030 Agenda for Sustainable Development have generated a fast growing interest in strengthening the links between climate change and other development priorities in Asia. Due to this growing interest, policymakers are increasingly looking for tools and methods that can analyse linkages between climate change and development priorities. The main purpose of the ACP White Paper 2018 is to broaden and deepen policymakers and practitioners understanding of tools that can quantify co-benefits.

Chapter 1 explains the importance of co-benefits and clarifies the term's definition: all of the benefits from actions that mitigate climate change and deliver other desirable development benefits. The chapter then describes some of the relevant climate change, sustainable development and air pollution policy processes that could promote co-benefits. It concludes that there is a growing opportunity for cross-national learning on co-benefits with the help of facilitative platforms that encourage the integration of co-benefits into nationally determined contributions (NDCs). Taking advantage of this opportunity will require greater guidance on the tools and methods that can quantify co-benefits and their applications.

Chapter 2 outlines some of the key features and applications of the Long-range Energy Alternatives Planning system Integrated Benefits Calculator (LEAP-IBC), a model that can estimate the impacts of different policy scenarios on multiple pollutants, human health and other endpoints. The chapter demonstrates how LEAP-IBC has been used in Bangladesh as part of a two-stage process to formulate action plans for short-lived climate pollutants (SLCPs). The chapter also shows that LEAP-IBC can be tailored to unique national circumstances—for example, a separate module was created to model contributions from rice parboiling units as they are considered important in Bangladesh.

Chapter 3 focuses on the tools to assess emissions of multiple pollutants in Nepal's brick sector. It shows that the destruction from the 2015 earthquake in Nepal created a surge in demand for bricks at the same time it opened an opportunity for many of the brick kilns to be rebuilt. The result was a change in the design of some of the kilns that led to a significant reduction in emissions. The chapter then describes how researchers employed a tool called the ratnoze—so-named because rats have a keen sense of smell—to develop accurate emission factors for several pollutants. These emission factors were then combined with activity data to calculate emission reductions prior to and after the kiln redesign. The chapter illustrates some of the challenges of gathering accurate data for brick kilns, ranging from the need to recalibrate emission instruments to the risks from sampling during inclement weather.

Chapter 4 employs the Greenhouse gas–Air pollution Interactions and Synergies (GAINs) model to estimate changes in emission, ambient air quality, changes in premature death, and climate from heavy-duty diesel regulations implemented in the Tokyo Metropolitan Region (TMR) in the early 2000s. GAINs can estimate the current and future emissions of pollutants based on activity data, uncontrolled emission factors, the removal efficiency of emission control measures and the extent to which such measures are applied. The modelling results focused on the impacts attributable to TMR diesel emission regulations, and the impact of different timings of policy implementation. The chapter demonstrates that the estimated emissions in the policy scenarios with the Automobile NOx and PM Law and TMR's diesel vehicle regulation were significantly lower than the scenario without those regulations. The estimates for ambient $PM_{2.5}$ concentrations, based on not only the emissions of primary PM but also of precursor gases, indicated that the ambient $PM_{2.5}$ concentrations significantly decreased by 25% between the year 2000 and 2010 under the combined influence of the NOx and PM Law and TMR diesel vehicle regulations.

Chapter 5 describes the use of the Transport Emissions Evaluation Model for Projects (TEEMP). TEEMP is a collection of spreadsheet-based tools for evaluating the *ex-ante* impacts of various transport measures at the project level. TEEMP are "sketch" models which enable the estimation of emissions in both "with project" and "no project" scenarios and can be used for evaluating short- to long-term impacts of transport projects. The chapter demonstrates the application of TEEMP to the Harbin Green Bus Corridor and the transport elements of the Philippines Intended Nationally Determined Contribution (INDC). Although the project emissions estimates are relatively small compared to the total transport emissions, these projects can help set the direction towards sustainable low carbon transport systems while achieving co-benefits such as reduced travel time, fatalities and accidents and fuel saved.

The final chapter reiterates some of the main findings and suggests areas for future research. Potentially rich areas for future study include looking at the application of co-benefits models to support integrated approaches to the sustainable development goals (SDGs); considering equity concerns in assessments and policy designs; and examining the potential and constraints on co-benefits as a communication tool compared to other concepts such as low carbon or sustainable development.

Chapter 1: Quantifying Co-benefits to Strengthen the Integration between Climate Mitigation and Sustainable Development in Asia

Authors: Eric Zusman and So-Young Lee/Institute for Global Environmental Strategies (IGES)

1.1. Introduction

The Asian Co-benefits Partnership (ACP) was established in 2009 as an informal and interactive platform for information sharing and awareness raising on co-benefits in Asia. Since its creation, the ACP has grown to more than 450 individual and institutional partners. One of the primary channels through which the ACP communicates with its partners and other stakeholders is a White Paper (ACP 2014, 2016). The ACP White Paper is published once every two years to broaden and deepen understanding of co-benefits among policymakers and practitioners working on sustainable development and climate change in Asia.

The ACP White Paper focuses on a timely theme. For the ACP White Paper 2018, the main theme is the methods and tools to quantify co-benefits. The ACP White Paper 2018 has the following three objectives related to that theme:

1. To describe decision-making tools that can quantify co-benefits;
2. To demonstrate how these tools can be been applied in policymaking settings in Asia; and
3. To discuss where quantifying co-benefit fits in international, regional and national policymaking processes.

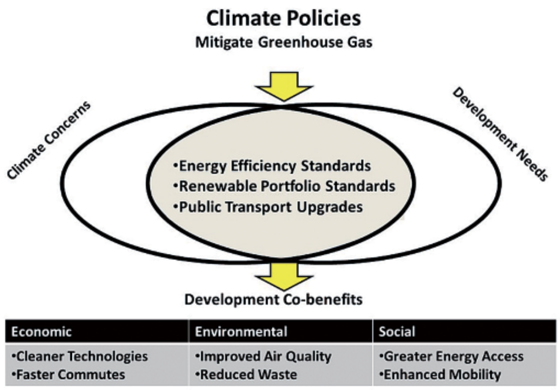
These three objectives suggest the importance of quantifying co-benefits. One reason why quantification is important is that assessing both climate and development benefits can reduce concerns about investing in a long-term, global and uncertain climate problem. Policymakers are generally more inclined to address climate change when their actions also deliver tangible near-term benefits. Precise estimates of benefits can further help simplify planning across different actors and agencies. This is partially because estimates of possible impacts can give high-level decision makers a clearer view of synergies and trade-offs. A more accurate assessment of these positive and negative interactions can further lead to interventions that enhance institutional coordination as well as improve monitoring and reporting of progress. Last but not least, quantifying both climate and development benefits can open new sources of climate and development finance.

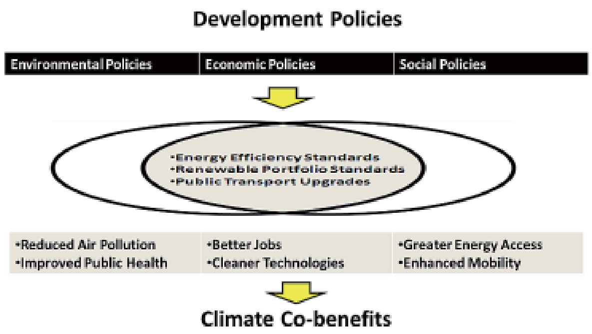
At the same time that quantifying co-benefits holds promise, it also raises questions. Some of these questions involve varying definitions and perspectives on co-benefits. Box 1.1 provides a brief review of some of the key definitions. As suggested in Box 1, rather than privileging one benefit over another, the ACP White Paper 2018 deliberately uses the term co-benefits in a broad sense to refer to all of the benefits from actions that mitigate climate change and achieve other desirable development outcomes. Other questions involve the kinds of decision-making tools that can be applied to quantify benefits in key sectors in Asia. Detailed discussions of those tools and their applications are provided in chapters 2 through 5. A third set of questions involve how co-benefits fit in key policymaking processes at different levels. The remainder of this chapter details the relationship between several key processes and co-benefits before setting the scene for the remainder of the White Paper.

Box 1.1: What are Co-benefits?

The term "co-benefits" has been defined differently over the past thirty years.

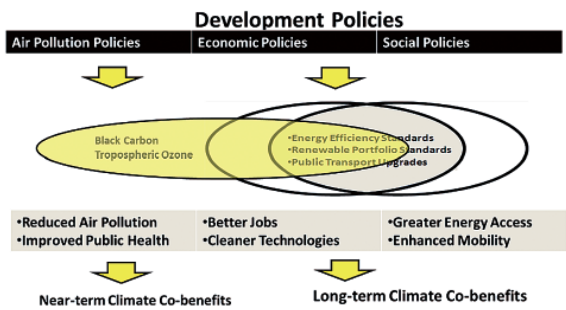
Initially, co-benefits was used to mean the additional benefits of climate policies in chiefly developed countries. A carbon tax or emissions trading scheme could deliver "development co-benefits," ranging from improved air quality to cleaner technologies to better jobs. These additional benefits could limit regrets policymakers might have about investing in climate mitigation at a period when climate benefits were still very uncertain.





More recently, the term's definition began to attract more interest in developing countries. For developing countries, co-benefits typically referred to the additional "climate co-benefits" of sectoral policies and plans that had another development objective beyond climate change as their chief goal.

A third way co-benefits has been used involves the multiple impacts of air pollution policies. This use is often employed by the air pollution community when discussing short-lived climate pollutants (SLCPs) such as black carbon that degrade air quality while warming the climate in the near-term.



The variation in the terms definitions has led to a focus a "co-benefits approach" that recognises that policy priorities and objectives may vary but all countries will increasingly need to look at multiple climate and development impacts. Further, it will be important to examine not only benefits but also possible negative impacts such as a loss of jobs. The White Paper 2018 uses the term co-benefits broadly to refer to all of the benefits from actions that mitigate climate change and achieve other desirable development outcomes. At the same time, many of the chapters focusing on quantification look closely at the links between air pollution and climate change.

1.2. Co-benefits in the International Climate Policy Landscape

The linkages between co-benefits and international climate policy trace back more than two decades to the United Nations Framework on Climate Change (UNFCCC). The UNFCCC included several references to sustainable development. In so doing, it represented an important initial step in a still evolving effort to mainstream development concerns into global climate agreements. The most notable result of the inclusion of this language in the UNFCCC were provisions related to sustainable development in the Kyoto Protocol's description of the Clean Development Mechanism (CDM). One of the CDM's primary objectives was promoting sustainable development in host countries (offering developed countries affordable mitigation opportunities was the other). The CDM nonetheless struggled to make significant headway with its sustainable development objective. The main reasons for this limited progress were concerns that uniformly acceptable definitions of sustainable development undermined national sovereignty; measuring co-benefits would increase transaction costs for profit-seeking investors; projects with strong linkages to development were not additional to business-usual development; and a global market-based mechanism built around pricing carbon could not financially reward national development benefits (Schneider 2007). Subsequent attempts to strengthen the integration of development concerns into climate actions aimed to address some of the challenges.

The recent addition to the international climate finance architecture with arguably the greatest potential to resolve the above issues is the Green Climate Fund (GCF). The GCF's sizable budget (responsible for allocating a portion of 100 billion US dollars per year by 2020), non-market allocation scheme, and emphasis on environmental, social and economic benefits were some of the design features that could help address previously mentioned barriers. However, a lack of consensus over the definition of co-benefits emerged as a familiar hurdle in discussions around the first set of GCF funding proposals. In a review of those proposals, Ecuador and South Africa preferred contributions to sustainable development be included in assessments of transformational change (Schalatek 2014) while other countries suggested using specific indicators for contributions to sustainable development (Schalatek 2013). Activities under the GCF further required stakeholder involvement that added to diversity in the definition of benefits—a challenge that is also an opportunity insofar as it empowered the involved stakeholders. The *de facto* position for the GCF has therefore been that co-benefits indicators shall be decided upon on a case-by-case basis (Umweltbundesamt 2017).

The Sustainable Development Mechanism (SDM), another recent addition to the climate policy landscape, also holds promise to move past some of the previously mentioned difficulties. The SDM was designed to succeed the CDM but with a stronger commitment to sustainable development. That stronger commitment was supposed to come from the regular use of a sustainable development tool developed initially to evaluate CDM projects. The SDM has nonetheless struggled to gain ground due, in part, to a need to "leave the definition of sustainable development up to the host country government…as well as the limited possibility of imposing international rules for achieving high levels of sustainable development benefits" (Umweltbundesamt 2017). The future of the SDM may hinge on further negotiations over Article 6 of the Paris Agreement. The International Emissions Trading Agency (IETA 2016) hinted that this future is uncertain when it argued for the creation of "Emission Mitigation Mechanism" rather than SDM under the Paris Agreement.

There are also several other finance mechanisms that could encourage the integration of development concerns in climate projects on a more modest scale or more indirect manner. The UNFCCC's Technology Mechanism and complementary Climate Technology Network Centre (CTCN) were designed for small-scale climate mitigation actions and low-carbon technologies that often bring significant development benefits in developing countries. Further, multilateral development banks appear likely to continue to work with a set of Climate Investment Funds (CIFs) that offer resources for climate actions with broader development benefits.

There are also notable bilateral funding mechanisms, such as Japan's Joint Crediting Mechanism (JCM) and International Climate Initiative (IKI), promoting co-benefits to varying degrees. For example, the IKI requires that proponents evaluate sustainable development criteria.

The international mechanism that has arguably enjoyed the longest running success promoting co-benefits is the Gold Standard. The Goal Standard is a certification scheme that project proponents can use to demonstrate their climate mitigation activities adhere to sustainable development standards. Environmentally and socially responsible investors can then purchase Gold Standard credits at a premium. Those purchases are typically made on voluntary carbon markets and come with assurances projects will deliver clearly demonstrable sustainable development impacts beyond mitigating climate change. In recent years, the "Gold Standard for the Global Goals" has reflected a notable attempt to align the requirements for goal standard certification with the Sustainable Development Goals (SDGs) (Gold Standard 2017). This step offers what some observers suggest will be key to ensure climate projects begin to achieve SDGs (Pickering A.J. et al. 2017). It is also supported by other trends discussed later in the chapter.

The final and perhaps most promising vehicles to support the alignment of climate and development concerns are the National Determined Contributions (NDCs) and related pledge-and-review architecture under the Paris Agreement. The NDCs are national plans or roadmaps that countries pledged to the UNFCCC to achieve the collective targets set out in the Paris Agreement. NDCs can take various forms; focus on multiple sectors; and include varied elements, ranging climate adaptation to other development priorities. The Paris Agreement establishes a mandatory five-year cycle to review and strengthen NDCs that is supported by stocktaking scheduled to formally begin in 2023. An initial more informal stocktaking exercise known as the Facilitative Dialogue is already underway (WRI 2017). At the COP23, the Facilitative Dialogue was renamed the Tanaloa Dialogue, signalling that the process would be more "inclusive, participatory and transparent" (UNFCCC 2017). The inclusion of non-party stakeholders (DW 2018; WRI 2018) has since moved forward with innovations such as an online platform for stakeholders to provide inputs and participants to submit their proposals (UNFCCC 2017). This dialogue can help countries and non-government actors to share experiences with integrating sustainable development into their NDCs (WRI 2018).

Formulating NDCs in countries and sharing them with other countries through the Facilitative Dialogue has potential to pay both climate change and sustainable development dividends. As will be discussed more in the Section 1.3, this potential is evident in the seven countries in Asia that make the link between NDCs and SDGs (TERI 2017). This potential is also being realised through increasing the inclusivity of national and subnational climate policymaking processes. The inclusion of the voices of marginalised stakeholders can address equity concerns and limit negative social impacts such as job losses. In another words, the process of integrating broader development concerns in NDCs can strengthen the links between the economic, social, and environmental dimensions of sustainable development.

1.3. Co-benefits in the 2030 Agenda for Sustainable Development and Other Relevant Processes

Strengthening the links between the economic, social, and environmental dimensions of sustainable development lies at the heart of the 2030 Agenda for Sustainable Development. More so than past development agreements, the SDGs call for countries to base their development plans on an indivisible set rather than standalone goals and targets (OWG 2014a; OWG 2014b; UNGA 2015; UNSD 2016). This emphasis on indivisibility and integration is encouraging countries to move away from single agencies working in siloes to multiple actors working across sectors. In response to this shift, some countries have begun drawing upon decision-making tools to identify synergies and trade-offs between different goals and targets (ICSU 2017; Zhou and Mustafa 2017). In so doing, they have begun to recognise the interrelationship between climate and other development objectives that are fundamental to co-benefits.

Part of the motivation for using these decision-making tools and identifying these interlinkages are voluntary national reviews (VNRs). The VNRs are national reports that countries deliver annually at the international High-Level Political Forum (HLPF). Each year the HLPF focuses on a cluster of several goals; the VNRs tend to concentrate on the featured goals. Countries nonetheless have the flexibility to determine what will be the content of their VNRs (including which SDGs they highlight); whether they will present in groups or alone; and if their report will be made in only one year, every year, or intervals between these two extremes. Though the SDGs, VNRs process is more flexible than the climate NDC process, their facilitative nature and emphasis on learning from other countries' experience can help strengthen linkages between climate and other development objectives. It may also help the decision-making processes and empower actors engaged in the discussions.

The other important process in SDG landscape involves the Addis Ababa Action Agenda of the Third International Conference on Financing for Development. This framework is encouraging the public and private sector to take a closer look at financing proposals that generate emission reductions as well as other benefits under the SDGs. Investments that can clearly demonstrate multiple benefits may further be more successful in leveraging funding through development cooperation channels under multi-lateral development banks and international development institutions. Interlinkages between climate and other development priorities may also be more appealing for central and commercial banks interested in investing in sustainable technologies and infrastructure. This is further reflected in a growing emphasis in using environmental, social and governance (ESG) to assess a business or investment's commitment to ethical or sustainability concerns.

Co-benefits have also other processes related to a number of additional pertinent issues. The New Urban Agenda—the chief outcome of the Habitat III processes—encourages cities to work across sectors when formulating and implementing climate actions. Meanwhile, several city networks such as C40, ICLEI, Rockefeller 100 Resilient Cities, Clean Air Asia, and CityNet have begun providing support for greater integration between climate and development priorities. International policy process such as the Sendai Framework on Disaster Risk Reduction (DRR) support integrated approaches to planning but with a focus on climate adaptation. While the ACP has concentrated on the links between climate mitigation and other development priorities, some mitigation actions enhance adaptation, resilience and DRR. Further, in many of the countries vulnerable to climate change, efforts to mitigate climate change often need to begin with a focus on resiliency.

1.4. Co-benefits in Air Pollution Processes and Initiatives

The final set of processes that promote co-benefits concentrate on air pollution, especially SLCPs. The Climate and Clean Air Coalition (CCAC)—an action-oriented voluntary network of state and non-state partners—aims to help stakeholders achieve multiple benefits from reducing SLCPs. The CCAC has grown from eight to 104 partners since 2012. In Asia, partners come from Australia, Japan, Korea, Mongolia, Bangladesh, Maldives, Philippines, Cambodia, Lao PDR and Viet Nam. Other signs that the varying impact of air pollution at the global level are apparent in the United Nations Environment Assembly (UNEA) meeting. The third UNEA concluded with a resolution that called for countries and other actors to strengthen controls of global atmospheric pollution and a "pollution-free planet."

Air pollution interventions have also garnered interest at the regional level in Asia. The Asia-Pacific regional office of UN Environment, for instance, recently convened a well-attended Summit under the theme of a pollution-free Asia. The Summit demonstrated support for strengthened action on air pollution. Meanwhile, the Asian Pacific Clean Air Partnership (APCAP), an initiative started in 2015 to promote regional cooperation on air pollution and science-based solutions, is also making important forward strides. Further, the Integrated Better Air Quality (IBAQ) program is helping to equip decision makers in cities with materials on air pollution control and climate change (Clean Air Asia 2016). Last but not least, several countries are strengthening air pollution and sectoral policies in ways that can benefit the local environment and the global climate.

1.5. Chapter Reviews

The past three sections—on climate, sustainable development, and air pollution processes—underlined the wide variety of platforms and mechanisms potentially supporting co-benefits. It also illustrated the difficulties of defining co-benefits in diverse national contexts. At the same time, the chapter highlighted recent reforms to the international and regional policy processes that are offering facilitative platforms that support learning in and between countries on co-benefits. Together the above developments suggest, that just as directly recognising and rewarding co-benefits in global or regional processes may be challenging, guidance on the tools for quantifying co-benefits at the national and subnational levels is increasingly needed. Table 1.1 provides a brief review of the scope, sectoral focus, specific applications and benefits from existing tools focusing chiefly on links between air pollution and climate change. While the remaining chapters review how these tools are applied in detail, this section summarises results.

Table 1.1: Co-benefits Analysis Tools

Name of Tool/ Method	Scope	Example of application(s)	Benefits
Transport Emissions Evaluation Model for Projects (TEEMP)	Excel based transport model that offers a "sketch" of multiple benefits	Bus Rapid Transit in Manila	• Air pollution emissions • GHG emissions • Time savings • Fuel savings • Accident reductions
International Vehicle Emissions (IVE)	Transport model that converts data on vehicle technology and activity into multiple emissions	Transport policies in Bandung, Indonesia	• Air pollution emissions • GHG emissions
SIM-air modelling system	Simplified dispersion model-converts emission estimates into pollution concentrations	Air pollution policies in India	• Air pollution concentrations
IIASA GAINs	Well-established suite of models that can estimate impacts of technologies on emissions, air quality, and health	Energy policies in China	• Air pollution emissions • Air pollution concentrations • Health benefits
Benmap	User friendly model that estimates number of disability life years from changes in air quality	Regulatory Change in Air Pollution Standards	• Health benefits
Leap Integrated Benefits Calculator	Extension of energy model with user friendly interface for air pollutants/GHGs, air quality change	Air pollution and energy savings in Bangladesh	• Air pollution emissions • Air pollution concentrations • Health benefits • Food security benefits

Chapter 2 outlines some of the key features and applications of the Long-range Energy Alternatives Planning system (LEAP), developed at the Stockholm Environment Institute (SEI) over the last 30 years. LEAP is an integrated, scenario-based modelling tool that can be used to track energy consumption, energy conversion, resource extraction and pollutant emissions across all sectors of an economy. It can be used to account for both energy sector and non-energy sector greenhouse gas (GHG) emissions as well as emissions of air pollutants and SLCPs. In recent years, collaborators at the US Environmental Protection Agency (US EPA) and the University of Colorado have extended the functionality of the LEAP platform with a new Integrated Benefits Calculator (IBC) module that can estimate the health impacts of different scenarios, leading to the creation of the LEAP-IBC. The chapter demonstrates how LEAP-IBC has been used in Bangladesh as part of a two-stage process to formulate action plans for SLCPs. The chapter shows that LEAP can be used to identify the interventions in sectors ranging from residential to agriculture and waste. It further demonstrates the flexibility the tool to accommodate unique national circumstances—for example, a separate module was created to model contributions from rice parboiling units as they are considered important in Bangladesh.

Chapter 3 focuses on the tools and methods to assess emissions of multiple pollutants in Nepal's brick sector. It shows that the destruction from the 2015 earthquake in Nepal created a surge in demand for bricks at the same time it opened an opportunity for many of the brick kilns to be rebuilt and to accommodate more efficient production methods. The result was a change in the design of some of the kilns that led to a significant reduction in emissions. The chapter then describes how researchers employed a tool called the ratnoze—so-named because rats have a keen sense of smell—to develop accurate emission factors for several pollutants. These emission factors were then coupled with activity data to calculate emission reductions prior to and after the redesign. The chapter illustrates some of the challenges of gathering accurate data for brick kilns, ranging the need to recalibrate emission instruments to the risks from sampling during weather.

Chapter 4 employs the Greenhouse gas–Air pollution Interactions and Synergies (GAINs) model to estimate changes in emission, ambient air quality, changes in premature death, and climate related from heavy-duty diesel regulations implemented in the Tokyo Metropolitan Region (TMR) in the early 2000s. GAINs is model developed by the International Institute for Applied Systems Analysis (IIASA) that can estimate the current and future emissions of pollutants based on activity data, uncontrolled emission factors, the removal efficiency of emission control measures and the extent to which such measures are applied (Amann et al. 2011). The model can also be employed to analyse the interconnections between different air quality problems, the interactions between pollutants, and the interdependencies between emission controls across pollutants and source categories. The modelling results focused on a range of impacts attributable to TMR diesel emission regulations, and the impacts of different timings of policy implementation. The chapter shows the estimated emissions in the policy scenarios with the Automobile NOx and PM Law and TMR's diesel vehicle regulation were significantly lower than the scenario without those regulations, and the reduction of PM and BC moved up approximately five years. The estimates for ambient $PM_{2.5}$ concentrations, based on not only the emissions of primary PM and but also of precursor gases, indicated that the ambient $PM_{2.5}$ concentrations significantly decreased by 25% between the year 2000 and 2010 under the combined influence of the NOx and PM Law and TMR diesel vehicle regulations. Overall the vehicle emission regulations and their enforcement facilitated the reduction of several hundred premature deaths due to ambient PM in Japan's Kanto region.

Chapter 5 describes the use of the Transport Emissions Evaluation Model for Projects (TEEMP). TEEMP is a collection of spreadsheet-based tools for evaluating the *ex-ante* impacts of various transport measures at the project level. TEEMP was developed in 2010 as a result of the collaboration between Clean Air Asia, Institute for Transportation and Development Policy (ITDP), Asian Development Bank (ADB), Cambridge

Systematics, and the United Nations Environment Programme (UNEP)–Global Environmental Facility (GEF) Scientific and Technical Advisory Panel. TEEMP are "sketch" models which enable the estimation of emissions in both "with project" and "no project" scenarios and can be used for evaluating short- to long-term impacts of transport projects. The chapter demonstrates the application of TEEMP to the Harbin Green Bus Corridor and the transport elements of the Philippines Intended Nationally Determined Contribution (INDC). Although the project emissions estimates are relatively small compared to the total transport emissions, these projects can help set the direction towards less carbon and emissions intensive transportation systems while achieving co-benefits such as reduced travel time, fatalities and accidents avoided, and fuel saved that may be a stronger motivating factor for transport planners and policymakers.

The final chapter reiterates some of the main findings and suggests areas for future research. Potentially rich areas for future study include looking at the application of co-benefits models to support integrated approaches to the SDGs; considering equity concerns in assessments and policy designs that can appeal to multiple interests; and examining the potential and constraints on co-benefits as a communication tool compared to other concepts such as low carbon or sustainable development.

1.6. Key Messages and Conclusion

Based upon this introductory and the other chapters, the ACP White Paper 2018 leads to several key messages, including:

- Quantifying co-benefits is important because it can address concerns about investing in a long-term, global, and uncertain climate problem. It can also lead to high-level decisions that improve institutional coordination, enhance monitoring and review systems, and attract development and climate finance.
- There has been a gradually evolving effort to strengthen support for sustainable development in climate agreements and climate finance mechanisms. The most successful of these efforts have been the Gold Standard (especially the ongoing alignment of the standard with the SDGs) and recent attempts to integrate development priorities into NDCs.
- The creation of "facilitative platforms" that enable cross-national learning about climate actions has significant potential to strengthen the integration of development priorities into NDCs.
- Some of the more valuable benefits from strengthening making NDCs more sustainable may involve empowering otherwise marginalised stakeholders in the decision making process and addressing equity concerns.
- Policymakers may also want to examine experiences with co-benefits as they take more integrated approaches to the SDGs and bring climate concerns into international and regional processes focusing on atmospheric pollution. The concept of co-benefits sits at the intersection of climate, sustainable development, and air pollution processes. It may therefore help to align national responses to the issues featured in these processes.
- While it may be impossible for these processes to link financial or other incentives to any particular co-benefits, there is considerable scope to enhance the capacities to quantify different kinds of benefits.
- There is no need to reinvent the wheel when quantifying co-benefits; there are already many existing tools and methods familiar to those working on co-benefits between air pollution and climate change.

- Some of these tools can be tailored to meet the unique needs of countries (LEAP-IBC in Bangladesh); identify emission sources for difficult-to-monitor sources (ratnoze in Nepal); examine the implications of the timing of transport policies (GAINs in Japan); or offer a sketch assessment of benefits that can lead to more rigorous evaluation of co-benefits (TEEMP in China and the Philippines).
- Policymakers will need additional guidance on what tools are best suited for which purposes. The ACP and many of its partners are well positioned to provide that guidance.

While the above messages are generally encouraging, they will require a significant amount of work and collaboration to gain traction. This year's ACP White Paper provides the motivation for supporting and accelerating those collective efforts.

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Chapter 2: Supporting National Planning for Action on SLCPs Using the LEAP-IBC Tool

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2.1. Introduction

Short-lived climate pollutants (SLCPs) are a group of pollutants that have relatively short atmospheric lifetimes (days to ~10-15 years), have a positive radiative forcing (i.e. contribute to global warming), and, in many cases, act as air pollutants with associated effects on human health and vegetation (including crop yield). SLCPs include methane, black carbon, tropospheric ozone (formed in the atmosphere from precursor methane, nitrogen oxide and volatile organic compound (VOC) emissions in the presence of sunlight), and hydrofluorocarbons (HFCs). In 2011, a global assessment of the benefits of implementing SLCP reduction strategies (UNEP/WMO 2011) estimated that the implementation of 16 measures that focus on major black carbon and methane emission sources (but that also reduce co-emitted pollutants) could prevent 2.4 million premature deaths per year attributable to air pollution exposure (within a range of 0.7–4.6 million), as well as avert the loss of 52 million tonnes of maize, rice, soybean and wheat production each year (within a range of 30–140 million tonnes), and avoid 0.5 degrees C of global temperature rise in the near term (2050) (Shindell et al. 2012; UNEP/WMO 2011).

Following the UNEP/WMO (2011) global assessment, the Climate and Clean Air Coalition (CCAC) was established to promote and catalyse action to reduce SLCPs. The CCAC initiative on Supporting National Action and Planning on SLCPs (SNAP) aims to "support the efforts of CCAC partner countries to scale up action on SLCPs." It does this by assisting countries with the construction of national-scale emission inventories of SLCP sources, undertaking quantitative assessments of the potential for policies and measures to mitigate those emissions, and importantly, quantifying the health, climate and crop-yield benefits of these strategies. Support from the SNAP initiative then helps countries to consider detailed implementation plans for selected mitigation measures and helps identify the actions needed to address SLCPs.

2.2. LEAP-IBC: A New Tool for National SLCP Action Planning

To enhance the ability of national governments to undertake these assessments, a new tool has been developed that allows countries to evaluate the present state of SLCP-relevant emissions at the national scale and to identify the major sectors producing those emissions. The tool also permits projections of these emissions into the future based on likely changes in activity in each sector, and allows countries to model the effect of implementing policies to reduce the emissions of all relevant substances associated with SLCP sources. Crucially, the new tool allows countries to assess the multiple benefits of reducing emissions including climate benefits (avoided global temperature change), health benefits (avoided mortality) and agricultural benefits (avoided crop losses).

This new tool is based on the Long-range Energy Alternatives Planning system (LEAP), developed at the Stockholm Environment Institute (SEI) over the last 30 years. LEAP has been applied extensively as an energy planning and greenhouse gas (GHG) mitigation analysis tool in more than 190 countries (Heaps 2016). LEAP is an integrated, scenario-based modelling tool that can be used to track energy consumption, energy conversion, resource extraction and pollutant emissions across all sectors of an economy. It can be used to account for both energy sector and non-energy sector greenhouse gas (GHG) emissions as well as emissions of air pollutants and SLCPs. More information on LEAP and examples of past LEAP applications are available at https://www.energycommunity.org. As part of the CCAC SNAP initiative, collaborators at SEI, the US Environmental Protection Agency (US EPA), and the University of Colorado have extended the functionality of the LEAP with a new Integrated Benefits Calculator (IBC) module[1]. The basic structure of LEAP-IBC is outlined in Figure 2.1.

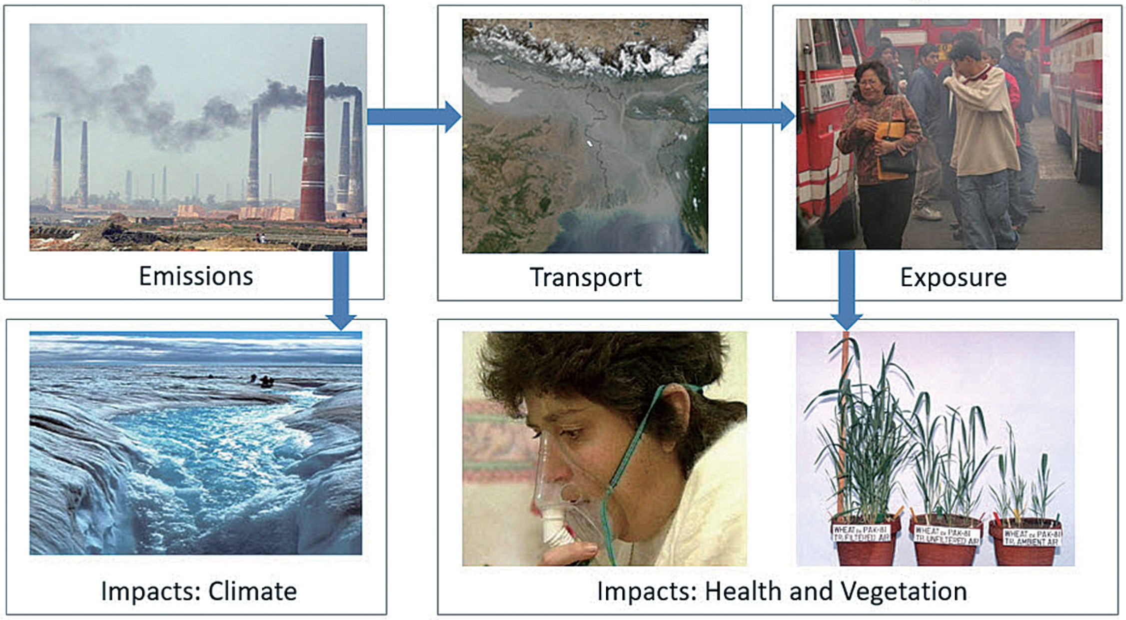

Figure 2.1: The pathway from emissions to impacts in LEAP-IBC

The IBC module takes emission estimates generated in LEAP for the country involved in the national-scale analyses and combines these with parameterised results from the global atmospheric geochemistry model GEOS-Chem Adjoint[2] as the basis for calculating population-weighted concentrations of pollutants in the atmosphere resulting from national emissions. This is complemented with further calculations of the contribution of emissions from the rest of the world to air pollution (fine particular matter and ozone) concentrations in the country, based on emissions from the International Institute for Applied Systems Analysis (IIASA) Greenhouse gas-Air pollution Interactions and Synergies (GAINS) model (Eclipse vs – REF) and the relevant GEOS-Chem Adjoint model coefficients. The IBC module then applies concentration-response functions used in the Global Burden of Disease Study (Burnett et al. 2014) and by the World Health Organization (WHO) to estimate health burdens (premature mortality). Similarly, concentration-response functions are also used to estimate crop yield losses induced by exposure to elevated levels of ozone, based on a previous global analysis (Van Dingenen et al. 2009). Finally, the IBC module also calculates the climate impacts of pollutants in terms of the global average temperature change resulting from the emissions emitted from each country being studied. Detailed information on how the IBC module calculates pollution concentrations and health, agriculture and climate impacts, can be found in Sections 2.2.1 and 2.2.2 respectively.

As well as adding the IBC module to the LEAP platform, a template LEAP data structure has been developed to assist countries wishing to use LEAP-IBC for their SNAP analyses. This structure contains default

1 For more information on LEAP-IBC, please see: https://www.energycommunity.org/default.asp?action=IBC
2 GEOS-Chem Adjoint is a global 3-D chemical transport model for atmospheric composition driven by meteorological input from the Goddard Earth Observing System (GEOS) of NASA and is based on emissions inventories from the EDGAR database (Janssens-Maenhout et al., 2017).

methods and default emissions factors for estimating emissions from all major source sectors and for all pollutants needed to estimate air pollution and climate impacts.

By taking an integrated perspective that encompasses all sectors of an economy, LEAP-IBC allows practitioners to study emissions from any one sector in the context of the total national emissions burden. By considering the multiple benefits of policies, LEAP-IBC allows policymakers to consider important co-benefits that can help to motivate more evidence-based decisions. For example, it can help to illuminate the climate co-benefits of an air pollution strategy or the air quality co-benefits of a climate mitigation policy.

The CCAC SNAP initiative is helping 12 countries to develop their SLCP national plans (Bangladesh, Philippines, Maldives, Ghana, Cote d'Ivoire, Nigeria, Togo, Morocco, Mexico, Colombia, Peru and Chile). These have so far used LEAP-IBC to create quantitative analyses that inform their National SLCP Action Plans.

Researchers in Nepal and Kenya have also begun to use the tool, while the Philippines, Morocco and the Maldives are starting their SLCP national planning processes this year (2018). The Philippines is currently undergoing a period of engagement with stakeholders in an effort to integrate the tool into policymaking in the country.

A key feature of LEAP-IBC is that it is designed for practitioners working in small- to medium-size developing countries, where data and modelling expertise is limited, rather than for expert modellers working in large industrialised country institutions. To support this target audience, SEI placed great emphasis on making the tool as transparent and usable as possible, with much of the design effort going into results visualisation and data management, in addition to developing the complex algorithms used to calculate impacts. See Figure 2.2 for a screenshot of the LEAP interface.

Figure 2.2: The User Interface of LEAP, showing results for a LEAP-IBC analysis

Because the IBC module has been embedded within LEAP, it is already widely accessible to the existing community of LEAP users (currently there are more than 36,000 users of LEAP in 190 countries) and it is available at no charge to government, academic and non-profit organisations based in low and middle-income countries. Because LEAP-IBC is designed to be used by in-country practitioners, the resulting analyses are more likely to reflect the local context and development concerns of the countries where they are being used. This, in turn, means that any solutions suggested by those analyses are more likely to be taken up by national decision makers.

2.2.1 Using the IBC module to estimate pollutant concentrations

The IBC module extends a standard LEAP analysis to include the assessment of impacts, and by comparing alternative policy scenarios, it gives an indication of the benefits of these scenarios in terms of avoided impacts. This approach allows emissions of all pollutants to be evaluated on a common scale. For example, one can assess the effectiveness of prioritising NOx vs. black carbon emission reductions in terms of changes in air pollution health burdens, the effect of short-lived vs. long-lived GHG mitigation plans on global temperature changes, as well as the synergistic effects of taking actions across multiple pollutants, and short- and long-lived greenhouse gases together to tackle air pollution and climate change.

To do this, LEAP-IBC takes the emissions generated in LEAP and estimates national population-weighted concentrations of fine particulate matter ($PM_{2.5}$) and ozone relevant for human health, and ozone concentrations relevant for vegetation impacts.

The national-scale emissions scenarios generated in LEAP are combined with estimated pollutant emissions for the rest of the world for the period 2010-2050, taken from the ECLIPSE (Evaluating the climate and air quality impacts of short-lived pollutants) scenarios developed by IIASA (Stohl et al. 2015). Two ECLIPSE scenarios are used within the IBC module: a baseline scenario that foresees only minor worldwide efforts to combat air pollution, and a maximum effort scenario that reflects full implementation of 16 measures from the previously mentioned WMO analysis, including the banning of agricultural residue burning. LEAP users can conduct sensitivity analyses to see the effect of differing levels of effort in the rest of the world on the impacts experienced in their own country.

The resulting global emissions for the whole world are then multiplied by coefficients from a global atmospheric chemistry transport model (GEOS-Chem Adjoint) in order to yield estimates of population-weighted concentrations of $PM_{2.5}$ and ozone for the target country from emissions in any grid square in the world. These coefficients quantify the sensitivity of emission changes in one part of the world to changes in $PM_{2.5}$ and ozone changes within the target country, accounting for the transport of pollutants from one area to another, and chemical reactivity in the atmosphere (Henze et al. 2007; Zhang et al. 2015). Figure 2.3

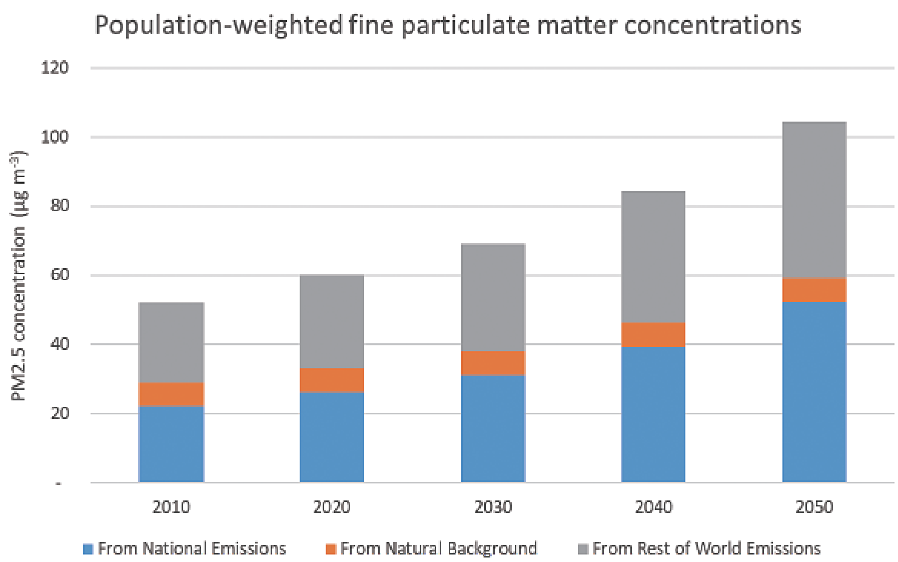

Figure 2.3: Illustrative example of population-weighted annual average $PM_{2.5}$ concentrations from 2010-2050 output from LEAP-IBC for a fictitious country. The $PM_{2.5}$ concentrations are disaggregated into contributions from emissions that occur within the target country, from anthropogenic emissions in other countries, and from natural background emissions

provides an example graph from LEAP-IBC showing population-weighted $PM_{2.5}$ concentrations, showing the contribution to $PM_{2.5}$ in the target country from emissions that occur within the country, from emissions that occur in other countries, and from natural emissions.

2.2.2 Using the IBC module to estimate health, crop and climate impacts

The calculated air pollution concentrations are next used with concentration-response functions to estimate premature mortality attributable to $PM_{2.5}$ and ozone exposure. Health effect studies have shown consistent associations between elevated $PM_{2.5}$ exposure and premature mortality (REVIHAAP 2013; US EPA 2013). In LEAP-IBC, the method adopted by the GBD to quantify these health effects is applied (Burnett et al. 2014; Forouzanfar et al. 2016). The GBD is an international project that estimates the contribution of different diseases and risk factors affecting health globally, and is currently updated annually.

Exposure to outdoor air pollution ($PM_{2.5}$ and ozone), and household air pollution ($PM_{2.5}$) are among the roughly 80 risk factors for premature death that are assessed as part of the GBD project (Abajobir et al. 2017; Forouzanfar et al. 2016). Specifically, the relationship between $PM_{2.5}$ exposure and premature death for ischaemic heart disease, chronic obstructive pulmonary disease, stroke and lung cancer is quantified using integrated exposure response (IER) functions that have been derived by integrating health effects information from ambient air pollution, household air pollution and smoking studies, providing a relationship across a wide range of $PM_{2.5}$ concentrations (Burnett et al. 2014). A similar approach is also used to estimate $PM_{2.5}$-associated lower respiratory infection premature deaths in children under five. For ozone, the relationship between ozone exposure and premature respiratory mortality is estimated using the results from a large United States health effects study (Jerrett et al. 2009).

In addition to air pollution exposure estimates calculated in LEAP-IBC, additional input data required are the population exposed to these concentrations, and the baseline mortality rates for each disease category. Default values for these variables are included in LEAP-IBC from international sources such as the United Nations Population Division and the GBD project.

Similarly, concentration-response functions are also used to estimate the yield loss of rice, wheat, maize and soy induced by exposure to elevated levels of ozone, based on a previous global analysis (Van Dingenen et al. 2009). In this case, the concentration-response functions are derived from experiments conducted in the United States. To estimate the crop yield loss, figures for the production of each crop are required, with default values taken from the FAOStat database in the default LEAP-IBC template.

Finally, to estimate the climate impacts, the effect of short- and long-lived climate forcers are taken into account. For the short-lived species, where they are emitted has an effect on their impact on the climate system. GEOS-Chem Adjoint modelling coefficients are used to quantify the effect of emissions of in the target country on radiative forcing in four latitudinal bands of the earth (arctic, northern hemisphere mid-latitudes, tropics, southern hemisphere extra tropics). For long-lived species that are globally mixed, the radiative forcing from national emissions (derived in LEAP) of these species is also quantified. The global average temperature change resulting from the radiative forcing in each year after the emissions is then quantified based on published relationships that link changes in radiative forcing in each band to global temperature changes (Lacey et al. 2017; Shindell 2012).

Each of these impacts is calculated every time LEAP-IBC is run. This allows users to assess the effect of different mitigation actions, which may be set up with a focus on air pollution abatement, SLCP mitigation, GHG reductions, or energy efficiency, on all impacts at once. In this way, co-benefit strategies for air pollution and climate can be identified, or trade-offs associated with a particular strategy can be highlighted. Additionally, the scenarios developed in LEAP can also be set up to assess the effect of slow or fast implementation, or low or high ambition scenarios. The benefits of high speed or high ambition strategies can therefore also be evaluated.

The following sections outline the different ways in which users in the 12 CCAC partner countries have been applying LEAP-IBC to undertake analysis of the potential of SLCP-focussed mitigation actions to reduce health, crop and climate impacts.

2.3. Examples of Applying LEAP-IBC for National SLCP Planning

Across the 12 CCAC Partner countries that have so far applied LEAP-IBC, the volume of data collected within each country by national ministries or other organisations that can be used to estimate emissions in LEAP varies substantially. In most cases, countries have started by using the default LEAP-IBC template that contains emission factors for all pollutant emissions for each sector, generally taken from international sources such as the Intergovernmental Panel on Climate Change (IPCC) (IPCC 2006), or the European Monitoring and Evaluation Program/European Environment Agency (EMEP/EEA) emission inventory guidebook (EMEP/EEA 2016), and has activity data for a large number of these sources, also taken from international databases. Having this default LEAP-IBC template as a starting point has two advantages. First, it allows those countries with relatively little data collected in-country to still undertake an SLCP assessment, relying mostly on international data for emission factors and some activity variables. Second, if users are interested in evaluating mitigation strategies for only a few source sectors, then they can improve the characterisation of emissions within these particular source sectors, while retaining the first-order estimate of emissions from all other sectors provided by the default data. This allows the effectiveness of mitigation strategies focusing on one source sector to be placed in the context of emissions from all source sectors.

2.3.1 The Bangladesh LEAP-IBC Application

Bangladesh is one country where LEAP-IBC is being applied as part of the second phase of its SLCP national planning process. A first phase was conducted in 2013, and focused on identifying the major source sectors and the options for mitigation, but the application of LEAP-IBC in this second phase will allow for a more specific look at policies and actions that could contribute to reducing SLCP impacts. The Ministry of Environment and Forests, and the Department of Environment Bangladesh is working with the Center for Environmental Geographic Information Services (CEGIS) and the Bangladesh University of Engineering and Technology (BUET) to develop the emission inventory that will form the basis for the LEAP-IBC analysis. This involves using the default LEAP-IBC template, populated with data from international sources for Bangladesh, and altering it to accommodate locally-derived data, but also changing the way in which emissions from specific source sectors are modelled.

In Bangladesh, one of the key source sectors that is an important focus for mitigation is the transport sector. In the default LEAP-IBC template, the emissions from the transport sector are based on estimates of the total energy consumed in these sectors, which are then split by the share of this energy consumption that is consumed as different types of fuel, for which default emission factors are specified. However, this method for estimating emissions does not easily allow for characterising mitigation scenarios such as increasing the vehicle emission standard, e.g. moving from pre-Euro to Euro 3, 4 or higher standards, or looking at policies related to modal shift, e.g. increasing the number of journeys taken using public transport and reducing the number of journeys taken by passenger cars. To allow for a more detailed assessment of the transport sector, the Bangladesh LEAP-IBC model was therefore altered from the default LEAP-IBC template to incorporate a more detailed representation of the transport sector. This included adding information on the number of vehicles of different types, for example, passenger cars, light commercial vehicles, heavy duty vehicles, urban buses, motorcycles, and then the proportion of those vehicles that used different types of fuel, and that were of different Euro (or equivalent) vehicle standards. For each of these sub-categories of vehicles, fuel economy, average distance travelled per year, and emission factors were entered. The emission factors are defaults taken from sources such as the EMEP/EEA (2016) guidebook, in the absence of locally derived emission factors. This more detailed approach to assessing emissions from the transport sector will therefore allow users in Bangladesh to assess the effectiveness of improving the vehicle fleet in terms of shifting to higher vehicle emission standards or from one mode of transport to another, which would have been substantially more challenging with the simpler approach in the default LEAP-IBC template.

Another potentially large emission source within Bangladesh is the residential sector, specifically from cooking using solid biomass (91% of people were estimated to cook using solid fuels in 2010 (Bonjour et al. 2013)). The default LEAP-IBC template characterises these emissions based on the energy consumed for cooking using different fuels and technologies (e.g. traditional and improved biomass stoves, or using LPG or natural gas). However, within Bangladesh, and other countries, there can be a large difference in the fuels and technologies in urban and rural households. Therefore, a more detailed assessment of emissions from the residential sector in LEAP-IBC would include modelling of urban and rural households separately, so that the effects of different policies and mitigation actions on urban and rural households could be evaluated. In addition to cookstove emissions, energy use from other activities can be captured within a LEAP-IBC analysis. The overall electricity demand from all energy sectors (e.g. residential, industry, commercial and public services) is then met in the 'transformation' section of LEAP, where emissions resulting from electricity generation using different types of fuels are quantified. Integrating the demand with the generation of electricity means that 1) increases in emissions from increased electricity demand can be modelled; 2) the emission reduction potential of energy efficiency policies within, e.g. the residential sector, or across multiple sectors, can be quantified; and 3) the benefits of moving to electricity generation to a greater extent from renewable sources can be modelled.

A further consideration in developing the LEAP-IBC application in Bangladesh was the ability for users to improve and update the model with additional data over time. To make this easier, the method for estimating emissions from Brick Kilns was changed from the default LEAP-IBC template. In the default LEAP-IBC template, the required activity data is the number of bricks produced per year, which is then split as the percentage produced in traditional and improved kilns. However, information on the number of bricks produced per year across Bangladesh is not routinely collected by government departments; rather, an annual inventory of the number of brick kilns operational within Bangladesh is collected. The template was then changed to take as input the number of brick kilns from the government statistics and then combined with average values for brick production for different types of kilns. This helps to ensure that the LEAP-IBC application in Bangladesh can be extended beyond the timeline of the national planning exercise.

In Bangladesh, there are also specific emissions sources that are potentially important, but which are not captured in the default LEAP-IBC template. For example, the parboiling of rice results in substantial emissions of PM, including black carbon (Figure 2.4 shows a rice parboiling unit). However, total emissions from rice parboiling had not been included in national emission inventories. As it is a sector specific to Bangladesh, it was not included within the default LEAP-IBC template as a separate sector. Fortunately, the flexibility of the LEAP system allows users to add data to reflect emission details that are important in a particular country context. This new source sector was therefore added to the default model, and emissions were estimated using the tonnes of rice parboiled per year, and the energy required to parboil one tonne of rice, taken from an analysis by GIZ (German Development Agency) (GIZ 2016). Default emission factors were then used for the burning of primary solid biomass. Including rice parboiling as a separate emission category allows the effect of mitigation strategies on rice parboiling to be assessed in the context of other actions that could be taken to improve air quality and reduce Bangladesh's contribution to climate change. For example, GIZ showed that improved rice parboiling could substantially increase the efficiency of the process, reducing the energy required to parboil one tonne of rice by more than half (GIZ 2016). The effect of this efficiency can now be assessed using their LEAP-IBC analysis.

Figure 2.4: Rice parboiling units in Bangladesh
(Images courtesy of Bangladesh University of Engineering and Technology)

Finally, emissions from non-energy sectors can also be modelled. The default LEAP-IBC template contains methods for capturing emissions from major non-energy sectors, including industrial process emissions, solvent use, agriculture, waste and vegetation fires. In Bangladesh, the emissions from open burning of waste have been modelled based on population and municipal solid waste generation rates, alongside estimates of the fraction of this waste that is collected, and the fraction that is openly burned locally. The agriculture sector can result in large emissions of methane from rice production. Of particular interest in Bangladesh are assessments of the benefits that could result from switching from continuously flooded rice paddy fields to fields that are intermittently aerated (a practice known as alternate wetting and drying (AWD)), which results in substantially lower methane emissions. The Intergovernmental Panel on Climate Change (IPCC) Tier 1 methodology is currently being used to represent these methane emissions for the Bangladesh template, which requires as activity data the number of hectares of land that is harvested every year, and the length of the cultivation period, disaggregated between continuously flooded, intermittently aerated, and rainfed and deepwater fields. Other agricultural emission sources accounted for in the LEAP-IBC template are methane and ammonia emissions from livestock enteric fermentation and manure management, fertiliser application, and emissions of a range of pollutants from agricultural residue burning.

The changes that have been made to model emissions using LEAP-IBC in Bangladesh provide examples of how and why users might want to take different approaches to estimating emissions from different source sectors. However, these are specific to the considerations of researchers and conditions in Bangladesh that determine the level of data available to estimate emissions from particular source sectors. In other countries, the priority sectors, the mitigation strategies, and the level of data available will be different. This means that the structure and data needed to represent those emissions, and to project them into the future will also be different. LEAP as a tool for SLCP, air pollution or GHG mitigation analysis is therefore not a prescriptive model that requires a common set of data for all applications. Instead, it has been designed as a flexible tool that can be used to model emissions using different input data.

The primary aim of LEAP is as a scenario planning tool, i.e. assessing how variables are likely to change into the future, and what affect a particular action or policy may have on this future if it were to be implemented. As such, emissions are projected from 2010 (the base year) to some future year (generally 2050). This can be done in a number of ways, but most commonly changes in the activity variables for each source sector are linked to changes in key socio-economic drivers to understand how they will likely change into the future. For example, projections of future emissions in the industrial, commercial and public services and transport sectors can be projected to change at the same rate as gross domestic product (GDP), accounting for elasticities in this relationship based on previously published work (Forouzanfar et al., 2016). In addition the effect of future policies that have already been committed to can also be represented in a baseline scenario. Mitigation scenarios can then be used to represent the effect of additional policy actions compared to this baseline. Figure 2.5 provides an illustrative example of an output from LEAP, showing the progression of black carbon emissions from 2010 to 2050 for a fictional country, split by the contribution of major source sectors.

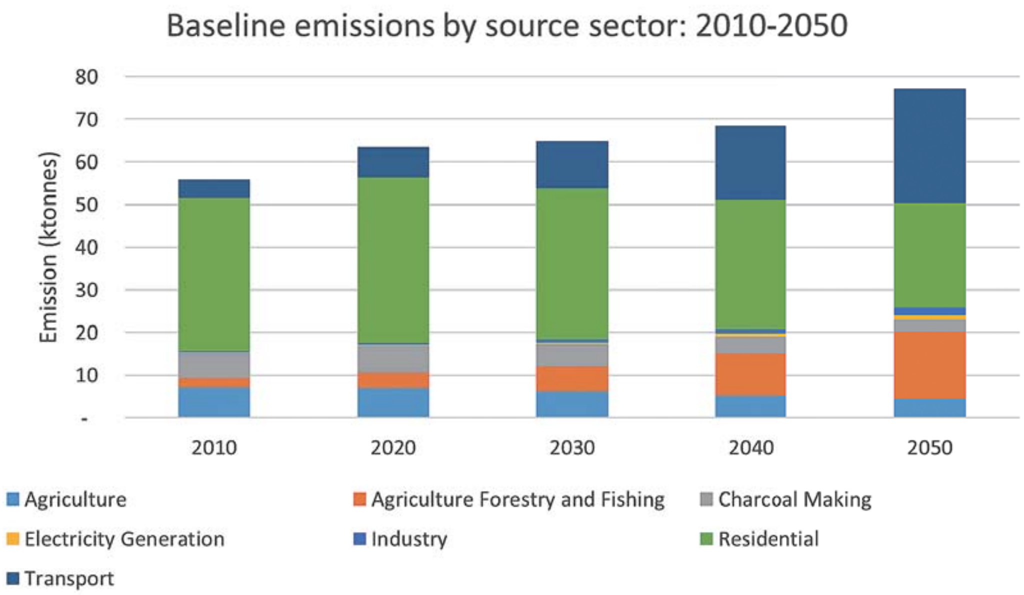

Figure 2.5: Illustrative example of baseline emissions from 2010-2050 output from LEAP for a fictitious country

2.4. Uncertainties in Using LEAP-IBC

Application of LEAP-IBC requires emissions to be projected into the future, generally based on changes in activity data linked to changes in socioeconomic drivers GDP, population, economic structure and technological change. These projections are inherently uncertain since they depend on political decisions yet to be made. The results generated by LEAP should not be considered as forecasts of what will happen, but rather as scenario-based explorations of the implications of alternative plausible futures.

Emission factors contain an uncertainty in the experimentally derived values, but there is potentially larger systematic uncertainty in transferring an emission factor derived in one region to the same activity in another region, with different factors altering the emissions from that source.

In undertaking an impact assessment, the GEOS-Chem-derived coefficients quantify the sensitivity of $PM_{2.5}$ concentrations in the target country to NOx, SO_2, NH_3, BC and OC emissions in grid squares across the world. These sensitivities are calculated for a base set of emissions, for the year 2010. The coefficients are applied in IBC to look at changes in $PM_{2.5}$ concentrations in the target country that result from changes in emissions in that country and across the world. They are linear coefficients, which means that a change in emissions results in a linear increase/decrease in $PM_{2.5}$ concentrations in the target country. The methodology therefore does not account for non-linear changes in target $PM_{2.5}$ concentrations resulting from non-linear chemical reactions in the atmosphere, e.g. combination between NOx, SO_2 and NH_3 to form secondary inorganic aerosol. For ozone, the GEOS-Chem Adjoint coefficients quantify the sensitivity of ozone concentrations in the target country to NOx, VOC, CO and CH_4 emissions in grid squares across the world. As for $PM_{2.5}$, these coefficients are also linear. Ozone formation depends on the relative emissions of VOC and NOx, with ozone increasing due to increasing NOx emissions in VOC-limited regimes, and due to increasing VOC emissions in NOx-limited regimes. Hence changes in the relative emissions of NOx and VOCs will result in non-linear changes in ozone concentrations. This interaction is not taken into account in the application of the ozone coefficients in IBC. The effect of the linearization of these atmospheric processes is discussed in Henze et al. (2007).

In quantifying impacts, the health impact assessment estimates premature mortality associated with $PM_{2.5}$ and ozone exposures, using concentration-response functions that have been used by the GBD project (Cohen et al. 2017; Forouzanfar et al. 2016). These concentration-response functions are based on health effects research that has been carried out in North America and Europe. It is assumed that the same relationships apply in other regions of the world, including those where $PM_{2.5}$ and ozone concentrations are much higher, and where the composition of $PM_{2.5}$ may differ. However, there is now evidence from nearly 115 studies that have reported a high degree of consistency between risk estimates for short-term air pollution exposure and mortality and morbidity reported in Asian studies and studies in other parts of the world (Pope and Dockery 2006).

Similarly for crops, agricultural crop yield loss is estimated using concentration-response functions that quantify the relationship between wheat, maize, rice or soy yield and ozone exposure. These functions are based on experiments carried out in North America, that assessed this relationship for ozone exposure between 20 and 90 ppb (Adams et al. 1989; Lesser et al. 1990). The relationship between yield loss and ozone exposures above 90 ppb is uncertain. To avoid unrealistic estimates of ozone-induced yield loss, for ozone concentrations above 90 ppb, there is assumed to be no increase in yield loss. This means that for mitigation scenarios to show a benefit for ozone crop yield loss, ozone concentrations must be reduced to below 90 ppb, e.g. a reduction from 110 ppb to 100 ppb in ozone exposure does not result in an estimated reduction in yield loss.

2.5. Understanding Implementation Pathways to Support National Planning

The quantitative analysis developed as part of LEAP-IBC provides estimates of the benefits of taking action to reduce SLCPs (or air pollution or greenhouse gas emissions) both historically and for scenarios at different points in the future. However, they make up only one component of the overall national planning activities that are undertaken within the CCAC SNAP initiative. The overall approach is included within the SNAP national planning guidance document (for example, see: http://bit.ly/2nPcH2K) and is adapted to the circumstances of individual countries.

In addition to the LEAP-IBC analysis, key additional processes which are undertaken include:

1. Prioritization of mitigation actions;
2. Identification of barriers to implementation;
3. Stakeholder engagement; and
4. Monitoring and evaluation protocol.

Setting strategic policy priorities is ultimately a judgement for ministers, but this can be supported by relevant information on the opportunities, constraints, costs and timescales associated with each of the emitting sectors and available mitigation options. For any country to set priorities, additional information is required including:

- major barriers to the implementation of the relevant measures;
- an inventory of processes, institutions, planning and policies relevant to the implementation of relevant measures;
- assessment of lag times from identification of a problem, decision to do something about it, and the actual implementation and emission reductions;
- costs of implementing the policy or strategy, and costs of the measure itself.

From an analysis of these factors, stories for the implementation of the measures can be developed and implementation pathways for the different measures identified. This can be done on a sector by sector or measure by measure assessment of opportunities and constraints, and as a basis for identifying a mitigation strategy for each of the relevant areas. In circumstances where resources and time are inevitably limited, some broad judgements of priority between sectors and measures have to be made. This can be informed by stakeholder engagement.

There may be several barriers to the implementation of key measures, due to financial, technical, institutional or other reasons, such as:

- lack of equipment to monitor emissions from vehicles as required by policy;
- increased operation and maintenance costs of moving from one fuel to another (e.g. to CNG from diesel);
- limited awareness of the importance of issues in key ministries;
- lack of data for emissions from new technology (e.g. new cook stove designs);
- weak or poorly enforced emission standards;
- lack of cost-benefit information;
- limited data (e.g. on venting of methane from coal mines); and
- lack of capacity in the private sector (e.g. to measure methane leakages).

A process for monitoring and evaluating progress towards the achievement of the national action planning is required to assess how the strategy is progressing. It is necessary to monitor all actions that have taken place, especially if they are outside of the direct control of those who have the mandate to focus on SLCPs. The action plan needs to make sure that the progress and focus on SLCPs continues, and allows mid-course corrections to be undertaken. The evaluation will enable assessment of whether countries have achieved what they set out to do. The monitoring and evaluation process needs to be outlined as part of national action planning.

2.5.1 The Bangladesh Case: 2013 to Present

The first SLCP national planning document for Bangladesh aimed at long-term mitigation of SLCPs within a time-frame from 2005-2030, including all the major emission sources on which action could begin immediately. In addition, the plan also analysed the information, capacity and finance gaps which would need to be filled to ensure effective long-term mitigation measures for reducing SLCPs from the sources. This plan also identified priority mitigation measures that could be mainstreamed into existing government programmes and suggested new national initiatives which could adopt international action programmes. Only 12 of the 16 abatement measures recommended by the UNEP/WMO (2011) global assessment for black carbon and methane were found to be relevant in the Bangladesh context and parboiling of rice was added as a Bangladesh relevant measure (see Section 2.2). The Bangladesh relevant measures were prioritised according to their relevance, as well as opportunities and barriers to their implementation. Then the assessment of key abatement measures was made through detailed analyses of existing and planned (draft) policies, rules and regulations; ongoing and future programmes/projects in different sectors; and through extensive consultation with stakeholders.

During the development of the first national planning document in Bangladesh quantitative assessment of benefits for each of the mitigation measures was not possible as the IBC part of LEAP-IBC was still under development and was only able to assess impacts on human health from PM exposure. However, seven criteria were used for the qualitative evaluation of the abatement measures: 1) impacts; 2) time to introduction; 3) time to benefit; 4) technical effectiveness; 5) implementation effectiveness; 6) tentative cost and 7) potential co-benefits. The second SLCP national planning document for Bangladesh has been developed using the latest version of LEAP-IBC in 2017 and consists of: 1) major sources and effects of SLCPs; 2) emission status of SLCPs; 3) the identification of mitigation measures to reduce the SLCPs; 4) preparation of a strategic action plan for reducing SLCPs and 5) priority measures for reducing black carbon and methane and evaluating opportunities and barriers to their implementation; 6) estimated benefits achievable through implementation of identified measures through application of benefits calculator, with the support from SEI and 7) preparation draft document on NAP for SLCP. Following preparation of the new draft version, detailed implementation strategies are being developed. The strategies will contain the mapping of current policies, policy frameworks, programmes and projects; possible implementation options and pathways; and delivery mechanisms for each measure. The possible pathways will be analysed to determine which measures could be most effectively integrated into the policymaking context of the country. This pathway analysis will be carried out through identification of the major actors, technologies and policy systems. The strategy will focus on two separate questions:

- How would any strategy fit within the overall planning process in the country?
- What are the potentially available delivery mechanisms for individual sectors?

For sustainable and efficient implementation of the final prioritized set of SLCP measures, a well-structured monitoring and evaluation plan is being developed by the Department of Environment, Bangladesh, in collaboration with relevant stakeholders. It is being developed to assess the objectives of the implementation process and the planned activities to determine whether they are appropriate and effective.

2.6. Future Work and Challenges

This chapter has shown how a tool such as LEAP-IBC, which is user-friendly and adaptable to national circumstances, can be used effectively to inform decision-making and implementation of measures for SLCP mitigation. It provides a quantitative assessment of the effect of different policies and measures on air quality, human health, vegetation impacts, climate change, and energy efficiency, and whether the effects on these areas are synergistic, or whether there are trade-offs. Many of the mitigation actions that could be taken to improve air quality or reduce GHG emissions can result in much broader economic and societal impacts. Understanding how to include the implications of implementation of new technologies is necessary to more fully understand potential trade-offs of mitigation actions for different populations. For example, gains in efficiency in different sectors, such as the brick kiln sector, can lead to a loss of livelihoods for many people and such consequences need to be taken into account, even qualitatively, for effective governance and social cohesion.

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Chapter 3: Assessing Co-benefits from Nepal's Brick Kilns: Measurement Opportunities and Challenges

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3.1. Introduction

In many parts of Asia, brick production plays a critical role in the development and expansion of housing, buildings, and infrastructure. In fact, some studies suggest that Asia is responsible for 90% of the total 1.5 trillion bricks produced per year globally (CCAC 2015). As many countries in Asia experience population increases and changing consumption patterns, the brick sector is likely to witness even more rapid growth. This growth cannot only help meet a fundamental need for shelter but provide employment. For instance, in Bangladesh the brick industry provides about one million jobs; the industry provides about ten times that amount in India. Further, because kilns are often small enterprises that employ migrant workers, they help alleviate poverty for vulnerable segments of the population. In short, the brick sector can deliver multiple benefits throughout Asia.

But the impacts that the brick industry in Asia are not wholly beneficial. The firing of brick kilns generates air pollution. Much of the emitted pollution are short-lived climate pollutants (SLCPs) (chiefly black carbon) that degrade air quality, threaten human health, and contribute to near-term climate change. This is particularly the case with the most affordable but inefficient bull trench kiln that tend to bring the highest short-term investment returns (USEPA 2012). The impacts of pollution from bull trench and other inefficient technologies can be even more serious because of tendency to cluster kilns together, leading to large clouds of particulate matter (PM) that intensify the effects of emissions on exposed populations. Because owners of the kilns often are not intimately involved in day-to-day kiln operations and are poorly informed about new technologies and operating practices, there can also be limited knowledge and incentives to change the technologies and practices behind the air pollution (USEPA 2012). In recent years, however, policymakers and researchers have begun demonstrate the potential to reduce emissions and generate other co-benefits from more efficient brick kilns.

Part of the push to reduce emissions is led by the Climate and Clean Air Coalition (CCAC). The CCAC–a voluntary a multi-stakeholder partnership formed in 2012 to accelerate and scale efforts to mitigate SLCPs–has found that replacing outdated with modern technologies "during the firing of bricks, can result in reductions of pollutant emissions from 10 to 50%, depending on the process, scale and fuel used" (CCAC 2015). Findings like these have motivated the CCAC to work with policymakers in Latin America to bring bricks into the nationally determined contributions (NDCs) and nationally appropriate mitigation action (NAMAs) that countries have pledged to the United Nations Framework Convention on Climate Change (UNFCCC). In Asia, the CCAC has focused on mobilising finances and technical support for the brick industry in Nepal.

3.2. The Case of Bricks in Nepal

The growing interest in mitigating harmful emissions from brick kilns has gained momentum from research showing that the emissions could be mitigated by switching to more efficient kilns. Options such as zig zag kilns, rather than the bull trench technologies, have potential to reduce emissions; other changes such as switching to hollow-brick production could deliver further reductions (Heierli and Maithel. 2008; Weyant et al. 2014). The overall impacts of these shifts was not only contingent on technologies, however. It would also depend upon the kiln design, fuel use and operation and maintenance of the new technologies. Many of changes required altering entrenched and longstanding production practices. In India, for example, fixed chimney kilns have been in use for over a century and still account for nearly 70% of the total brick production (Lalchandani and Maithel 2014).

One of the reasons changes to technologies and practices and policies in the sector have become more feasible is a better understanding of the magnitude of the harmful impacts of brick emissions. In a particularly relevant study in Nepal's Kathmandu Valley, 95% of the residents in the surveyed area experienced respiratory disease in the past year. This number was striking when compared with only 51% of the control population suffering respiratory effects. Even if there were other factors contributing to ill health, the significant gap between the affected and control population suggests a high correlation between residents' proximity to brick kilns and adverse impacts on respiratory systems (Joshi and Dudani 2008). The remainder of this chapter reviews efforts to alter kiln design and production processes and then quantify emission reductions from that same region in Nepal.

3.2.1 Changing Kiln Designs and Production Processes in Nepal

When Nepal experienced a serious earthquake in 2015, many of the country's kilns suffered damages at the same time as other buildings and infrastructure experienced similar structural impacts. This meant the many kilns would need to be rebuilt so that they could provide the bricks to help reconstruct parts of the country affected by the earthquake. The combination of their own internal damages and the surge in demand for bricks created an opportunity to introduce less polluting technologies and production and operating practices.

Some of the key changes involved the overall structure and stacking of the bricks. The key switch in this regard was from conventional fixed bull trench to a zigzag technology. The latter configuration ensures greater heat as the firing is structured around a zigzag across 16 or more chambers. In a zigzag kiln, hot air cools gradually because it moves through multiple chambers, thereby saving heat and fuel (Guttikunda and Khaliquzzaman 2014). Some of the other changes listed below concentrated on the kiln design.

- Chimneys: During the 2015 earthquake, the kiln chimneys were the part of the kilns most impacted by the seismic activity. The mostly circular shaped chimneys were initially constructed with conventional practices that did not involve structural analyses that could potentially safeguard them from damages during earthquakes. Following the quake, a computational fluid dynamics analysis showed circular and square chimneys had similar discharge performances. The square chimney was furthermore easier to construct. Some of the reconstructed kilns then switched to square chimneys that adhered to safer Nepalese and Indian standard codes. Part of this safer redesign involved introducing a reinforced concrete frame in the chimney construction.
- Flue duct and inlets: Significant amounts of heat could be lost due to the design of flue ducts and inlets. A pressure loss calculation covering issues such as roughness, joints, friction and turbulence were given careful consideration in re-designing these parts of the kiln. Concrete pipes (Hume pipes) that were 40 inches in diameter were used to expedite construction.
- The outer wall: The temperatures inside kilns are typically higher than the temperature outside. There is often significant heat loss from the kiln through the main kill wall due to these differences. Compared to the conventional 18 inch wall, reconstructed walls were five feet wide. This helped to reduce the leakage of air by an estimated 40%.

- Wicket gates: The wicket gates openings on the outer wall of the kiln that facilitate the movement of bricks in and out of the kiln. There were three important considerations taken into account in redesigning the wicket gates: 1) minimum heat loss; 2) easy transportation of green and fired bricks; and 3) efficient access to green bricks in the dug. Heat loss and air leakage calculations led to a decision to switch to a more optimal number of six wicket gates (three on either side) along with a 10 feet wide opening for easy transport of the bricks.
- Floor: About 10-20% of the total heat input was lost due to high moisture content from the ground. Well-insulated floors reduce the heat loss and increase burning efficiency. Layered insulation consisting of rammed earth and sand aluminium sheets that were then topped by brick were introduced to reduce heat loss and boost efficiencies.

3.2.2 The Costs and Benefits of the Rebuilt Kilns

The cost of rebuilding was approximately USD 150,000 or 50% more than rebuilding the conventional kiln. Some of the costs were incurred when the chimneys were reinforced with steel, aggregate and cement to make them more stable. Increases in the wall height and width and additional soiling to make the floor thicker and better insulated were also part of the calculation. The need to have engineers on-site to supervise the reconstruction was added to the final cost figure, though in-kind support from entrepreneurs who wished to convert their kilns reduced labour costs. The costs for construction and materials depends heavily on context, and may vary in other countries.

The modified brick kilns generated multiple benefits that were greater than these costs. The list of benefits begin with financial savings. Estimates suggest that the payback period on the reconstruction costs were likely to fall within two years. This is partially due to the efficiencies from the structural changes as well as zigzag technology that save more energy than straight-line stacking of bricks. The operating costs are much less for zigzag stacking, in part, because this approach allows for continuous firing that enables uniform baking and produces higher quality bricks. The baking process also tends to be much faster, reducing the number of days per cycle of brick production.

There were also positive effects on emissions that are central to co-benefits analysis. When bricks are stacked in a zigzag pattern, less residual coal is needed due to efficiency gains in combustion. The amount of coal saved per cycle of brick production is around 4 to 5 tonnes. These effects were actually important drivers for entrepreneurs to switch technology because they were so visually apparent. When the burning becomes efficient and complete combustion happens, the thick black smokes emitted from the stack become less visible white smoke. These visible impressions are supported by measurement that showed the modified kilns were producing up to 40% less PM and black carbon emissions. Calculating these reductions is nonetheless not easy.

3.2.3 Calculating emission reductions

Emission measurements were conducted with a newly fabricated instrument developed by University of Illinois, Urbana and Mountain Air Engineering. The instrument is the appropriately named the “ratnoze” since rats have a keen sense of smell. The ratnoze is a portable sampling system specifically designed for measuring solid fuel combustion emissions. The system can be used for measuring emissions brick kilns, and other large and small scale industrial combustion sources with and without exhaust stacks. The ratnoze includes a sensor box, probe, carrying case, and accessories; it can be used to conduct emission sampling for $PM_{2.5}$, PM_{10}, CO, CO_2, SO_2 and black carbon.

Even with the ratnoze, emission measurement from the kilns are challenging. Part of the challenge is brick baking is a continuous process as the kiln operates 24 hours a day. This necessitates collecting samples; sampling duration of eight hours were used for data collection.

To understand the impacts of the changes to design and production, specific energy consumption and emission measurement were performed in the modified and traditional kilns. This required a significant amount of logistical legwork prior to the actual sampling. For instance, it was important to engage the kiln owners prior to the sampling to assemble scaffolding and ensure there was access to an electric power line. These preparations were needed both to support the eight hour sampling of emissions as well as measuring energy and brick production.

For the emissions, the ratnoze and flue gas analyser were used to measure real-time concentrations of gaseous and particulate pollutants. Filter samples were collected for gravimetric $PM_{2.5}$ mass determination. Real-time pollutant concentrations from the ratnoze and flue gas analyser were used to calculate emission factors for CO_2, CO, PM, VOC and SO_2 in an application of the carbon mass balance method.

In addition to the emissions factors, the other key variable–the total amount of fuel fed during the sampling period–was calculated by counting the number of spoons that fed the fuel in the firing zone along with the average weight of fuel in each spoon. The product of average weight of one spoon of fuel and the number of spoons used to feed the fuel can be employed to calculate the total amount of fuel used to fire a specified number of bricks. Coal is the primary fuel used to fire bricks. Sawdust, rice husks, bagasse, charcoal, briquette, and other sources are often secondary fuels, either separately or mixed with coal. A fuel sample was taken for the ultimate/proximate analysis and a specific energy consumption was calculated for each kiln.

Moving from the straight-line bull trench kilns to the zigzag kilns would bring about an emission reduction of approximately 30% in CO_2 emissions. Black carbon and PM emission factors were even lower in zigzag kilns compared to straight line bull trench kilns for both per kg of fuel and per brick produced. The reasons for the relatively greater reductions for black carbon and PM is that the stacking pattern of zigzag kilns itself acts like a filter and reduces the PM emissions. This suggests that converting traditional bull trench kilns to zigzag can bring about 20% of PM and 60% of black carbon reduction.

3.2.4 Challenges to quantifying emissions reductions

There were several challenges to arriving at accurate estimates of emissions. Some of these were technical in nature; others involved the less manageable changes to the broader political environment.

- The scaffolding: Most of the brick kilns in South Asia do not have a measurement platform on the chimney. Hence a temporary structure (height greater than 40 ft) from bamboo and wood (basically with local materials) has to be erected before the measurement. Safety precautions also need be taken during the measurement.
- Instruments handling: Many of the instruments accumulate dust from the emissions during the measurements. Making the instruments functional requires extensive cleaning in addition to numerous and repeated calibration and validation runs. This can also lead to additional costs for servicing and maintenance of the equipment.
- Weather conditions: Excessive heat, wind, rain, and thunderstorms are some of the weather-related challenges that can make it risky for researchers to engage in continuous measurements.

- Political unrest: Unexpected changes in local politics, riots and strikes can make it difficult to perform planned and ongoing measurements. Measurement efforts have to be stopped immediately and researchers in the field need to relocate to safe places in event there is an outbreak of unrest. This may also cause a repetition of kiln measurement in the same area along with additional unplanned costs for completing the study.

These challenges were in many ways offset by the fact that the switch to the more efficient kilns was not so complicated. The modified kilns are not very different from the kilns which the entrepreneurs have been operating. Thus adopting few changes was easy to handle. Coal saving, better quality bricks and reduced baking time were some of the factors that made the shift appealing. The reductions in emissions were another set of influential factors.

3.3. Conclusions

About 330 billion bricks are produced annually in South Asia. This regional total contributes approximately 0.94 million tonnes of PM; 3.9 million tonnes of CO, and 127 million tonnes of CO_2 per year. Shifting from traditional bull trench to zigzag technologies can reduce CO and PM emission by 40% to 60%. Emission measurement coupled with energy monitoring is critical to the attaining those kinds of reductions. If the region is only able to reduce 40% of the emission there will be a huge benefit on climate and health. Globally, air pollutants have been shown to cause as many as 7 million premature deaths every year, destroy millions of tonnes of crops, and contribute to climate change. Further climate change has important regional dimensions. Glacier retreat with increased risk of glacial lake outburst floods, changing monsoon patterns and attendant effects on food security and reduced visibility are some of the associated other problems which could be minimised. These benefits would likely help persuade policymakers and kiln owners to expand the number of modified kilns in and beyond South Asia. Working toward a standardised set of methods for quantifying emissions, as is done in this chapter, can add to those efforts.

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Chapter 4: Assessment of the Impacts of Regulations for In-use Heavy-duty Diesel Vehicles and the Timing of Policy Implementation Using the GAINS Model: Case of the Tokyo Metropolitan Region

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4.1. Introduction

The transport sector plays a crucial role in both air pollution and climate change. It contributes to ambient air pollution, which causes millions of premature deaths worldwide each year. The sector also consumes more than half of global oil production and is a source of nearly a quarter of anthropogenic carbon dioxide (CO_2) emissions. Among the sources of such emissions, diesel fuelled heavy-duty vehicles, including commercial freight trucks and buses, require special attention. While the share of heavy-duty vehicles is only 11% of motor vehicles worldwide, they contribute disproportionately to oil consumption, greenhouse gas (GHG) emissions and air pollution. It is estimated that they are responsible for almost half of vehicle CO_2 emissions and over two-thirds of vehicle particulate emissions (Kodjak 2015). Particulate emissions also affect the climate forcing, and the warming effects of black carbon, which intercepts and absorb sunlight, are increasingly drawing attention (UNEP and WMO 2011). For those reasons, the control of diesel heavy-duty vehicles is important not only to protect human health but also to mitigate climate change.

Tailpipe emission standards to control motor vehicle emissions have been introduced in many parts of the world since they were first established in California and the United States (US) in the late 1960s. In North America, Europe and Japan, more stringent emission standards have been developed and adopted following improvements in research on the adverse effects of pollution as well as technical solutions. In Asia, most countries, except Japan, have chosen to adopt the European tailpipe emission standards and associated clean and low-sulphur fuels. Table 4.1 summarises the development of emission standards for heavy-duty vehicles in select Asian countries as well as the European Union (EU) and US (Yang, Muncrief, and Bandivadekar 2017).

Table 4.1: Timelines for the phase-in of heavy-duty vehicle emission standards for some Asian countries, EU and the US (simplified by the authors based on Yang, Muncrief, and Bandivadekar 2017)

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<tr><th></th><th>1990</th><th>1991</th><th>1992</th><th>1993</th><th>1994</th><th>1995</th><th>1996</th><th>1997</th><th>1998</th><th>1999</th><th>2000</th><th>2001</th><th>2002</th><th>2003</th><th>2004</th><th>2005</th><th>2006</th><th>2007</th><th>2008</th><th>2009</th><th>2010</th><th>2011</th><th>2012</th><th>2013</th><th>2014</th><th>2015</th></tr>
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<tr><td>EU</td><td colspan="2">Since 1970</td><td colspan="4">Euro I</td><td colspan="4">Euro II</td><td colspan="5">Euro III</td><td colspan="3">Euro IV</td><td colspan="5">Euro V</td><td colspan="3">Euro VI</td></tr>
<tr><td>US</td><td colspan="8">Since 1968</td><td colspan="6">US1998</td><td colspan="3">US2004</td><td colspan="3">US2007</td><td colspan="6">US 2010</td></tr>
</table>

Notes
(1) This table is simplified and does not distinguish whether the standards were in place from the beginning of the year or enforced later in the year. For example, Euro II to IV were implemented in October but the figure simply indicates the adoption from the beginning of the year.
(2) For the Japanese standards, the acronyms indicate the followings. STES: short-term emission standards. LTES: long-term emission standards. NSTES: new short-term emission standards. NLTES: new long-term emission standards. PNLTES: post new long-term emission standards. Starting years for LTES and NSTS vary depending on the vehicle weight. The table shows those for vehicles over 3,500 kg.

While emission standards are effective in reducing the emissions from new vehicles, their immediate impact on air quality is limited as long as in-use vehicles with higher emission rates are still on the road. Therefore, this chapter sheds lights on regulations for in-use vehicles, by examining the case of regulations implemented in the Tokyo Metropolitan Region (TMR) in Japan in the early 2000s.[3] The regional effort to enforce emission standards on all vehicles on the road, including in-use diesel trucks and buses, in October 2003 was followed by a significant improvement in terms of attainment of the environmental quality standard (EQS) for suspended particulate matter (SPM).[4] However it is not straightforward to identify exactly how much this improvements can be attributed to TMR diesel regulations because they were not the only regulations implemented in the area. Other regulations on diesel vehicles were being implemented at the same time, including the national emission standards targeting new vehicles and the Law Concerning Special Measures to Reduce the Total Amount of Nitrogen Oxides and Particulate Matter Emitted from Motor Vehicles in Specified Areas (Automobile NOx and PM Law).

Therefore, this chapter aims to identify how much of an impact can be attributed to TMR heavy-duty diesel regulations, in terms of emission reductions, improvement in ambient air quality, reductions in premature deaths, and climate related impacts. For this purpose, the study employs the Greenhouse gas–Air pollution Interactions and Synergies (GAINS) model. As one of the features of TMR regulations was the concurrent implementation of different regulations, the chapter further examines the difference in impact if the timing of policy implementation had been different. In addition, the chapter estimates the costs associated with the implementation of the TMR regulations.

4.2. Case Study and Relevant Research

In the early 2000s, the Tokyo Metropolitan Government (TMG) was facing a challenge to meet the EQS at roadside stations: no roadside monitoring station in its jurisdiction attained the standard for SPM in 2001 or 2002. To tackle this situation, TMG enacted a ban across Tokyo on the use of diesel vehicles out of compliance with the emissions standards for particulate matter (PM) as a part of its ordinance in 2000. This scheme was unprecedented in Japan for two notable reasons: it was the first policy to be employed by a local government regulating the use of diesel vehicles; and it regulated not only new vehicles, but also in-use vehicles. Neighbouring prefectures soon followed suit and comparable ordinances were adopted by Saitama Prefecture (July 2001), Chiba Prefecture (March 2002) and Kanagawa Prefecture (September 2002). Thus, the ban on the use of non-compliant diesel vehicles came into effect across those four prefectures (making up the TMR) on 1 October, 2003 (Matsumoto 2015).

TMG soon thereafter declared the measure a success: the attainment ratio of EQS for SPM concentrations at roadside air pollution monitoring stations in Tokyo reached 97.1% in 2004—a marked improvement over the 0% in 2002 and 11.8% in 2003 (TMG 2014).

Several academic studies have since been conducted to assess the effectiveness TMR regulations. These studies arrived at the following conclusions:

- The elemental carbon (EC) emission factors were reduced as a result of the TMR diesel regulation, from 0.092g/vehicle/km in 2001 to 0.047g/vehicle/km in November 2003, based on the monitoring of EC concentrations of the fine particulate in a tunnel exclusive for automobile vehicles in Tokyo (Ishii and Tsukigawa 2004).

3 While there are various names and definitions to refer to the area surrounding Tokyo, TMR in this chapter refers to Tokyo and surrounding three prefectures, namely, Saitama, Chiba and Kanagawa.

4 SPMs are particles that pass through an inlet with a 100% efficiency cut off at 10 μm aerodynamic diameter. SPM differs from PM10 due to the difference in cut-off rates and approximately equivalent to PM7 if the same criterion is applied. The EQS for SPM indicates that the daily average for hourly values not exceed 100 μg/m³, and hourly values not exceed 200 μg/m³ (set in 1973).

- Exhaust particulate emissions from diesel-powered trucks and buses registered in Tokyo were reduced by 17% and 31% in 2003 and 2004 (Rutherford and Ortolano 2008).
- Mass concentrations of black carbon (MBC) decreased significantly from 2.6 μg/m³ to 0.5 μg/m³ between 2003 to 2010, which was mainly attributed to stringent vehicle emission regulations (Kondo et al. 2012).
- TMR diesel emission controls were associated with improvements in both air quality and reduction in mortality for all causes, cardiovascular disease, ischemic heart disease, cerebrovascular disease, pulmonary disease, and lung cancer (Yorifuji et al. 2011; Yorifuji, Kashima, and Doi 2016).

While there is generally an agreement that the TMR's programme improved the air quality, there is no consensus on exactly how many of these improvements can be directly attributed to TMR diesel regulations. This is partially related to the challenges of disentangling the impacts of TMR's and other diesel regulations such as the national emission standards and the Automobile NOx and PM Law. For instance, Rutherford and Ortolano (2008) concluded that the bulk of emission reductions after 2002 can be attributed to TMR regulations rather than national emission control policies. Yorifuji, Kashima and Doi (2016) also showed the potential additional effects of the TMR's diesel reduction, by comparing the decline in $PM_{2.5}$ and the age-standardised mortality rates of Tokyo's 23 wards with those of Osaka (where the NOx and PM Law started to be implemented at the same time, but the diesel emission control was not introduced until 2009 with less stringency). On the other hand, Iwata (2011) estimated that significant emission reductions can be attributed to vehicle-type regulations by the Automobile NOx and PM Law and the TMR diesel regulations provided additional reductions in this case.

4.3. Methodologies and Data

4.3.1 The GAINs model

The GAINS model is an integrated assessment model that can estimate the current and future emissions of pollutants based on activity data, uncontrolled emission factors, the removal efficiency of emission control measures and the extent to which such measures are applied (Amann et al. 2011). The model can also be employed to analyse the interconnections between different air quality problems, the interactions between pollutants in the atmosphere, and the interdependencies between emission controls across pollutants and source categories. Since the model is available as a web-based software package, it offers an easily accessible and practical tool to identify cost-effective emission control strategies and to improve air quality at the lowest cost by considering the previously mentioned interactions.

The GAINS model's highest profile applications involve international negotiations such as the Convention on Long-range Transboundary Air Pollution (CLRTAP). In these negotiations, the GAINS model helps focus debates on policy issues (e.g. desired levels of environmental quality, willingness to spend economic resources for such purposes and the distribution of efforts) by separating them from the multiple technical and scientific complexities that are described in GAINS based on generally accepted scientific understanding (Amann et al. 2011).

The application of GAINS has not been limited to Europe, however. In recent years, GAINS-China and GAINS-India have been developed, and various studies using the model in these countries have been conducted and published. For China, such studies include the analysis of nitrogen oxides (NOx) emissions (Zhao et al. 2013) and emission trends and mitigation options for air pollutants (Wang et al. 2014). For India, they include development of an emission inventory of non-methane volatile organic compounds (NMVOC) from anthropogenic sources (Sharma et al. 2015) and evaluation of black carbon emission inventories (Gadhavi et al. 2015). The GAINS model has also been used for regional scale analysis in East Asia. For example, Akimoto et al. (2015) employed GAINS to evaluate the changes in air quality in East Asia to assess different co-control scenarios of short-lived climate pollutants (SLCPs) in the region. Chen et al. (2015) used the GAINS model to estimate the cost of ozone and $PM_{2.5}$ emission reduction. The International Institute for Applied Systems Analysis (IIASA) and the Institute for Global Environmental Strategies (IGES) also applied the GAINS model to the transport sectors in Thailand, India, China and Indonesia to quantify the missed benefits due to governance failures as part of the research on "Measures to Address Air Pollution in China and other Asian Countries using a Co-Benefit Approach" commissioned by the Ministry of the Environment of Japan (MOEJ) in the fiscal years 2013 and 2014 (Amann et al. 2015).

4.3.2 Applying GAINS to TMR diesel regulations

To assess TMR diesel regulations, the GAINS model was used in the following steps. First, data on vehicle activity, emission factors, and control measures was validated and further updated by collecting related national and regional statistical data. Data collection was conducted for the years 2000, 2005, 2010 and 2015, corresponding to the five-year intervals that can be entered into the GAINS model. Further details on the data elements are presented in the following sub-sections (see the sections for activity data, emission data and abatement measures). Second, based on the collected data, the GAINS database was updated to more accurately reflect the situation in the TMR. Third, the model was run to estimate emissions, ambient concentrations, health impacts and climate impacts for alternative hypothetical scenarios with different assumptions on the timing of implementation of the diesel emission regulation policy. Fourth, the results of the estimations were analysed to identify the impact attributable to TMR diesel emission regulations, and to assess the impact of different timings of policy implementation. Fifth, the costs of the mitigation measures to comply with the TMR diesel regulations were calculated.

The GAINS model contains relevant databases not only for European countries but also for Asian countries. The database for Japan is based on ECLIPSE (Evaluating the climate and air quality impacts of short-lived pollutants) database (version V5a).[5] The GAINS model data was updated and calibrated for TMR using the local statistical data collected for this research.

The 47 prefectures of Japan are allocated to six regions in the GAINS model.[6] This allocation was used in particular for the association of data on energy supply and demand and for the transport data per prefecture. The association largely follows the regional classification employed by the Ministry of Economy, Trade and Industry (METI).

4.3.3 Activity data

The data items on which the local data was collected include: fuel consumption by fuel type (gasoline, diesel, gas); vehicle kilometres travelled by the vehicle categories (heavy and light duty trucks, buses, passenger cars and motorcycles); and age distribution and fleet turnover according to Japanese statistics. The sources of statistical data are listed in Table 4.2.

4.3.4 Emission data

Local parameters related to emission rates of NOx and PM by emissions standards according to Japanese measurements were drawn from a government-commissioned report on vehicle emission factors and total emission estimation (Suuri Keikaku 2015). Data used for recalibration include: emission factors and formula for

5 For the details of the ECLIPSE V5a, please see: http://www.iiasa.ac.at/web/home/research/researchPrograms/air/ECLIPSEv5a.html

6 They are: Hokkaido-Tohoku (Hokkaido, Aomori, Iwate, Miyagi, Akita, Yamagata, Fukushima), Kanto (Ibaraki, Tochigi, Gunma, Saitama, Chiba, Tokyo, Kanagawa), Chubu (Niigata, Toyama, Ishikawa, Fukui, Yamanashi, Nagano, Gifu, Shizuoka, Aichi), Kinki (Mie, Shiga, Kyoto, Osaka, Hyogo, Nara, Wakayama), Chugoku-Shikoku (Tottori, Shimane, Okayama, Hiroshima, Yamaguchi, Tokushima, Kagawa, Ehime, Kochi), and Kyushu-Okinawa (Fukuoka, Saga, Nagasaki, Kumamoto, Oita, Miyazaki, Kagoshima, Okinawa)

Table 4.2: Sources of Activity Data

Category	Statistical source	Publisher
Fuel consumption (total)	General Energy Statistics	Agency for Natural Resources and Energy
Fuel consumption (vehicles)	Statistical Yearbook of Motor Vehicle Fuel Consumption (up to 2005) Statistical Yearbook of Motor Vehicle Transport (after 2010)	Ministry of Land, Infrastructure and Transport
	Fuel Sales by Prefecture	Petroleum Association of Japan
Vehicle kilometres travelled	Statistical Yearbook of Motor Vehicle Fuel Consumption(up to 2005) Statistical Yearbook of Motor Vehicle Transport (after 2010)	Ministry of Land, Infrastructure and Transport
Vehicle fleet	Number of Vehicle Fleet Average Vehicle Age by Vehicle Class	Automobile Inspection and Registration Information Association

computation (by regulation year and speed); accumulated vehicle kilometres travelled (by vehicle category and age); and deterioration adjustment coefficient factor function (by pollutants, vehicle category, fuel, first year of registration).

4.3.5 Abatement measures

Abatement measures and different after-treatment options are explicitly represented in the GAINS model. They penetrate the fleet to different degrees of fleet turnover as a function of policies, e.g. through market uptake, forced retirement or incentives. In the case of TMR regulations, the reduction in PM emissions due to retrofitting with particulate control devices such as diesel particulate filters (DPFs) or diesel oxidation catalysts (DOCs) was also taken into account. Due to the lower efficiency of PM reduction of DOCs, not all vehicles could technically comply with the TMR's regulation by using DOCs. Old vehicles not meeting the 1994 standard needed to be retrofitted with DPFs, which were more expensive (Yokemoto and Hiruta 2004).

4.3.6 Modelling of ambient PM concentrations and health impact assessment

A new set of source-receptor relationships was implemented to calculate concentrations of ambient PM. The source-receptor coefficients were derived from a set of sensitivity simulations performed with the full chemical transport model by the European Monitoring and Evaluation Programme (EMEP) (Simpson et al. 2012) for the meteorological year 2015. They reflect the contribution of local and regional sources of primary PM and its precursors on concentrations of $PM_{2.5}$ on a 0.5°×0.5° grid, with additional calculation of local concentration increments in urban areas. The precursors considered in this study included sulphur dioxide (SO_2), NOx, ammonia (NH_3), and volatile organic compounds (VOC). Both the dispersion of primary PM as well as the chemical formation of secondary inorganic and secondary organic aerosols in ambient air are also considered.

The population distribution as well as the death rates by age and disease for Japan were updated (UN DESA 2011; Forouzanfar et al. 2015). The estimation of health impacts, quantified by the number of premature deaths due to exposure to ambient $PM_{2.5}$, was updated following the methodology of the Global Burden of

Disease 2013 (Forouzanfar et al. 2015) and the 2016 Assessment on the Burden of Ambient Air Pollution by the World Health Organization (WHO 2016). Integrated exposure-response functions for cause specific mortality from five diseases (Ischemic Heart Disease, Chronic Obstructive Pulmonary Disease, Lung Cancer, Stroke, and Acute Lower Respiratory Infections) (WHO 2016) were implemented in GAINS and used to calculate the attributable number of deaths as a function of exposure to ambient PM concentration.

4.3.7 Data required for climate impact assessment

The GAINS model can calculate the change in radiative forcing for each policy scenario, based on the emissions estimates of both potent climate forcers (such as black carbon) and cooling agents (such as SO_2). The coefficients for radiative forcing were drawn from the published forcing assessments for greenhouse gases (GHGs) and aerosols (IPCC 2007; UNEP and WMO 2011; Aamaas et al. 2016).

4.3.8 Cost data

The costs to comply with the TMR's diesel regulation depends on decisions made by the vehicle owners. If an owner chose to retrofit the vehicle with a certified control device, the costs would include the purchase and installation of the retrofit device, possibly also additional maintenance costs. When the owner replaced the vehicle with a new vehicle meeting the new emission standards, the costs would be the opportunity costs for the shortened use-life of the vehicle, possibly also a loss in its resale value. Data for the unit costs for retrofitting were taken from Yokemoto and Hiruta (2004) and the opportunity costs of vehicle replacement were adopted from Arimura and Iwata (2015). The number of vehicles subject to the regulation and the data of the ratio of retrofit and replacement was based on the study by Ishii and Tsukigawa (2004).

4.4. Development of Alternative Policy Scenarios

In order to estimate the emissions reduction attributable to TMR diesel emission regulations and to examine the possible impacts of different timings of implementation, four policy scenarios were developed based the current legislation (CLE) as a reference point (Table 4.3). The first policy scenario was a hypothetical reference scenario with only national vehicle standards for new vehicles to model the emissions without the other two regulations actually implemented in the TMR (CLE without NOx and PM Law). The second was a hypothetical scenario modelling one of the additional regulations, which regulates vehicle registrations and operations in major metropolitan areas in addition to the national standards (CLE with NOx and PM Law). The third scenario models was the actual policy package, which factors in TMR diesel vehicle regulations on top of the assumptions of the second scenario (CLE with TMR diesel control). The fourth was also hypothetical but reflects the assumption that TMR diesel vehicle emission regulations would have been implemented five years earlier than the actual case (TMR diesel control early). The possibility was also examined of setting a scenario whereby TMR diesel vehicle regulations would have been introduced five years later than they actually were. However, it was decided not to include the case because the provisions of the NOx and PM Law would have had almost the same effect if the TMR regulations had been delayed. Hence, it was assumed that a delay in Tokyo's regulations equals (almost) the CLE scenario with the NOx and PM Law.

The scenarios assumed that regulations lead to emission reductions by facilitating the fleet turnover or retrofitting pollution control devices such as DPFs or DOCs. It was also assumed that the implementation was successful (with no loopholes). Details of the national emission standards, Automobile NOx and PM Law, and TMR diesel vehicle regulations are provided below.

Table 4.3: Summary of Policy Scenarios

	National Standards	Automobile NOx-PM Law	TMR diesel regulation
	emission of new vehicles	*registration of new and in-use vehicles*	*operation of in-use vehicles*
CLE without NOx-PM Law	Phased-in	Not introduced	Not introduced
CLE with NOx-PM Law		Implemented	
CLE with TMR diesel control			Introduced in 2003
TMR diesel control early			5 years earlier (1998)

4.4.1 National emission standards

Japanese vehicle emission standards, which are uniform throughout the country, are set based on the Air Pollution Control Act. These standards are applied to new vehicles and have been tightened gradually (MLIT 2016). All the policy scenarios in this study assume that the nationwide vehicle standards have been introduced and enforced following actual policy development. Table 4.4 shows the historical development of the emission standards for new heavy-duty trucks and buses (> 3.5 t).

Table 4.4: Vehicle Emission Standards for New Vehicles (Diesel Heavy Duty Vehicles, > 3.5 t)

Name of the emission standard	Starting year	Test mode	CO (g/kWh)	HC (g/kWh)	NOx (g/kWh)	PM (g/kWh)
Short-term	1994	D13	9.2	3.8	7.8/6.8	0.96
Long-term	1998		7.4	2.9	4.5	0.25
New short-term	2003		2.22	0.87	3.38	0.18
New long-term	2005	JE05	2.22	0.17	2.0	0.027
Post new long-term	2009		2.22	0.17	0.7	0.010
Year 2016	2016	WHTC/ WHSC	2.22	0.17	0.4	0.010

Sources: MLIT 2016

The introduction of more stringent vehicle emission standards requires reducing the sulphur content in diesel fuel. In Japan, sulphur contents have been lowered in a stepwise manner. The limit was lowered from 2,000 ppm to 500ppm in 1997, further tightened to 50 ppm in 2005, and made even more stringent to 10 ppm in 2007.

4.4.2 Automobile NOx and PM Law

In addition to the nationwide regulations, further regulatory measures were introduced in congested metropolitan areas, namely, TMR, Osaka/Hyogo Metropolitan Area, and Aichi/Mie Metropolitan Area, based on the Automobile NOx and PM Law. The Law was enacted in 2001 adding PM as a controlled pollutant to the preceding Automobile NOx Law. In those designated areas, vehicles (trucks, buses, special vehicles and diesel passenger vehicles) not meeting specified emission standards were prohibited from being registered and operating. These regulations on registration and operation based on vehicle type can be categorised as vehicle-type regulations (VTR) (Arimura and Iwata 2015; Iwata 2011; Iwata and Arimura 2009). The specified standards for vehicles heavier than 3.5 tonnes were the same as the national long-term regulations (applied in 1998) for both NOx and PM. For vehicles up to 3.5 tonnes, the PM standard was set at half the level of new short-term regulation (applied in 2003), while the NOx standard was the same as the one for the heavier vehicles (Refer to Table 4.4 for the details of the standards).

This law is unique as it regulates in-use vehicles and enforces earlier replacement of older vehicles with vehicles meeting more stringent emission standards (Iwata and Arimura 2009). As the timing of the ban depends on the initial year of registration, the assumptions about the fleet turnover were modified in the GAINS dataset based on the table of vehicle lifetime in the designated areas by Iwata and Arimura (2009). When the vehicles registered in the designated areas failed to meet the standards, the owners had various choices: either to retire the old fleet without replacement, replace the vehicles with new ones, or register them outside the designated areas. This analysis assumed that most truck owners would choose to purchase the same type of new vehicle to comply with the regulations, following the assumptions employed by Iwata and Arimura (2009).

4.4.3 TMR's emissions regulation on in-use diesel vehicles

The ban on the use of diesel vehicles that are not compliant with PM emission standards is also known as operational regulations (OR) (Arimura and Iwata 2015; Iwata 2011). As mentioned in Section 2, this ban came into effect across TMR (Tokyo, Saitama, Chiba and Kanagawa) in October 2003.

The in-use vehicle emissions standard employed in the TMR regulations corresponds with the national long-term PM emission standard for new vehicles (nationally enforced in 1998 for new vehicles). In Tokyo and Saitama, the standard was strengthened in 2006 by applying the values for the national new short-term regulations (nationally enforced in 2003 for new vehicles).

Alternatives for the owners of non-compliant vehicles were either to retrofit the vehicle with approved PM reduction devices (DPFs or DOCs) or to replace the vehicle with a new one complying with the standard. The study referred to Ishii and Tsukigawa (2004) and Rutherford and Ortolano (2008) for the numbers of the vehicles which had taken such measures to set assumptions about the fleet turnovers.

The major differences between the Automobile NOx and PM Law (VTR) and TMR's diesel emission regulation (OR) are summarised in Table 4.5.

4.4.4 Assumption about enforcement

As noted above, this chapter assumed that the regulations were implemented without loopholes. Although perfect enforcement might sound optimistic, various sources support assumptions on the high-rates of compliance of vehicle-related regulations in Japan.

While enforcement of the emission standards is a common challenge in motorised countries, Japan, along with the United States and Republic of Korea, is considered to be one of the countries with the most comprehensive compliance and enforcement programmes for vehicle emissions and energy efficiency in terms of legal framework, conflicts of interest prevention, resource sustainability, and testing design (Yang, Muncrief, and Bandivadekar 2017).

Table 4.5: Summaries of Automobile NOx and PM Law and TMR's regulation

		Automobile NOx and PM Law (vehicle type regulation: VTR)	PM (g/kWh) (operational regulation: OR)
Target pollutants		NOx, PM	PM
Regulated vehicles		Vehicles registered in the designated area	All vehicles that operate within the participating municipalities (including in-flow traffic)
Vehicle classes		Trucks, buses, special purpose vehicles, and diesel passenger vehicles	Diesel trucks, buses, and special purpose vehicles
Emission standards	NOx	Long-term regulation	Not regulated
	PM	> 3.5t: long-term regulation	Long-term regulation (In Tokyo and Saitama, new short-term regulation since 2006)
		Up to 3.5t: 50% of new short term regulation	
Start of implementation		October 2002	October 2003
Grace period		8-12 years since the first registration (depending on the first registration, preparation period can be granted)	7 years since the first registration
Enforcement measures		Vehicle Inspection and Maintenance	Inspections (on-road, distribution centres)
Penalties		imprisonment (up to 6 month) or fines (up to JPY300,000)	Publication of the names of violators and fines up to JPY500,000.
Economic incentives		Preferential treatment of automobile acquisition tax related to vehicle replacement. Tax exemption for purchase of low pollution vehicles.	Financial support for the cost of retrofitting PM reduction devices. Low-interest loans for purchase of low emission vehicles.

Source: MOEJ website, modified by authors based on Nagai 2004; MOEJ and MLIT 2002

As for the actual impact of the Automobile NOx and PM Law, the survey results by the Japan Automobile Manufacturers Association (JAMA) in 2005 found that most truck owners chose to purchase the same type of new vehicle in response to the regulations while only a few vehicle owners decided on vehicle retirement (Iwata and Arimura 2009).

With respect to the TMR diesel regulations, studies suggest high rates of compliance (Yokemoto and Hiruta 2004; Ishii and Tsukigawa 2004). Ishii and Tsukigawa estimated that approximately 80% of the vehicles registered in Tokyo had taken measures to comply with the regulation (i.e. either replaced with cleaner vehicles or installed the emission devices) by the time the regulation was enforced (Oct 2003), and approximately 90% had taken such measures by the end of the year. It is worth noting that the enforcement on the ground was further facilitated by an information campaign and subsidies (Matsumoto 2015). The total financial support provided across the TMR for installation of emission reduction devices to in-use vehicles was estimated to be JPY17.8 billion in total, indicating that addressing diesel vehicle emissions was a high priority for the prefectures in the TMR. The local governments also introduced incentives in conjunction with financial institutions to offer low-interest loans to purchase low-emission vehicles (Nagai 2004).

4.5. Results

Based on the above data and methods, the estimates were calculated on the total emissions of pollutants, composition of the primary PM emissions, ambient $PM_{2.5}$ concentrations, and health impacts, as shown in Figures 4.1 to 4.4 below.

4.5.1 Total Emissions of pollutants

Total emissions were calculated for each region of Japan, following the classifications in the GAINS model. Figure 4.1 shows the estimates for NOx, $PM_{2.5}$ and black carbon emissions in the Kanto region, which consists of seven prefectures, including three other prefectures (Ibaraki, Tochigi, Gunma) in addition to the four TMR prefectures.

It shows that the national policy alone, i.e. the prescription of more stringent emission standards for new vehicles, would have led to a significant reduction in air pollutants. It also demonstrates that the combination of the Automobile NOx and PM Law and the TMR's diesel vehicle regulation would have accelerated the reduction in pollutant emission, by approximately five years for PM and black carbon. It further indicates that the NOx and PM Law would have provided the majority of the accelerated emission reduction.

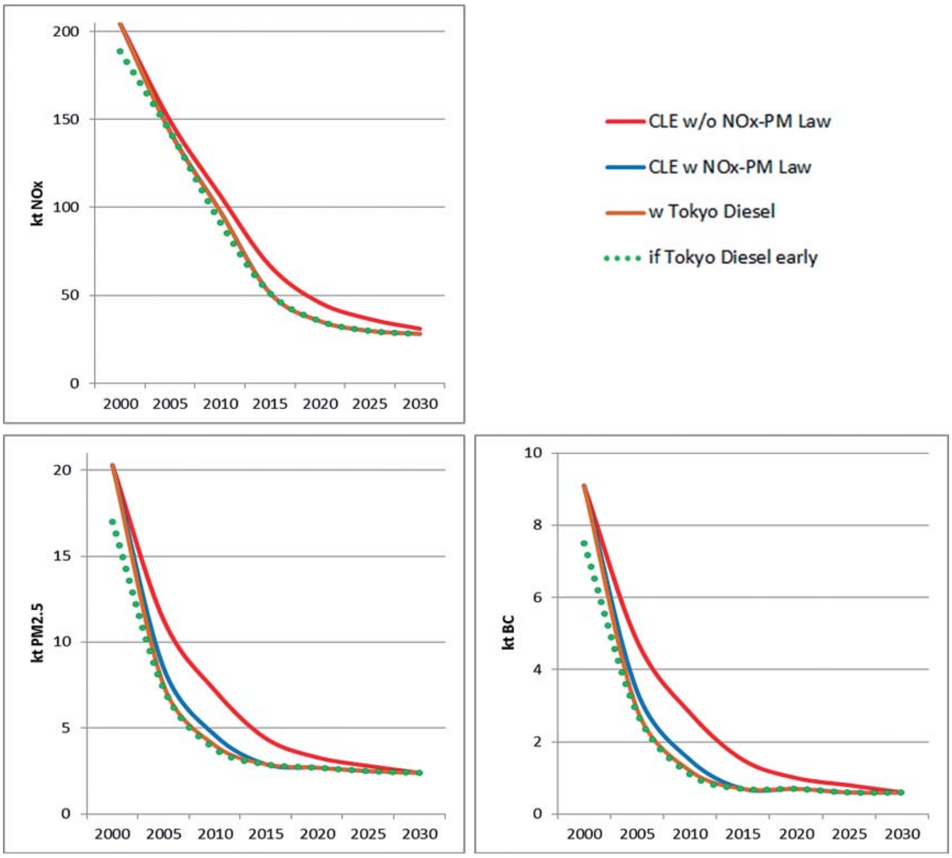


Figure 4.1: Development of NOx, $PM_{2.5}$ and black carbon emissions from road vehicles in the Kanto region

Purely national policies without and with the NOx and PM Law are compared to the actual legislation, including the Tokyo diesel vehicle regulation as well as their accelerated introduction.

Comparing the two scenarios in which TMR regulations were adopted but at different times (CLE with TMR diesel control and TMR diesel control early), no significant difference could be observed for NOx, $PM_{2.5}$ and black carbon. It should be noted that this does not necessarily mean that early adoption of TMR regulations would have no impact. In fact, in the controlled analysis in the preliminary study where the NOx and PM Law was not factored in, it was estimated that five-year early adoption would have brought limited but visible impacts for $PM_{2.5}$ and black carbon. Thus, this result suggests any advantage of the early introduction of the OR would have been offset by the VTR. This implies that the impact of different timings of policy implementation would have been affected by other regulations.

4.5.2 Composition of the Primary PM emissions

Figure 4.2 shows the development of primary PM emissions and breakdown of the emission sources, not only from road vehicles but also all sources/sectors in the Kanto region. The red dotted lines show the total emissions if only national vehicle emission legislation had been introduced, i.e. without the NOx and PM Law for metropolitan regions and without the specific TMR diesel regulation. Although the study focuses on the transport sector, the modelling analyses for ambient concentration cannot be implemented without data for primary PM and precursor emissions from all sectors, as ambient concentration is a consequence of emissions of primary PM from all sources, as well as chemical formation resulting in the secondary pollutants and their transportation, dilution, and possible dissipation in the atmosphere.

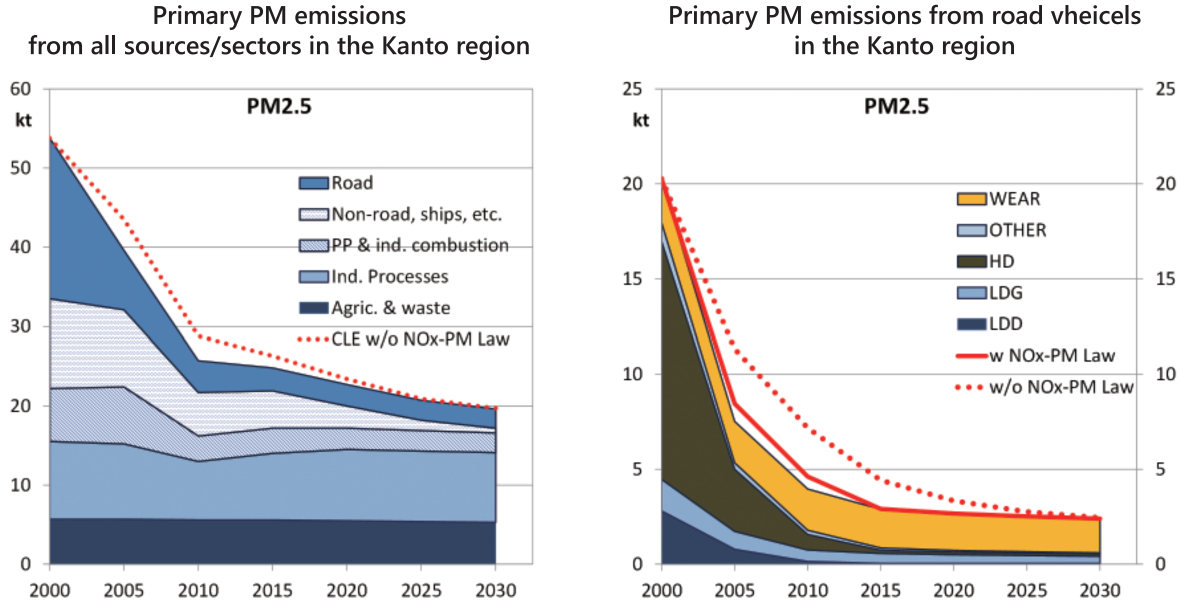


Figure 4.2: Development of primary PM emissions from all sources/sectors in the Kanto region (left) and from road vehicles only (right)

Red dotted lines are the emissions if only national vehicle emission legislation had been introduced. (PP: power plants, WEAR: wear from roads, tires, and brakes, HD: heavy-duty vehicles, LDG: light-duty gasoline fuelled vehicles; LDD: light-duty diesel fuelled vehicles)

Before the introduction of the TMR's diesel regulation in 2003, road transport contributed almost 40% to the emissions of primary PM in the Kanto region. This share however quickly dropped to 20% in 2005 with the accelerated introduction of the DPFs, and further declined to only 12% from 2015 onwards. Thus, road transport had the biggest reduction rates from all sectors, not least as a consequence of the regulations.

However, because of the declining share of road transport to total primary PM emissions, the difference between the scenarios is estimated to become smaller. It should be also noted that with decreasing tailpipe emissions and increasing traffic volume, the absolute amount of non-exhaust emissions, i.e. wear from roads, tires and brakes, is projected to become the dominant source of primary PM emissions from road vehicles from 2015 onwards.

4.5.3 Ambient $PM_{2.5}$ concentrations

Figure 4.3 shows the ambient $PM_{2.5}$ concentrations estimated based on the emissions of primary PM and of precursor gases. Roughly 40% of ambient $PM_{2.5}$ concentrations in Kanto are estimated to be primary PM, the rest is secondary PM as well as natural dust and sea salt. One quarter of total $PM_{2.5}$ in Kanto is estimated to originate from sources outside the Kanto region. In addition, more than 80% of ambient $PM_{2.5}$ in the Kanto region were attributed to sources other than road vehicles.

The figure shows that the ambient $PM_{2.5}$ concentrations decreased significantly by 25% between the year 2000 and 2010 under the combined influence of the NOx and PM Law and TMR's diesel vehicle regulation. In absolute terms, this corresponds to a reduction by 4 to 5 µg per m³ on population weighted average. The reduction rate then would decline: the ambient concentrations are expected to decline only by another 2-3 µg per m³ for the next 20 years.

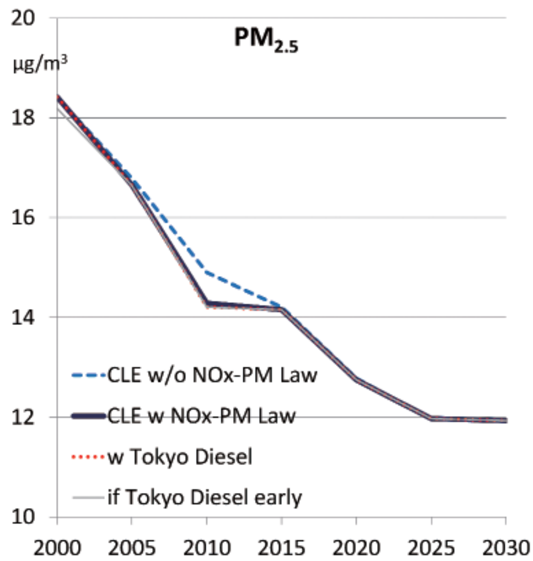


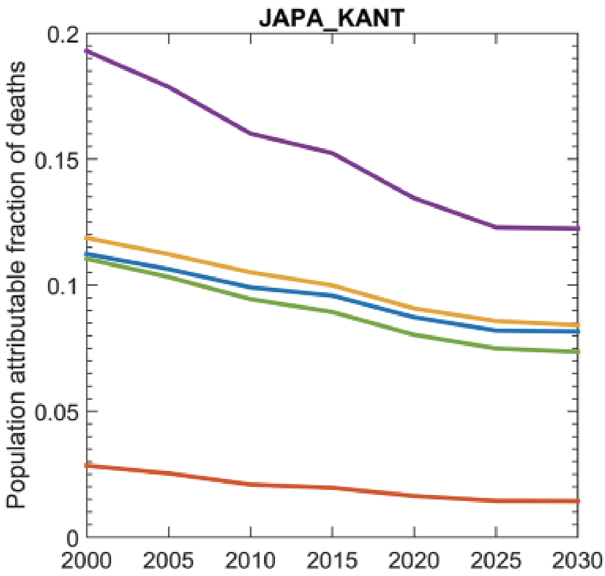
Figure 4.3: **Trend in the ambient (population weighted) $PM_{2.5}$ concentration in the Kanto region for the different scenarios**

The figure suggests that TMG diesel vehicle regulations have only a marginal influence on this development; ambient PM concentrations were slightly lower with Tokyo's policies than without (visible e.g. in the year 2010), and concentrations could have been even a little lower if the diesel vehicle ban had been implemented five years earlier. However, it can be inferred that the most important policy was the NOx and PM Law mandating the deregistration of the oldest and most polluting diesel vehicles. TMR diesel vehicle regulations added to the earlier regulations and were more stringent, but the phasing-out of the oldest vehicles displayed the biggest single effect.

4.5.4 Impacts on mortality

Figure 4.4 shows trends in premature death data (due to acute lower respiratory infections, chronic obstructive pulmonary disease, ischemic heart disease, lung cancer and stroke), attributable to ambient $PM_{2.5}$ over time in the Kanto region. The data in Figure 4.4 represent the share premature deaths attributable to $PM_{2.5}$ in total deaths. As expected, decreasing ambient concentrations of $PM_{2.5}$ lead to a decreasing attributable relative burden of air pollution related deaths.

However, when the total mortality is considered, the contribution of improvement in the air quality is estimated to be outweighed by demographic effects. Overall death rates more than doubled between the years 2000 and 2030, despite better living conditions. This is largely a reflection of the rapid aging of the population. Therefore, the total number of premature deaths attributable to ambient $PM_{2.5}$ level is projected to increase over time regardless of the exact vehicle emission control standards.



Legend:
ALRI: Acute lower respiratory infections;
COPD: Chronic obstructive pulmonary disease;
IHD: Ischemic Heart Disease;
LC: Lung Cancer; Stroke

Figure 4.4: Development of premature deaths attributable to ambient $PM_{2.5}$ over time in the Kanto region, shown as share of total deaths, as a function of the five diseases associated with air pollution

The impact of both the NOx and PM Law and TMR diesel vehicle regulations is estimated by comparing with a counter-factual scenario assuming adoption of national vehicle emission standards only if neither policy in place ("CLE without NOx and PM Law"). It is estimated that 500 to 600 premature deaths would have been avoided by the NOx and PM Law and by TMR diesel vehicle regulations (Figure 4.5). The impact reaches a peak in the years with the biggest difference in emission and ambient concentrations, i.e. around the year 2010, and then peters out towards 2030 as the differential impact on the vehicle fleet and its emissions became marginal.

4.5.5 Climate related impacts

The diesel control measures have both mitigating and warming impacts on climate change. The accelerated introduction of the DPFs contributes to a strong reduction in emissions of diesel soot (calculated here as black carbon), which is also a potent climate forcer. On the other hand, the application of the filters requires the introduction of

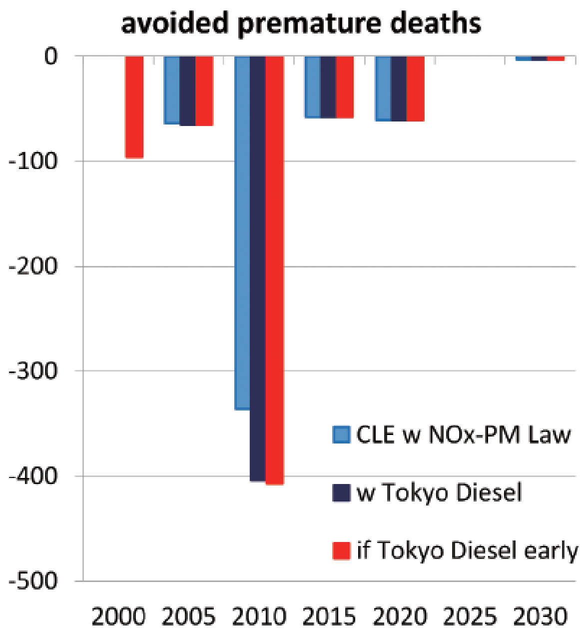


Figure 4.5: Avoided premature deaths attributed to less ambient $PM_{2.5}$ in the Kanto region following the introduction of the NOx and PM Law and of Tokyo's Diesel Vehicle Regulation

low-sulphur fuels, and thus leads to lower emissions of SO_2, which acts as a cooling agent in the atmosphere. Using the GAINS model, the balance was calculated by applying the radiative forcing potentials of each emission component to the emission estimates discussed previously, as shown in Figure 4.6. The figure shows that the reduction in diesel soot would outweigh the opposite effect from the desulphurisation of the fuel. Forcing is estimated to be reduced in all emission control scenarios, with the highest visibility in the period 2000-2015 where emissions differ most. It also indicates that TMR diesel regulations would have had a significant climate mitigation advantage over the case where only the national standards and the Automobile PM and NOx Law had been enforced. Furthermore, it shows additional climate impacts for the case where TMR diesel policy would have been implemented five years earlier.

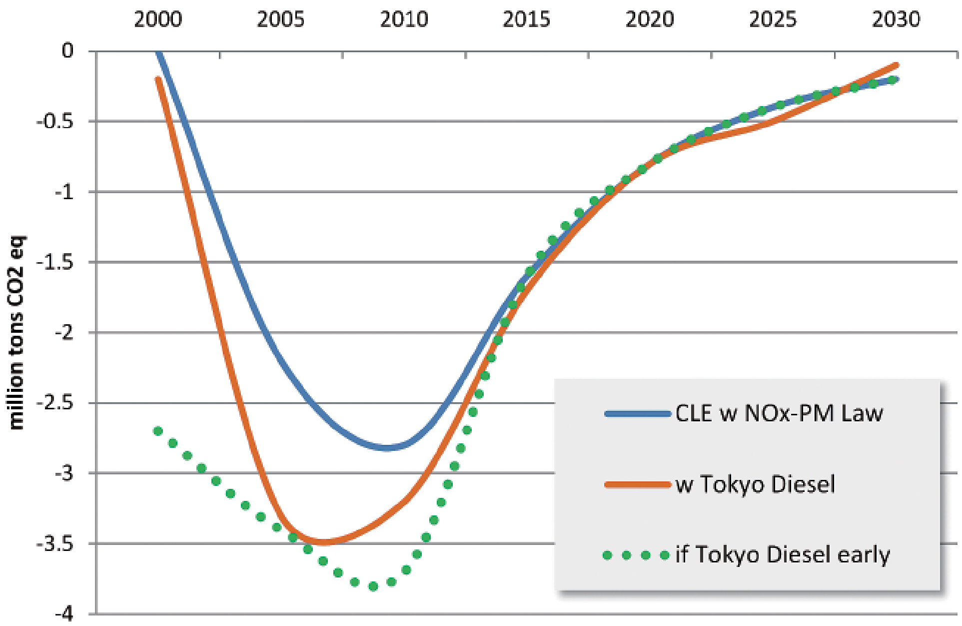


Figure 4.6: Difference in climate forcers in the Kanto region when accounting for all greenhouse gases and air pollutants using the Global Temperature Change Potential with 20 years horizon as metric

4.5.6 Additional costs to comply with TMR diesel control

Due to the difference in the grace periods for the Automobile NOx and PM Law and TMR diesel regulations, TMR regulations shortened the operating life of vehicles compared to the case with NOx and PM Law only (Table 4.5). The reduced years varied from one to five years depending on the vehicle classes (Yokemoto and Hiruta 2004). Under these circumstances, the choices for the vehicle owners were: (1) retrofitting with certified devises; (2) replacing with new vehicles meeting the long-term regulations or new short-term regulations; or (3) stopping operation. Drawing on the data on associated costs for each category and actions taken by the vehicle owners, this chapter found that the costs associated with the first implementation phase would have amounted to approximately JPY50 billion for the vehicles registered in the TMR (Table 4.6).

Table 4.6: Summary of cost calculation: Number of vehicles affected, unit costs and resulting total costs (For the vehicles registered in the TMR only).

	Number of vehicles affected[a]	*Percentage to the total*	*Unit costs [million JPY]*	*Sub-total [billion JPY]*	*Total costs [billion JPY]*
Retrofit	52,000	26%	~85%: DOC @ 0.30[b] (0.3-0.5)	13.3	22
			~15%: DPF @ 1.1[b] (0.8-1.5)	8.6	
Replacement (opportunity costs)	127,000	63%	~ 0.23[c]		29.2
Stop operation	23,000	11%	-/-	-/-	-/-
Total	**202,000**				**51**

a): TMG (2014) / Ishii & Tsukigawa (2004). b): Yokemoto & Hiruta 2004. c) Arimura and Iwata (2015)

4.5.7 Uncertainties and caveats

While the analysis presented above was based on the best available data for TMR and the updated assumptions about transport legislations and their enforcement, the data and model structure of GAINS does not allow for equally detailed implementation of the information. The GAINS model requires aggregations and simplifications, which lead to the following uncertainties. First, as the temporal resolution in the GAINS model is five years, additional assumptions were needed to reflect the impact of the legislation introduced in the years in between, such as TMR diesel policy starting in 2003. In this study, the detailed local data on the age structure of the fleet and kilometres driven were used to estimate the structures in 2005, 2010 and beyond. Second, the vehicle classes defined by the Japanese Road Trucking Vehicle Act did not perfectly match the specifications in the GAINS dataset. Therefore, the Japanese statistical data on vehicles was re-allocated into the four GAINS vehicle classes. Hence, there was a possibility of gaps in the estimates. Third, the estimate were based on the average emission factors, while the real-life emission factors vary depending on the time of the day due to factors such as traffic congestion. This also affects the accuracy of the estimated emissions.

With regard to the health impact assessment, the biggest uncertainty is the form and magnitude of the health response (i.e. premature deaths) to a change in ambient $PM_{2.5}$ concentrations. In particular, the current formulation from the Global Burden of Disease (GBD) Study assumes a relatively strong increase of the relative risk with increasing $PM_{2.5}$ concentrations at the low ambient concentrations observed and estimated in Japan, while the increase in relative risk is rather small for the high ambient PM levels found in Asian developing megacities. There is also considerable uncertainty about the existence of a lower threshold for impacts. Due to a lack of epidemiological evidence at low concentration levels, the GBD 2013 exposure-response functions used here assume no impacts of $PM_{2.5}$ exposure below concentrations of approximately 5µg/m^3, which are projected to be reached in some cleaner parts of Japan. In addition, the study assumes a proportionality of premature mortality to total $PM_{2.5}$ mass concentration and does not consider possible differences in toxicity of different components of PM (Kiesewetter et al. 2015).

However, since the same assumptions were used in each of the scenarios, the authors believe the differences between scenarios reflect rather accurately the impacts of analysed policy variants on emissions across the key source categories within the Kanto region.

4.6. Conclusion

The results of this modelling case study quantitively demonstrated the additional positive impacts of regulations on heavy-duty vehicles in the metropolitan area in terms of the emissions, air quality, health impacts and climate impacts, compared to the case where the regulations were limited to the national vehicle emission standards for new vehicles. The estimated emissions in the policy scenarios with the Automobile NOx and PM Law and TMR's diesel vehicle regulation were significantly lower than the scenario without those regulations, with the reduction of PM and black carbon accelerated by approximately five years. The estimates for ambient $PM_{2.5}$ concentrations, based on not only the emissions of primary PM but also of precursor gases, indicated that the ambient $PM_{2.5}$ concentrations significantly decreased by 25% between the year 2000 and 2010 under the combined influence of the NOx and PM Law and TMR diesel vehicle regulations. Regarding the health impacts, it was estimated that those vehicle emission regulations and their enforcement would have facilitated the reduction of several hundred premature deaths due to ambient PM in Kanto. The study further assessed the climate impacts attributable to heavy-duty vehicle regulations and concluded that the regulations had positive mitigation impacts. Further, the additional costs associated with the implementation of the TMR regulations were estimated to be approximately JPY50 billion for the vehicles registered in Tokyo metropolitan area. The estimates are subject to several uncertainty factors but provide a basis for comparison of impacts which would have resulted from different policy scenarios.

In terms of the relative contribution of different regulations, the results of both emission and ambient concentrations suggested that the VTR by the Automobile NOx and PM law had larger impacts than the OR by TMR regulations. As a result, the impact of the early adoption of TMR regulations was estimated to be short-lived, as the Automobile NOx and PM law would have a larger impact by promoting vehicle turnover once implemented. This indicates that the common perception that attributes significant improvement in the TMR during the 2000s solely to TMR regulations is not in fact accurate and any improvements should rather be understood as the outcome of a combination of multiple regulations at the national and regional levels. Such a breakdown of the contribution of different policy measures cannot be identified only with the *ex-post* monitoring of vehicle numbers or air quality measurement. This is where the strength of the GAINS model can be fully utilised, as the model can trace the reduction by linking emissions with the actual transport and energy activity data, considering the changes due to the regulations (i.e. vehicle turnover or reduction in emission factors) based on the existing data.

One cannot conclude, however, that the in-use diesel regulations were ineffective or unnecessary simply due to the relatively limited contribution to emission reductions. The important policy impact of the OR is that the operational restrictions were applied to all vehicles regardless of the area of vehicle regulations, while the VTR only affected vehicles registered in the regulated areas. It can be expected that the OR facilitated the adoption of cleaner vehicles or PM control devices on a geographic scale larger than the TMR. Furthermore, the implementation of the OR could have improved the effectiveness of the VTR, even in the cases when vehicle owners changed the location of vehicle registration to avoid the impact of regulations.

Interestingly, the assessment of the climate impacts suggested significant mitigation effects attributable to TMR diesel regulations. The reason why this chapter identified more distinctive climate impacts than the emission reductions and ambient concentration of $PM_{2.5}$ requires further investigation.

This chapter suggests that the Asian countries can consider regulating not only new vehicles but in-use vehicles to address the issue of air pollution from the transport sector. It showed that regulations on in-use vehicles require a relatively shorter period before the tangible environmental improvement can be realised. The results also implied that policymakers need to consider the composite effects of different levels of regulations, namely, national, regional and local regulations. For this purpose, GAINS is one of the tools that can be used to estimate impacts of individual regulations with different timings of regulations.

More specific policy implications include the following. First, emission control policies need to target the major contributor to air pollution. In the TMR's case, in-use heavy duty vehicles was the right target, as the roadside PM pollution was strongly related to emissions from diesel trucks, notably those without DPFs. Second, the availability of proven mitigation measures offering a significant reduction potential (in this case, DPFs and DOCs) and enabling conditions such as supply of low-sulphur diesel fuel is a prerequisite. Third, considering the transport of air pollutants and chemical reactions, cooperating with neighbouring local governments is important. Fourth, if the emission reduction rate between old and new vehicles is small, a policy targeting the phase-out of old vehicles will have only limited success. Last but not least, compliance and enforcement are essential for the successful implementation of policies.

Acknowledgements

This project is funded by the Ministry of the Environment, Government of Japan as a part of the project "Measures to Address Air Pollution in China and other Asian Countries using a Co-Benefit Approach" during Japanese fiscal years 2015 and 2016.

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Chapter 5: Estimating Co-benefits from Transport Projects in Southeast Asia Using the TEEMP Tool

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5.1. Introduction

Since 2005, Southeast Asia's population has grown 1.2% annually on average, resulting in 629 million people living in the region as of 2015. Projections suggest that continued rapid growth may bring the region's population to 713 million people by 2025 (Table 5.1). In addition, Southeast Asia's economic performance has been generally robust since the global recession slowed much of the world's development from 2007 to 2012. The region's average gross domestic product (GDP) growth rate was 4.8% between 2013 and 2015. This figure was only moderately lower than the pre-recession 5.1% rate in 2007 (Table 5.2).

Table 5.1: Population Estimates for ASEAN Member Countries

	Population			
	2014	2025	CAGR (1990-2013)	CAGR (2014-2025)
Unit	Million		%	
ASEAN	615	715	1.5	1.4

Table 5.2: GDP Estimates for ASEAN

	GDP			
	2014	2025	CAGR (1990-2013)	CAGR (2014-2025)
Unit	Billion USD		%	
ASEAN	2405	4034	5.1	4.8

Source: IRENA & ACE 2016

These data points are important because population and economic growth are often associated with increases in transport demand. As of 2012, the transport sector accounted for the second largest share of final energy demand in Southeast Asia. The total final energy demand for Southeast Asia grew from 274 Mtoe[7] in 2000 to 437 Mtoe in 2013. These figures may also increase sharply, particularly if the current 34% demand for motorised private two- and four-wheeled modes shifts upward (Figure 5.1)[8] Some sources suggest such an upward shift and limits on transport infrastructure could result in a worrying increase in transport energy demand by 4.5% per year between 2013 and 2025 under business-as-usual conditions in Southeast Asia (ASEAN 2017) (Figure 5.2).

7 Million tonnes of oil equivalent

8 The ADB Transport Databank Model is a spreadsheet-based tool that uses available data on vehicle stock, fleet characteristics, and transport activity to estimate fuel consumption and emissions based on policies that would avoid exceeding the 2-degree Celsius global temperature increase. It follows the approach of its predecessors: the ICCT Roadmap Model and the IEA Mobility Model (MoMo). The estimates in this study were made using the ADB Transport Data Bank model using assumptions on vehicle kilometers that are not country-specific. Many countries have limited country-specific data on vehicle kilometers, passenger kilometers, and ton kilometers. There are also limitations with respect to country definitions on vehicle types.

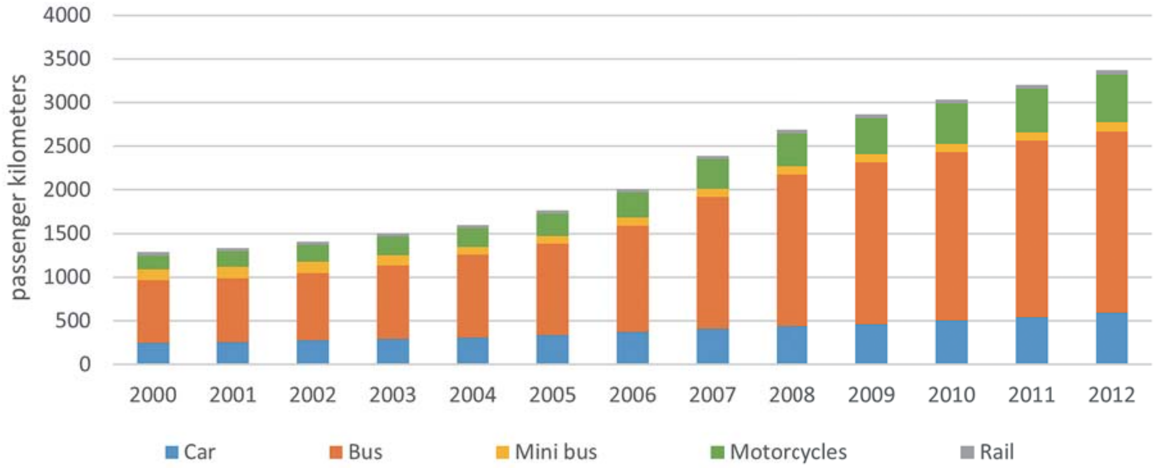

Figure 5.1: Estimated demand for land transport from 2000 to 2012 (Passenger kilometers)
Source: Asian Development Bank 2017

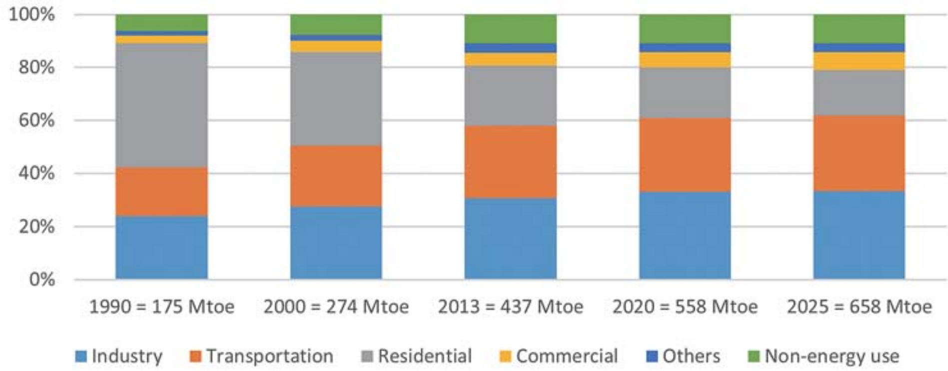

Figure 5.2: Total Final Energy Consumption in 1990, 2000 and 2013 by sector
Source: ASEAN 2015

One reason that the previous paragraph's projections are worrying is their impacts on the environment. As the demand for transport energy increases, the combustion of fossil fuels contributes to growth in carbon dioxide (CO_2) emissions. Using the Asian Development Bank (ADB) Transport Databank Model, it is estimated that the total energy consumption from the transport sector in Southeast Asia stood at about 149 Mtoe in 2015 (Figure 5.3-a) with emissions from the transport sector reaching 532 million-ton CO_2 (Figure 5.3-b)—a figure that is more than twice 2005 levels[10].

9 The ADB Transport Databank Model uses a bottom-up approach of modelling fuel consumption and emissions by modelling vehicle stock uptake, accounting for fuel efficiencies by vehicle type and fuel type.

10 The estimates were made using the ADB Transport Data Bank model using emission factors that are not country-specific.

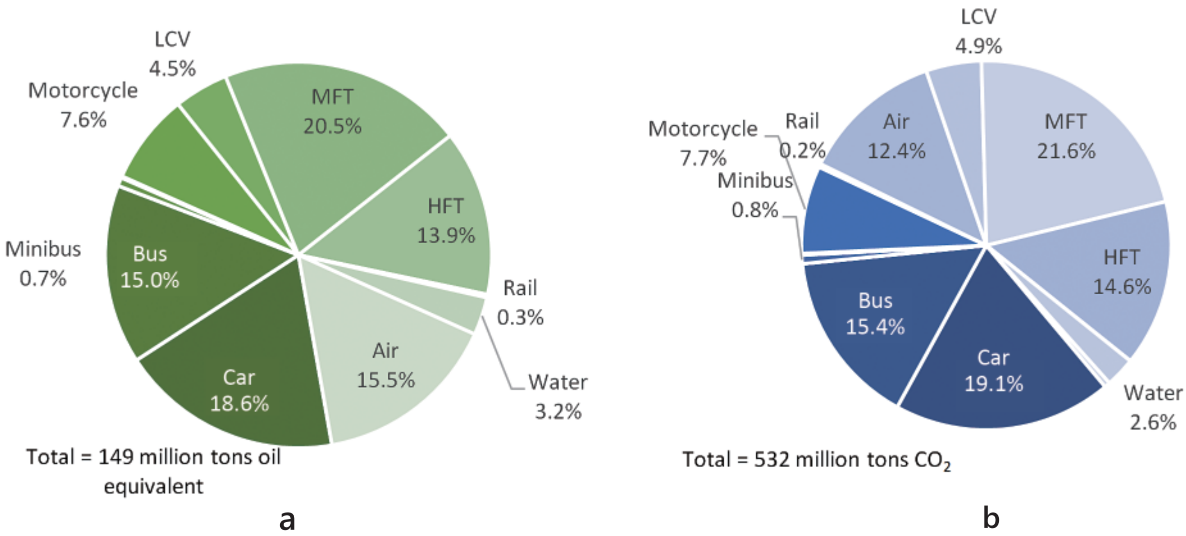

Figure 5.3: (a) Estimated total energy consumption and (b) CO_2 emissions from transport of Southeast Asian countries in 2015

Note: LCV = Light Commercial Vehicles, MFT = Medium Freight Trucks, HFT = Heavy Freight Trucks
Source: Clean Air Asia estimates using the ADB Transport Databank Model

To reverse these trends, estimating emissions from current and future transport scenarios is imperative. It is this realisation that has placed an emphasis on the methods and tools that allow for evidence-based decision-making. However, evidence-based decision-making requires data and emissions indicators. For example, without sufficient data it is impossible to understand the impacts of transport infrastructure on the environment and climate. Traditional tools and methods for evaluating emissions require investing significant financial and human resources to collect data. In rapidly motorising regions such as Southeast Asia, it can be a significant challenge to acquire such data. Simple, user-friendly tools to evaluate the impacts of transport projects are therefore a growing need in the region. The Transport Emissions Evaluation Model for Projects (TEEMP) was developed to meet this need.

5.1.1 Overview of the Transport Emissions Evaluation Model for Projects (TEEMP)

The TEEMP is a collection of freely downloadable spreadsheet-based tools or modules that can be employed to evaluate the impacts of transport projects.[11] Developed in 2010, the TEEMP is the result of the collaboration between Clean Air Asia, the Institute for Transportation and Development Policy (ITDP), ADB, Cambridge Systematics, and the United Nations Environment Programme (UNEP)–Global Environmental Facility (GEF) Scientific and Technical Advisory Panel. The TEEMP was initially developed for evaluating emissions from ADB's transport projects, and has since been modified and extended to GEF projects.

The TEEMP evaluates CO_2 emissions and PM and NOx emissions (for some interventions) from transport projects using simple equations and default values from feasibility studies and project operations. As noted previously, traditional approaches to modelling emissions often involve time- and labor-intensive methods for collecting transport data. For instance, the basic four-step model[12] requires trip generation surveys, network modelling, and simulation. Due in part to these requirements, data may be a significant constraint.

11 http://cleanairasia.org/transport-emissions-evaluation-model-for-projects-teemp/
12 The four-step model is a mathematical and statistical method of modelling and analysing a bounded traffic system. The four steps in the model involves modeling (1) trip generation & attraction, (2) trip distribution, (3) mode choice and (4) trip assignment.

To illustrate, an analysis of data limitations (Clean Air Asia 2012) in Asia showed that the minimum data needed for transport activity, fuel efficiency, and average occupancy are either sparse or non-existent (Figure 5.4).

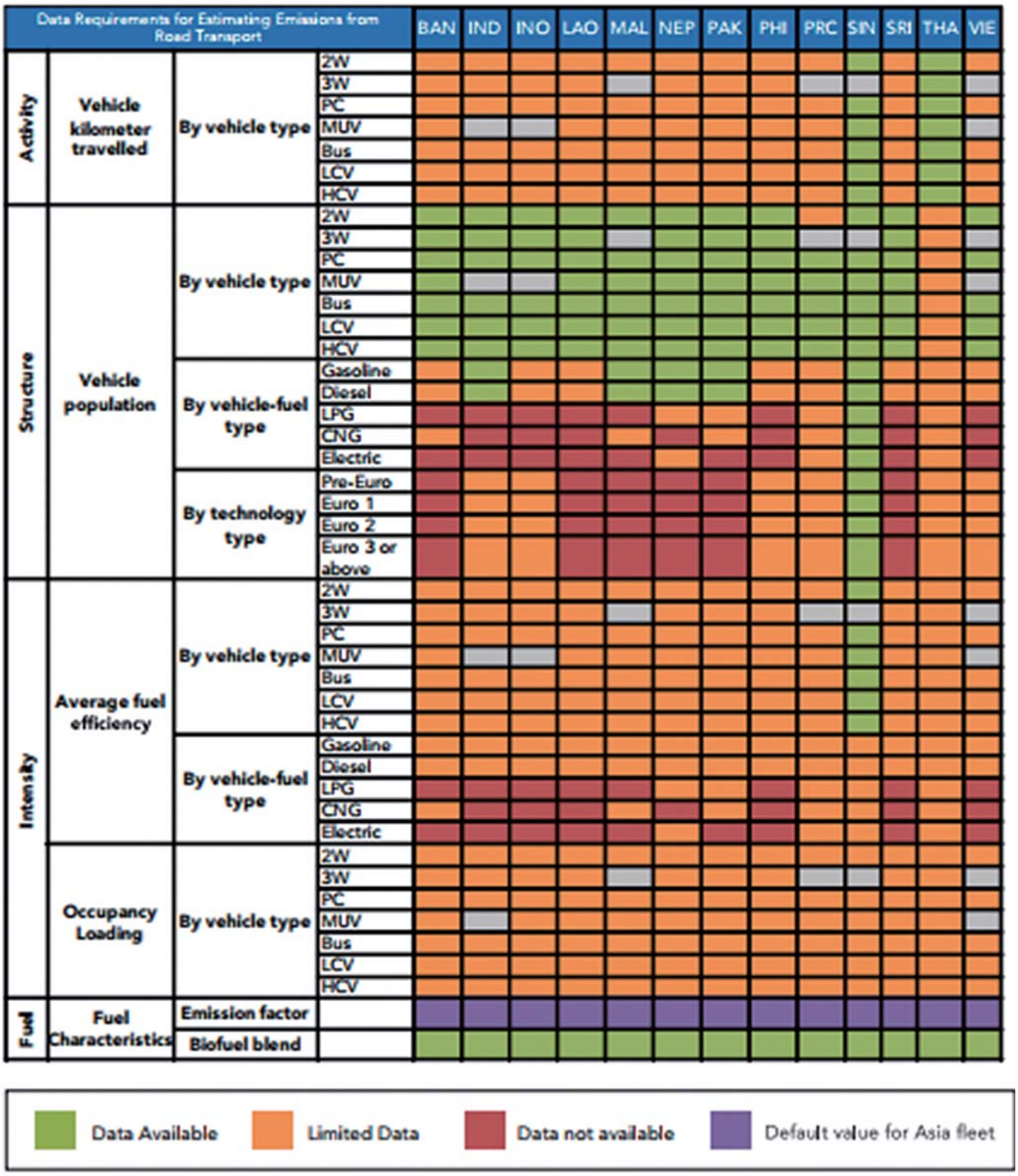

Figure 5.4: Overview of data availability of input parameters from selected countries in Asia
Source: Clean Air Asia 2012

TEEMP focuses on road transport projects. Since its development, several modules for TEEMP have been developed for different transport projects such as the bus rapid transit (BRT), bikeways and pedestrianisation, and city-level emissions assessment. Many of the modules focus on urban transportation, but some modules apply to non-urban projects (e.g. roads, railways).

The following TEEMP modules are currently available[13]:

- TEEMP Roads – This module allows for estimating the effects of a road project (expressways, urban road and rural highway) on the transport system over a user-specified number of years. The model incorporates assumptions on traffic elasticity and volume-capacity saturation limits in the calculations.
- TEEMP Railway – This module estimates emissions from rail projects and allows for comparison of the emissions impacts of a highway project of the same length and ridership. The emission estimates cover both operations and construction.
- TEEMP Metropolitan Rapid Transit (MRT) – This module estimates emissions by assuming the shift of ridership from road-based modes to the MRT.
- TEEMP BRT – This module estimates emissions of ridership shifting to a BRT by incorporating planned bus capacities and bus types.

TEEMP follows the ASIF[14] framework for estimating transport emissions (Figure 5.5).

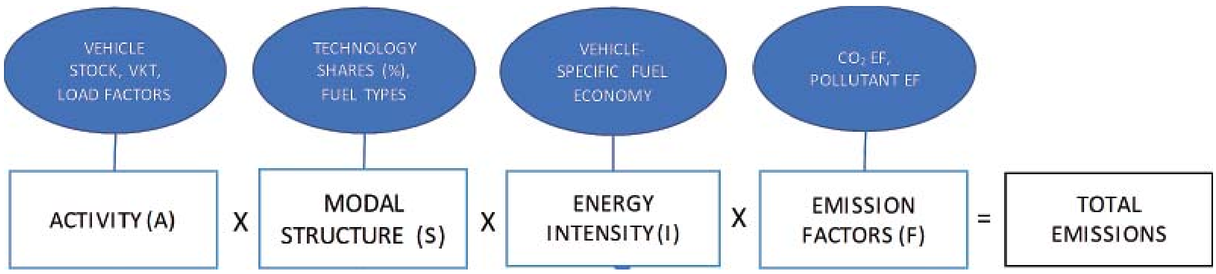

Figure 5.5: Activity, Structure, Intensity and Emission Factor (ASIF) framework for emissions estimation

The TEEMP are "sketch" models that enable the estimation of emissions for "with" and "without project" scenarios (Box 5.1). The TEEMP provides a rapid assessment of emissions that can then supplement more rigorous evaluations of environmental impacts. Further analysis on co-benefits such as improved safety, reliability, comfort would likely be needed as part of these assessments. A complete transport impact assessment, for instance, typically includes a road safety assessment to quantify deaths avoided. The TEEMP looks at emissions per project; it is not for a macro-level analyses. Although, as will be shown in the Philippines case study later in the chapter, it can complement analyses of national plans. The criteria for prioritising projects under these plans would be up to the decision-makers.

13 https://www.thegef.org/publications/manual-calculating-ghg-benefits-gef-transportation-projects
14 ASIF means Transport Activity, Modal Structure, Energy Intensity, and Emission Factors, pertaining to broad categories of transport data and indicators.

Box 5.1: TEEMP BRT Module overview

The TEEMP can evaluate impacts of project and no-project scenarios (baseline) and compare the difference between the two scenarios. TEEMP estimates project impact through a basic equation:

$$\text{CO2 Impact} = (\text{CO2}_{\text{Baseline}} - \text{CO2}_{\text{Project}})$$

Where:

CO2 Impact	= CO_2 emissions change due to the project (tons CO_2/year)
$\text{CO2}_{\text{Baseline}}$	= CO_2 emissions generated in the baseline scenario (tons CO_2/year), a scenario where the rail system is not put in place
$\text{CO2}_{\text{project}}$	= CO_2 emissions due to the project (tons CO_2/year), mainly through the operations

The baseline emissions are calculated by multiplying the supposed vehicle activity to be done without the operations of the project buses by the emission factors of the baseline vehicles.

$$\text{CO2}_{\text{Baseline}} = \sum_i \sum_a \left(\left(\frac{\text{VKT}_{\text{Baseline vehicle i,a}}}{\text{EE}_{\text{Baseline vehicle i,a}}} \right) * \text{EF}_{\text{a}} \right)$$

Where:

$\text{CO2}_{\text{Baseline}}$	= CO_2 emissions in the baseline scenario (tons/year), a scenario where the system/project is not put in place
$\text{VKT}_{\text{Baseline vehicle i,a}}$	= vehicle activity that would have been performed by baseline vehicle type *i*, fuel *a* in the absence of the BRT buses (vehicle-km/year);
$\text{EE}_{\text{Baseline vehicle i,a}}$	= energy efficiency of the baseline vehicle type *i*, fuel *a* (vehicle-km/liter)
EF_{a}	= emission factor of fuel *a* (kgCO_2/liter)

$$\text{CO2}_{\text{PROJECT}} = \sum_{PROJECT} \left(\left(\frac{\text{VKT}_{\text{PROJECT}}}{\text{EE}_{\text{PROJECT}}} \right) * \text{EF}_{PROJECT} \right)$$

Where:

$\text{CO2}_{\text{PROJECT}}$	= CO_2 emissions generated in the scenario (e.g. rail/BRT) project (tons/year) (refers to operation emissions)
$\text{VKT}_{\text{PROJECT}}$	= vehicle activity in the project scenario (rail/BRT) (vehicle-km/year)
$\text{EE}_{\text{PROJECT}}$	= vehicle fuel efficiency in the project scenario (vehicle-km/liter)
$\text{EF}_{\text{PROJECT}}$	= emission factor of diesel fuel (kgCO_2/liter); it is assumed that the BRT will be diesel

5.1.2 Structure of the TEEMP

Figure 5.6 shows an example of the parameters in the TEEMP BRT module. The tool calculates emissions savings as the difference between the "with" and "without project" scenarios. The user is asked to input values based on the project design, particularly the length, estimated ridership, speed, and bus technology. The user may also include information on the bus corridor under the "without project" scenario such as the ridership of existing vehicles (e.g. cars, buses). The user may then specify and simulate mode shifts from the existing system to the BRT system to arrive at the "with project" scenario.

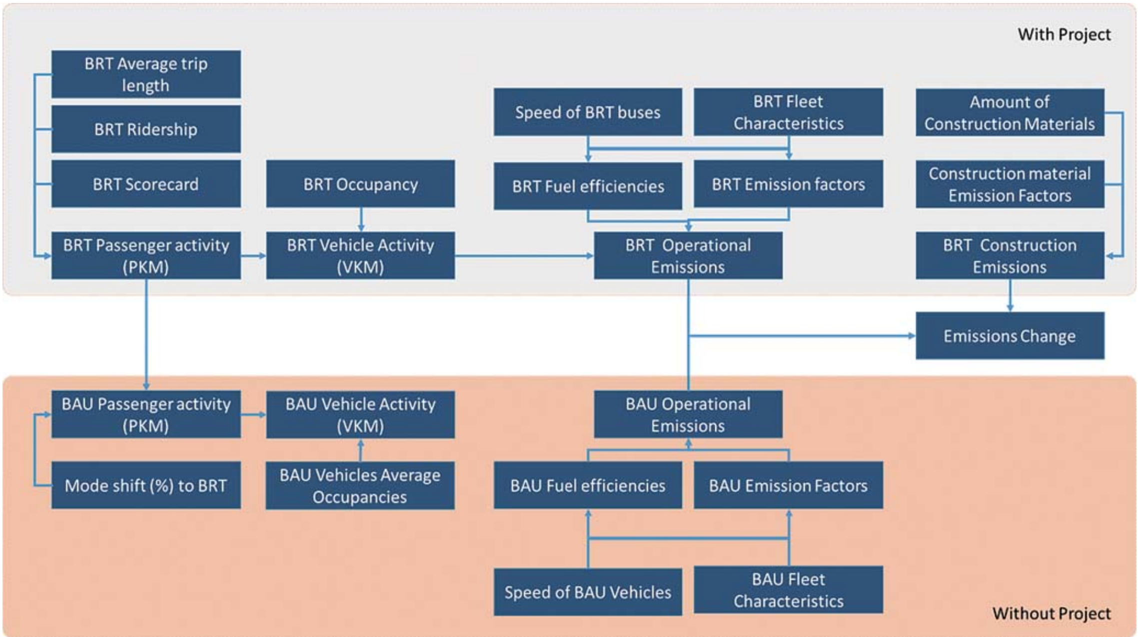

Figure 5.6: General Flow of Parameters in the TEEMP BRT Tool (Full Model)
Source: Gota S., and Clean Air Asia 2014

The results of the TEEMP evaluation can help identify alternative options and facilitate decision-making. By using TEEMP, analysts have an opportunity to examine the project's emissions and include those calculations in an economic analysis or monitoring plans. TEEMP aims at aiding analysts with these analyses and plans but it merits highlighting that CO_2 emissions alone is rarely the sole basis for a project. However, since CO_2 is often closely associated with other desirable features of a project, it can provide useful insights for decision makers even as other factors weigh more heavily in decisions. Box 5.2 reviews recent applications of TEEMP.

Box 5.2: Recent TEEMP applications

- ***Reduction in CO_2 Emissions through an Electric Tricycle Replacement Scheme in Pasig City, Philippines: An MRV Demonstration Study*** – The project aimed at shifting energy demand from petrol towards electricity sources through the replacement of old motorcycles that are used for tricycles in the city of Pasig, Philippines. TEEMP was used to estimate project emissions under static and dynamic scenarios setting.
- ***Transport Related Co-benefits Training and Research in Bandung City, Indonesia*** – The project aimed at gathering evidence on the potential impacts of eco-driving in real life conditions, as well as provide capacity building on eco-driving for the stakeholders.
- ***Harbin Green Bus Corridor Project*** – The Harbin Green Bus Corridor is a part of a Smart Public Transportation Project supported by the World Bank. The objective is to construct an integrated bus corridor for improving bus share rate towards developing efficient, economical, convenient, reliable, accessible, safe and comfortable public transport system, encourage low-pollution and low-emission non-motor transport modal, and apply modern intelligent information system, with the aim to promote urban sustainable transport development. TEEMP was applied to assess CO_2 and air pollutant emissions from project components (i.e., bus priority corridor vs business-as-usual). The Green Bus Corridor is also called a bus priority corridor, which is a public transport development system including three bus lanes, bus stops and priority signal control.

Source: CAA Center 2013

In the next sections, two case studies are presented: the Harbin Green Bus Corridor Project that the World Bank used as a basis for financing the city's green bus corridor project, and several transport projects that were part of the Philippine's Intended Nationally Determined Contributions (INDCs) in the lead up to the Paris Agreement. While the first case was an application outside Southeast Asia, it demonstrates how co-benefits analysis go beyond using CO_2 as a metric in assessing transport impacts on a project-level, which could also be applied to other cities in the region. The Philippines case, on the other hand, provides an example of how the use of the TEEMP can inform national-level initiatives such as the INDCs.

5.2. Case Study: Harbin Green Bus Corridor Project

This section discusses the application of the TEEMP on the Heilongjiang Cold Weather Smart Public Transportation project, particularly the Harbin Green Bus Corridor in 2016. The Heilongjiang Cold Weather Smart Public Transportation System was a World Bank project that aimed to improve public transport in Harbin and Mudanjiang, Heilongjiang. Public transport services in the two cities suffered from insufficient capacity and aging buses. Buses ran at low speeds with irregular schedules due partially to poorly designed roads and the lack of modern traffic management systems. When the project was being implemented, an intelligent transport system (ITS) that could address some these issues was still being planned, suggesting Harbin and Mudanjiang were behind other major cities in China. The combined result of many of these factors were long waiting times in cold weather for overcrowded buses that discouraged potential passengers from taking public transport.

The TEEMP application for the Harbin Green Bus Corridor project assessed GHG emissions and pollutants (CO_2, PM, NOx) from the "with" and "without project" scenarios. The project analysis was assumed to last for 20 years—with 2015 as baseline and 2034 end year. The TEEMP assessment covered cost and emissions impacts (CO_2, PM, NOx), construction emissions, and land-use impacts[15].

15 In order to capture the impact on land use developments and subsequent impacts on emissions, a land use multiplier was proposed. This multiplier tried to capture the impact on land use by the bus corridor as a result of improved accessibility.

5.2.1 Methodology

It was assumed that without the project, the users would use existing modes (e.g., passenger cars, taxis, current bus) in the corridor. The analysis was limited to the Green Bus Corridor transport system. Emissions savings were calculated as the difference between the "with" and "without project" scenarios as shown in Box 5.3.

Box 5.3: Equation for Estimating CO_2 Emissions from a Transport Project

$$\mathrm{CO_2\ Impact} = (CO_{2\,\mathrm{No\ Project}} - CO_{2\,\mathrm{With\ Project}})$$

Where:

$\mathrm{CO_2\ Impact}$	= CO_2 emissions change due to the project (tons CO_2/year)
$CO_{2\,\mathrm{No\ Project}}$	= CO_2 emissions generated in the scenario without the Green Bus Corridor (tons CO_2 /year)
$CO_{2\,\mathrm{With\ Project}}$	= CO_2 emissions from the Green Bus Corridor (tons CO_2/year)

The primary CO_2, PM and NOx savings were from the mode shift impacts and increases in speed and occupancy. The impacts on the movement of other modes of transport (i.e. speed increase, or increased travel by private modes due to induced traffic) were not included to simplify the analysis. The increase in traffic that might be induced from greater road space would require more data-intensive modelling and additional surveys; acquiring this data was deemed too costly and unnecessary for this rapid assessment.

5.2.2 Land Use Impacts

Investment in transport systems affects land use. As the accessibility to high quality public transit improves, land value and potential for growth also tend to increase. Changes in transit access and land use influence travel demand. These changes affects mode choice, transport energy consumption and emissions. These built-environment impacts can be summarised by the five "D's" below (Cervero and Kockelman 1997).

- Density is considered as activity level per unit area. The activity can be population and employment.
- Diversity is measured as availability and intensity of different types of land use.
- Design refers to the type of local street design. More than aesthetics, design refers to the "functional value" of the built environment.
- Destination accessibility is a measure of the access to trip attractions.
- Distance to transit is a measure of public transport accessibility.

To capture the impact of land use on emissions, a land use multiplier was proposed for the Harbin Green Bus Corridor Project. This multiplier was an attempt to capture the impact on land use patterns from improved accessibility. These impacts can increase public transport ridership due to, for example, increases in biking and walking from the improved connectivity that often results from land use modifications.

5.2.3 Data Needs

Ridership Projections, Existing Trip Mode Share, and Speed

The assumed corridor characteristics including ridership, modal shift, and average speed for the years 2015, 2024, and 2034 were based on prior research on the Green Bus Corridor (Table 5.3). A report suggested that bus ridership would grow by at least 10% as an effect of project.[16] For modal shifts, the forecasting results suggested that public transport share would increase to 40% in 2020 and 45% in 2030. With the construction of the Green Bus Corridor system, the average speed of the three bus lanes would improve to 20 kilometers per hour or more compared with no priority corridors. The mode shifts to the Green Bus Corridor from other modes (e.g. cars, 2-wheelers, taxis, existing buses) were based on a previous report[17]. The shift from other modes were conservative since it was assumed that a large share of the shift would come from buses. For the speed of main existing transport modes, it was suggested that cars run at 29 kph, 2-wheeler at 22 kph, taxis at 29.7 kph, and buses at 18.9 kph in the project corridor. The Green Bus Corridor average speed was set as 50 km/h based on the project feasibility study report. The TEEMP used the average speeds and emission factors proposed for 50kph. Lastly, the assumed trip length of passengers in the Green Bus Corridor was the same with bus trip projected in the report, which were 11.8, 14.3 and 14.3 kilometers respectively in 2015, 2024 and 2034.

Table 5.3: **Harbin Green Bus Corridor Ridership, Mode Shift, and Average Speed Forecast**

		2015	2024	2034
Bus Corridor Ridership - ('000)/day		261.46	462.83	755.22
Forecast Mode Shift to Green Bus Corridor in years 2015, 2024 and 2034				
	Car	17%	17%	17%
	2-wheeler	1%	1%	1%
	Taxi	14%	14%	14%
	Bus	55%	55%	55%
	Other	13%	13%	13%
Average Speed (kilometers/hour)				
	Cars	29	29	29
	2-Wheeler	22	22	22
	Taxi	29.7	29.7	29.7
	Bus	18.9	18.9	18.9
Green Bus Corridor Trip Length		11.8	14.3	14.3

16 "Investigation and analysis of integrated transport demand forecast", Transportation Research Center of Northeast Forestry University
17 "GEF project carbon emission reduction estimation in Harbin"

Fuel Split, Emission Standards and Emission Factors

Fuel split and emission standards of the transport system in the Green Bus Corridor were based on government plans. According to the roadmap for fuel split and emission standards for China from 2014 to 2017, new vehicles should meet Euro V equivalent emissions standards within two years; these standards were assumed to stay at this level for the 20 years of the project. The project also considered the entry of liquefied natural gas (LNG) buses to the corridor.

The default PM, NOx and CO_2 emission factors embedded in the TEEMP are based on several studies in Asia.[18] The TEEMP's approach in estimating emissions incorporates speed impacts based on the COPERT model using the estimated average speed of existing vehicles in the corridor.

Vehicle Occupancy and Fuel Efficiency

Vehicle-specific fuel efficiency (km/liter) and occupancy (average number of persons per vehicle) were also assumed for vehicles that run on the proposed Green Bus Corridor (Table 5.4). The TEEMP calibrates the fuel efficiency of different modes at different speeds using insights from existing models such as COPERT, CORINAIR etc. The current fuel efficiency values have been taken from literature and expert judgement due to the lack of local values. The fuel consumption values were adjusted with speed, affecting fuel consumption estimates from the model.

Table 5.4: **Fuel Efficiency by Mode and Fuel Type**

		TEEMP analysed for Harbin Speed		Occupancy
		Petrol (km/liter)	Diesel (km/liter)	
Private	Car	6	14.20	1.5
	2-wheeler	55.66	1.10	1
	Taxi	6	14.29	1.8
Public	3-wheeler	25	14.29	1.8
	Bus	15	17.5	40
	Other	n/a		39
	GREEN BUS CORRIDOR	25.27 (LNG)		41.34

5.2.4 Results

Without accounting for land use impacts (Table 5.5), the results of the TEEMP show that the Green Bus Corridor can potentially mitigate 5,355 tons of CO_2 emissions per year while reducing tailpipe emissions by 0.15 tons of PM and 11.35 tons of NOx per year. The co-benefits include 1.081 billion hours of travel time savings, 750 avoided deaths per year, and USD 1.5 billion in fuel savings. These co-benefits are achieved by using highly efficient Euro IV buses in Harbin. Importantly, by incorporating land use impacts, the benefits are estimated to be 100% to 150% greater (Table 5.5). It should nonetheless be noted that for the reasons highlighted previously that these are indicative results. Further research is needed for more accurate estimates of land use impacts.

18 Draft report on "Emission Factor development for Indian Vehicles ", Automobile Research Association of India and Central Pollution Control Board, India

Table 5.5: Results without Land Use Impact

Ridership/year (millions)		Emissions Savings	
2015	92.32	PM reduction (tons)	74.69
2024	163.43	NOx reduction (tons)	5,725.72
2034	266.67	CO_2 reduction (tons)	2,702,269.15
Financial Indicators		**Emissions Savings**	
EIRR	37%	PM reduction (tons/km)	2.96
NPV (million USD)	$ 458.00	NOx reduction (tons/km)	226.94
Project Cost (million USD)	196.98	CO_2 reduction (tons/km)	107,105.40
Co-benefits		**Emissions Savings**	
VKT Saved (millions)	6,576.21	PM reduction (tons/km/yr)	0.15
Time travel savings ('000s hours)	1,081,925.18	NOx reduction (tons/km/yr)	11.35
No. of fatalities reduced	750.73	CO_2 reduction (tons/km/yr)	5,355.27
No. of injuries reduced	11,260.93		
Fuel Savings ('000 USD)	1,457,183.17		
Emissions reduction ('000 USD)	75,228.10		

Legend: EIRR: Economic Internal Rate of Return; NPV: Net Present Value; VKT: Vehicle Kilometers Travelled

The TEEMP analysis on the Green Bus Corridor project in Harbin showed a cumulative net savings of USD 4.45 billion from 2015 to 2034 (Figure 5.7), more than covering the initial construction cost of USD 196.98 million in 2015. The fuel savings amounted about USD 3.018 billion or an average of USD 150.9 million per year. These savings were attributable to the corridor's transport system becoming more efficient with ridership by private cars and other modes shifting to more high-occupancy buses.

There were nonetheless a few limitations with these estimates. One was the use of general emission factors based on literature and expert judgement as there was no local emissions factor data. Further, the mode share data used was for the year 2010. The development of local emission factors and to continue updating mode share data would likely lead to more accurate estimates.

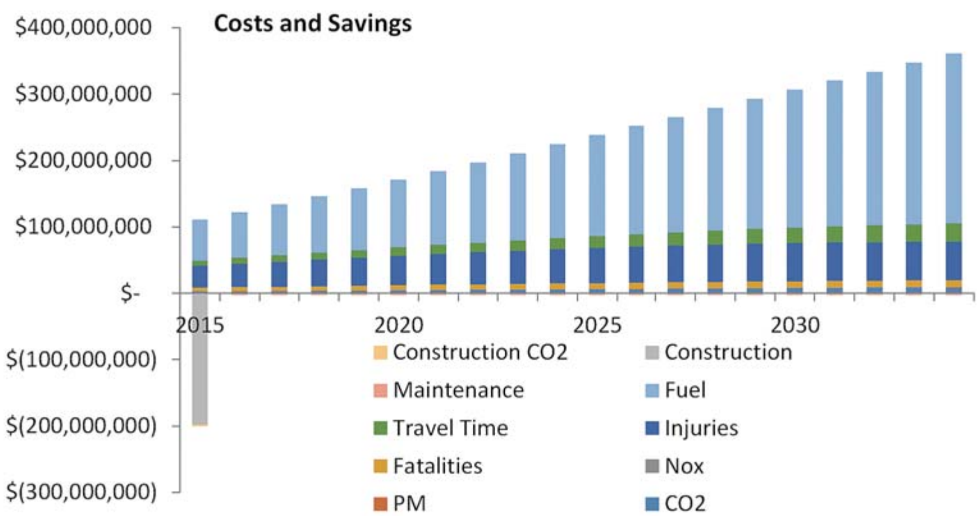

Figure 5.7: Costs and Savings of the Harbin Bus Project

5.3. Case Study: The Philippines Intended Nationally Determined Contributions (INDCs) Using TEEMP

This section presents the application of the TEEMP to evaluating emissions from select transportation projects in the Philippines' INDC. In this case, the TEEMP only facilitated discussions with the Department of Transportation (DOTr) around the INDC and its results were part of several selection criteria for projects. For example, the TEEMP accompanied a multi-criteria analysis (MCA) led by the Low Emissions Capacity Building (LECB) Programme of the United Nations Development Programme (UNDP).

As discussed in Chapter 1, in the lead up to the 21st Conference of Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) the Philippines joined many countries in preparing a roadmap for climate change actions from 2015 through 2030 known as an INDC. This roadmap would be called an NDC after it was officially pledged to the UNFCCC as the removal of the "I" suggested the pledged actions were no longer intended. The Philippines Second National Communications to the UNFCCC demonstrated clearly that the transport sector was the single largest contributor to emissions and would need to be a key area for projects under the INDC (Table 5.6).

Table 5.6: **Official GHG Emissions Estimates Based on the 1st and 2nd National Communications of the Philippines to the UNFCCC**

Sub-sector	ktCO$_2$e		GHG % Contribution		AAGR (1990-2000)
	1994	2000	1994	2000	
Power Generation/Energy Industries	15,508	21,219	31%	30%	5%
Transport	**15,888**	**25,936**	**32%**	**37%**	**9%**
Industries	9,497	9,142	19%	13%	-1%
Residential	4,359	7,029	9%	10%	8%
Agriculture/forestry/fishing	1,189	887	2%	1%	-5%
Commercial	3,370	1,923	7%	3%	-9%
Fugitive	227	3,530	0%	5%	58%
Total	**50,038**	**69,667**	**100%**	**100%**	**6%**

The Philippine divided responsibilities across several agencies to formulate the INDC. The DOTr led the work on the sector, while the Climate Change Commission (CCC) led the efforts to bring together the multiple sectors in the INDC. In 2015, the DOTr decided to use this process requested to estimate complementary GHG emissions and mitigation potential for several priority projects.

5.3.1 Methodology

An analysis of the priority pipeline projects of DOTr was conducted to supplement the discussions on the INDC. Two of the selected interventions were BRT projects while the remaining were rail projects. Both the BRT and rail projects can mitigate CO_2 emissions by "shifting" passenger trips into transport modes that are more efficient and less emissions intensive. The TEEMP modules (i.e., BRT and MRT) are designed to calculate emissions impacts of such projects based mainly on the estimated ridership and mode shift distribution of the trips using the preferred modes (project vehicles) in a "without project" scenario.

Table 5.7: **Priority projects identified by the Philippine Department of Transport for INDC**

Transport Type	Project Name	Short Description	Expected Impact Related to the Emission Reduction Estimation
Rail	LRT 1 South Extension	Construction of a 11.7 kilometer of railway from Bacoor Station to Niog Cavite	320,000 additional passengers/day
Rail	LRT 2 East and West Extensions	Construction of a 3.93 kilometer from Emerald to Masinag, Antipolo, and 4.15 kilometers from Divisoria to Pier 44	220,000 additional passengers/day
Rail	MRT 3 Capacity Expansion	Procurement of additional rolling stock; improvement of signaling systems	200,000 additional passengers/day
Rail	MRT 7	Construction of a 22.8 kilometer railway from Elliptical Road, Quezon City to San Jose del Monte, Bulacan	200,000 passengers/day
Rail	Mass transit System Loop	Construction of a 12.7 kilometer subway connecting Makati City and Taguig City	350,000 passengers/day
Rail	North-South Railway	Construction of a 37.5 kilometer railway from Tutuban to Malolos, Bulacan in the North and 16-kilometer railway from Mamatid and Calamba	450,000 additional passengers/day
Bus/BRT	C-5 BRT	Construction of a 24 kilometer BRT to run from Commonwealth to Food Terminal Incorporated	50,000 passengers/day
Bus/BRT	Manila BRT	13 kilometers of bus rapid transit will be situated from Recto to Quezon City	290,000 passengers/day

Source: Limcaoco, 2014

In terms of GHGs, the analysis focused on CO_2. Project emissions (i.e., emissions resulting from project implementation and operations) were limited to the operations of the vehicles (in this case, BRT buses and trains). The analysis utilised information through the review of available literature, as well as from the discussions during an INDC workshop for the transport sector held in June 2015. For cross validation of results, a separate estimation exercise was done in parallel by USAID (2015) Building Low Emission Alternatives to Develop Economic Resilience and Sustainability (B-LEADERS) Team. The literature review was extensive to ensure that assumptions were sound and reasonable. It should also be noted that TEEMP BRT and MRT modules require different parameters (Table 5.8).

Table 5.8: **Key parameters and basis for projects in the application of TEEMP**

Parameter	Unit	Source and Remarks
BRT Projects		
Energy Efficient BRT	Km/liter	International Council on Clean Transportation (ICCT) (2013)
Days in operation	Days/year	Assumption
Emission Factor (diesel)	kgCO_2/liter	GEF, STAP (2011)
P.TripsBRT	Thousand/day	These are DOTC values. As per a suggestion during an INDC workshop, the maximum ridership values were multiplied by 50% for the first year, 70% for the second year, 90% in the third year, and 100% for the succeeding years
Trip Length	Km/trip	Based on the suggestion of the DOTC that the passenger trip lengths be 60% of the system length
Occupancy	Passenger-km/ Vehicle-km	Average value; based on the seating capacity of a BRT bus model being used in the region[19]
Mode Shift	% - Car	Validated during the INDC workshop (assumed as mode shift values are not readily available, based on the available substitute modes in the relevant corridor)
Rail Projects		
Energy Consumption Light Rail Commuter bus	Kwh/pkm[20]	The values are computed based on the pkm estimates (ridership * average passenger trip lengths) and the estimated total energy consumption per year as given by DOTC or from other sources (e.g. Almec 2014). The kwh/ pkm derived values are within the range from a review of global rail systems as provided in an information note provided by the UNFCCC on performance benchmarks of rail based systems (UNFCCC, n.d.).
Days in operation	Days/year	Assumption
Emission Factor	kgCO_2/kwh	Calculated based on the projected electricity mix (DOE) of the Luzon grid. The values represent the min (starting year) and max (ending year) emission factors. The Luzon grid will experience relatively higher shares of coal-fired electricity generation, thus, there is an increase in the grid emission factor.
P.TripsBRT	Thousand/day	These are DOTC values. As per a suggestion during an INDC workshop, the maximum (additional) ridership values were multiplied by 50% for the first year, 70% for the second year, 90% in the third year, and 100% for the succeeding years. These values account for the additional ridership that would be added in the case of the project.
Trip Length	Km/trip	These are assumptions already take into consideration system expansion (if applicable to the projects).
Mode Shift	%- Car	Validated during the INDC workshop (assumed as mode shift values are not readily available, based on the available substitute modes in the relevant corridor)

19 Sunlong SLK6121UF14H

20 LRT 1 & 2 values were calculated based on the historical electricity consumption values quoted in Almec (2014) and the ridership values from the LRTA website. The values for the MRT 3, 7, North-South railway were computed from the ridership values and energy consumption values that were provided by DOTC and the computed trip lengths.

A critical step in applying the TEEMP was the choice of emission factors (Table 5.9) and fuel efficiency of baseline vehicles. Although the TEEMP contains default values, further research was conducted to get more accurate emission factors that reflect localised emissions estimates.

Table 5.9: Emission factors included in the application of TEEMP for DOTr priority projects

Parameter	Unit	Remarks
$EE_{Baseline\ vehicle}$	Km/liter	ICCT (2013), CAA (2012), DOE-UPNEC (2013)
EF_{diesel}	$kgCO_2$/liter	GEF, STAP (2011)
$EF_{gasoline}$	$kgCO_2$/liter	GEF, STAP (2011)
$Occupancy_{Baseline\ Vehicle}$	PKM/VKM	DOTC & UPNCTS (2012), Almec (2014)

5.3.2 Results

The results (Figure 5.8) of the TEEMP application showed that the DOTr priority projects can reduce up to 398.8 thousand tons of CO_2 per year (2020-2030 period). This is equivalent to 153 million liters of diesel reduced per year. The cumulative CO_2 emission reduction potential would be in the range of 4.3 million tons between the period 2020 to 2030. This is equivalent to 1.6 trillion of diesel equivalent reduction in fuel consumption.

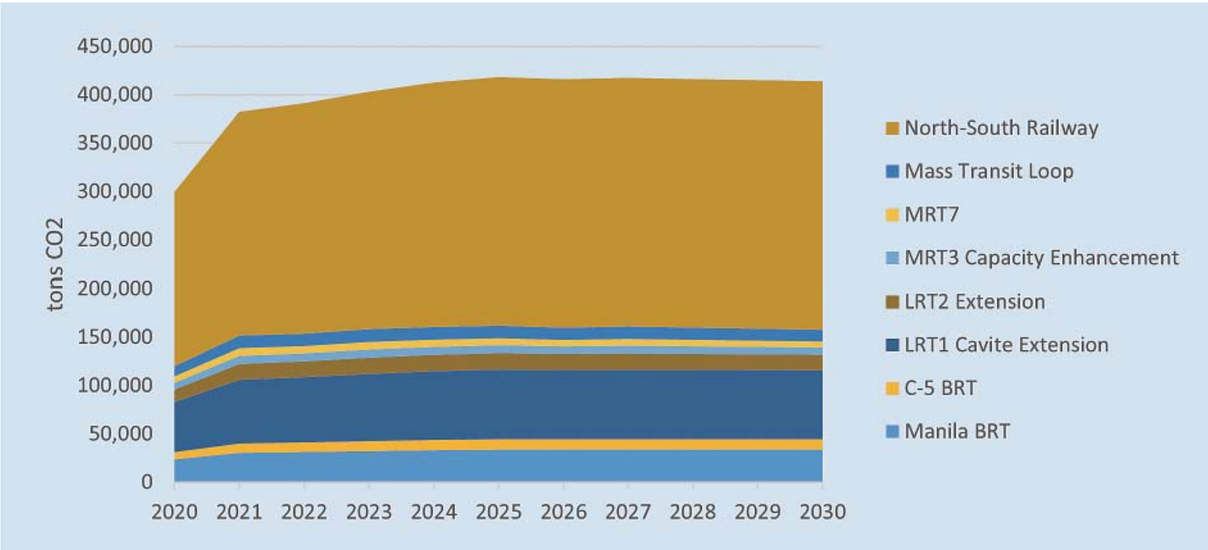

Figure 5.8: CO_2 Emission reduction potentials (2020-2030) of the selected DOTr projects

5.4. Conclusion

This chapter provided an overview of the co-benefits from transport projects and how they may be quantified with rapid assessment tools such as the TEEMP. As emphasised in this chapter, the TEEMP is a sketch tool that provides *ex-ante* project emissions estimates useful for environmental impact assessment.

The case of the Harbin Green Bus Corridor showed the detailed application of the TEEMP. Much of the data is taken from pre-assessment or feasibility studies conducted on the project corridor. For this case, the TEEMP supplemented environmental impact assessment requirements. On the other hand, it was also shown that the application of the TEEMP can be used for comparing the impacts of projects, as was done for the Philippine INDC.

Although the project emissions estimates are relatively small compared to the total transport emissions of a city or country, it is clear that these projects that can set the direction for sustainable low carbon transport systems. The TEEMP can provide estimates of emissions and other co-benefits such as reduced travel time, fatalities and accidents avoided, and fuel saved, all of which are important co-benefits of transport.

It should be noted that the TEEMP does not calculate other co-benefits of transport projects such as jobs displaced or generated and local income creation which could be of interest to decision makers. There are also non-quantifiable benefits that are not captured in the TEEMP, such as quality of life and improved accessibility. This suggests that the TEEMP should be used with multi-criteria analysis and workforce analysis for a complete accounting of transport co-benefits.

Acknowledgements

Clean Air Asia analysed the transport elements of the Philippines INDC in 2015 to support the then Department of Transportation and Communications (now the Department of Transportation). This work was funded by the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) International Climate Initiative (ICI) as part of the "GIZ INDC Project -Philippines" under the "Support to the Climate Change Commission in Implementing the National Climate Change Action Plan (SupportCCC)."

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Chapter 6: The Way Forward

Author: Eric Zusman/IGES

The ACP White Paper 2018 focused on methods and tools to quantify co-benefits and their applications in Asia. It began with the contention that employing these methods and tools will be increasingly important for decision makers in Asia. Part of this growing importance stems from reducing policymaker concerns about investing scarce resources in climate actions with uncertain benefits; more accurate estimates may also prompt high-level officials to introduce institutional reforms that strengthen interagency coordination and monitoring and reporting protocols that enhance policy compliance. Beyond possible changes to national policies and institutions, there are also growing opportunities to use co-benefits as a vehicle to attract flows of climate and development finance. Sources of finance that can achieve multiple benefits appear to be growing with reforms within and linkages between the international climate finance and development policy landscape. Though it is unlikely that a large-scale finance mechanism will tie funding to any specific co-benefit (beyond GHGs) in the near-term, there is likely to be more resources for policymakers and investors that can clearly demonstrate the multiple benefits that lie at the core of co-benefits analysis. Hence, there is a growing demand for more guidance on the tools and methods that can clearly demonstrate those benefits.

Many of the tools and methods that have an established track-record in quantifying co-benefits come from analyses of integrated air pollution and climate change strategies. Some of these tools and methods can be incorporated into the formulating of national determined contributions (NDCs) under the Paris Agreement and voluntary national reports (VNRs) under the 2030 Agenda for Sustainable Development. The fact that there is growing concerns over the multiple impacts of air pollution from Asia at the global, regional and national levels suggests that there is likely to be a strong interest in using these tools to make the links across several related policy areas at multiple levels. Making these links will also require greater guidance on what tools and methods are most appropriate in which contexts.

The ACP White Paper's main chapters—Chapters 2 through 5—begin to offer some this guidance by describing how several tools have been applied to quantify co-benefits in Asia. Chapters cover how the Long-range Energy Alternatives Planning system-Integrated Benefits Calculator (LEAP-IBC) model has been applied to quantify the sources and solutions to air pollution in Bangladesh as well as how the Greenhouse gas-Air pollution Interactions and Synergies (GAINs) model has helped estimate changes in emissions, ambient air quality, premature deaths, and climate impacts from heavy-duty diesel regulations in the Tokyo Metropolitan Region (TMR). Chapters also show how the use of ratnoze measurement tool helps assess the difficult-to-measure impacts of the redesign of brick kilns in Nepal as well as how to employ Transport Emissions Evaluation Model for Projects (TEEMP) to provide an initial scoping of the Harbin Green Bus Corridor and the transport elements of the Philippines Intended Nationally Determined Contribution (INDC).

Collectively the main chapters suggest that there is no need to reinvent the wheel; there are already a number of tools and methods that can be employed in diverse settings. There is also the potential to use multiple tools at different stages of decision-making and different levels of analysis. For example, the TEEMP tool may be well suited to provide an initial low cost scoping of possible transport interventions to be followed by a more rigorous analysis of costs and benefits with GAINs. Similarly, the LEAP-IBC tool could be used to assess the multiple impacts of an integrated climate and air pollution control strategy that could be supplemented by a more detailed examination of emissions from brick kilns that are part of that strategy. There is hence considerable scope for pursuing complementarities between these different tools that can be discussed more in future publications.

The White Paper also raises a few areas that appear ripe for future research. These begin with using some of the tools developed for co-benefits analysis to inform integrated approaches to the sustainable development goals (SDGs). As noted previously in this White Paper, there is a growing number of tools and techniques that can demonstrate interlinkages and conflicts between different goals and targets at one point in time. However, there is a growing need to examine how these interlinkages and conflicts could evolve over time. This is particularly important because synergies between multiple goals and targets have the potential to generate non-linear or disruptive changes that are central to achieving transformation through the 2030 Agenda. By the same token, the collective impacts multiple conflicts over time may also lead to systemic failures and tipping points that prove irreversible. The combination of tools that examine interlinkages across goals and scenarios over time may shed light on how policymakers can move closer to positive and avoid negative disruptions.

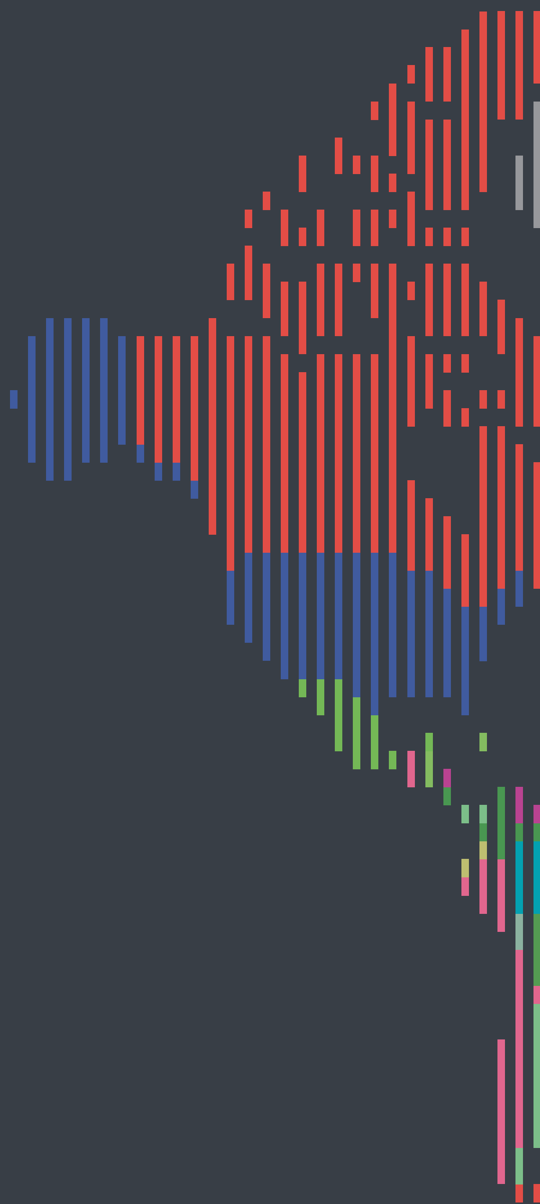
Another area with potential for follow-up research involves the relationship between maximising multiple benefits and minimising costs. Clearly, some of the benefits can accrue from policies with co-benefits are social in nature. For example, poorer segments of the population often benefit more than wealthier populations integrated air pollution and climate change policies because they tend to live closer to the sources of pollution. Similarly, as was pointed out earlier in chapter 1, potentially marginalised stakeholders can gain important benefits from the participating in relevant policymaking processes. At the same time, a failure to fully account for equity concerns or create sufficient channels for participation in policymaking processes can lead to inequitable results that are unlikely to be socially sustainable. More work is needed into how to account for equity effects in co-benefits analysis and how to make processes in which those analyses are used truly inclusive. This work may also examine how different combinations of policies can be combined to reduce socially harmful side effects such as job loss.

A final area for possible study involves the use of co-benefits as a communication tool. The term co-benefits can, at times, lead to more confusion than clarity. Some of this confusion involves what is the main and secondary benefits. Other reasons for the confusion stem from the sense that co-benefits adds another abstract concept for policymakers that are already struggling with green growth, low carbon development and sustainable development. There appears to be a need for research that determines which of these terms, if any, resonate most with decision makers in Asia and the populations they serve. Some of this research could conducted with interviews and surveys and draw upon insights from communication and policy research. The main aim of this research—similar to the primary objective of the ACP—is to help policymakers and practitioners align their climate and development strategies in Asia.

Asian Co-benefits Partnership

White Paper 2018
Quantifying Co-benefits in Asia: Methods and Applications

> Asian Co-benefits Partnership (ACP) is a voluntary information sharing platform. The ACP seeks to collaborate with organisations working to mainstream co-benefits into decision making processes in Asia.



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