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The Cost of Climate Stabilization in Southeast Asia, a Joint Assessment with Dynamic Optimization and CGE Models

Francesco Bosello, University of Milan, FEEM and CMCC
Giacomo Marangoni, FEEM and CMCC
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Summary

Southeast Asia is at a time one of the most vulnerable region to the impacts of a changing climate, with millions of its inhabitants still trapped in extreme poverty without access to energy and employed in climate-sensitive sectors, and, potentially, one of the world's biggest contributors to global warming in the future. Fortunately, major Southeast Asian countries are also implementing policies to improve their energy and carbon efficiency and are discussing if and how to extend these further. The present study aims to assess the implications for energy consumption, energy intensity and carbon intensity in the Southeast Asia region of a set of short-term and long-term de-carbonization policies characterized by different degrees of ambition and international cooperation. The analysis applies two energy-climate-economic models. The first, the fully dynamic Integrated Assessment model WITCH, is more aggregated in the sectoral and country representation, but provides a detailed technological description of the energy sector. The second, the ICES Computable General Equilibrium model, offers a richer sectoral breakdown of the economy and of international trade patterns, but is less refined in the representation of technology. The joint application of these two complementary models allows the capture of distinct and key aspects of low- carbon development paths in Southeast Asia.

Keywords: Climate Change Mitigation, Asian Economies, Computable General Equilibrium Models

JEL Classification: Q54, Q58, C68

Address for correspondence:
Carlo Orecchia
Fondazione Eni Enrico Mattei
C.so Magenta, 63
20123 Milan
Italy
E-mail: carlo.orecchia@feem.it

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Francesco Bosello, Professor, University of Milan, Fondazione Eni Enrico Mattei (FEEM) and Centro Euro-Mediterraneo sui Cambiamenti Climatici (CMCC)

Giacomo Marangoni, Researcher, Fondazione Eni Enrico Mattei (FEEM) and Centro Euro-Mediterraneo sui Cambiamenti Climatici (CMCC)

Carlo Orecchia*, Researcher, Centro Euro-Mediterraneo sui Cambiamenti Climatici (CMCC) and Fondazione Eni Enrico Mattei (FEEM)

David A. Raitzer, Economist, Asian Development Bank (ADB)

Massimo Tavoni, Professor, Politecnico di Milano, Fondazione Eni Enrico Mattei (FEEM) and Centro Euro-Mediterraneo sui Cambiamenti Climatici (CMCC)

Abstract

Southeast Asia is at a time one of the most vulnerable region to the impacts of a changing climate, with millions of its inhabitants still trapped in extreme poverty without access to energy and employed in climate-sensitive sectors, and, potentially, one of the world's biggest contributors to global warming in the future. Fortunately, major Southeast Asian countries are also implementing policies to improve their energy and carbon efficiency and are discussing if and how to extend these further.

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*** Corresponding author: Email: carlo.orecchia@feem.it;**

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1. Introduction

The present study aims to assess the implications for energy consumption, energy intensity and carbon intensity in the Southeast Asia region of a set of short-term and long-term de-carbonization policies characterized by different degrees of ambition and international cooperation.

Southeast Asia is at a time one of the most vulnerable region to the impacts of a changing climate, with millions of its inhabitants still trapped in extreme poverty without access to energy and employed in climate-sensitive sectors, and, potentially, one of the world's biggest contributors to global warming in the future. Indeed, in recent decades, the region's growth in emissions has been more rapid than in any other area of the world, also fostered by an extensive use of fossil fuel subsidies and economic incentives for deforestation.

Fortunately, major Southeast Asian countries are also implementing policies to improve their energy and carbon efficiency and are discussing if and how to extend these further. This study firstly offers an insight on the costs, not only in terms of GDP, but also in energy consumption possibility, that five developing Southeast Asian economies (Indonesia, Malaysia, Vietnam, the Philippines and Thailand) could experience in 2020 following the implementation of their national de-carbonization targets. Then focuses more on the long term investigating three different scenarios: a fragmented regime where countries continue with uncoordinated nationally-determined commitments (i.e. Copenhagen pledges and INDC), a coordinated, but mid-ambition global decarbonization goal aiming at stabilizing GHG concentration at 650 ppm, and one more ambitious aiming to a 500 ppm stabilization.

The analysis applies two energy-climate-economic models. The first, the fully dynamic Integrated Assessment model WITCH, is more aggregated in the sectoral and country representation, but provides a detailed technological description of the energy sector. The second, the ICES Computable General Equilibrium model, offers a richer sectoral breakdown of the economy and of international trade patterns, but is less refined in the representation of technology. The joint application of these two complementary models allows to capture distinct and key aspects of low-carbon development paths in Southeast Asia.

Particular care has been devoted to in both models to describe land-use emissions from deforestation and peat oxidation as well as abatement opportunities from averted deforestation through reducing emissions from forest degradation and deforestation (REDD).

The study finds that to minimize long-term costs, Southeast Asian emissions need to decline by 20%–25% compared to the baseline in 2025 and by 60% by 2050. Decarbonization of the energy sector is found to derive from increased efficiency of energy use, replacement of carbon-intensive fuels with cleaner alternatives, and reduction in energy consumption. However, the relative importance of these three components depends largely on the availability of low-carbon technological options. Up front investments in low carbon technologies prove to be crucial to keep decarbonization costs manageable and to avoid drastic reduction in energy consumption, especially in the 500 ppm stabilization and after 2035. On the contrary, arrangements to avoid deforestation and the possibility to use avoided deforestation credits in the carbon market prove to be critical to reduce decarbonization costs especially in Indonesia in the mid-term.

3. Reference scenario

ICES and WITCH are harmonized fully in terms of population, GDP and emissions. This pattern is already evident in the world figures (Figure 1). In the baseline, both models project a world population reaching roughly 9.3 billion and a GDP of $180 trillion by 2050. Emissions from fossil-fuel intensive industries (i.e., excluding land-use emissions) are comparable, steadily increasing, and expected to reach between 70 and 77 giga tons (Gt) of CO2 equivalent by mid-century, but they assume a clear convex pattern in ICES and a concave one in WITCH.

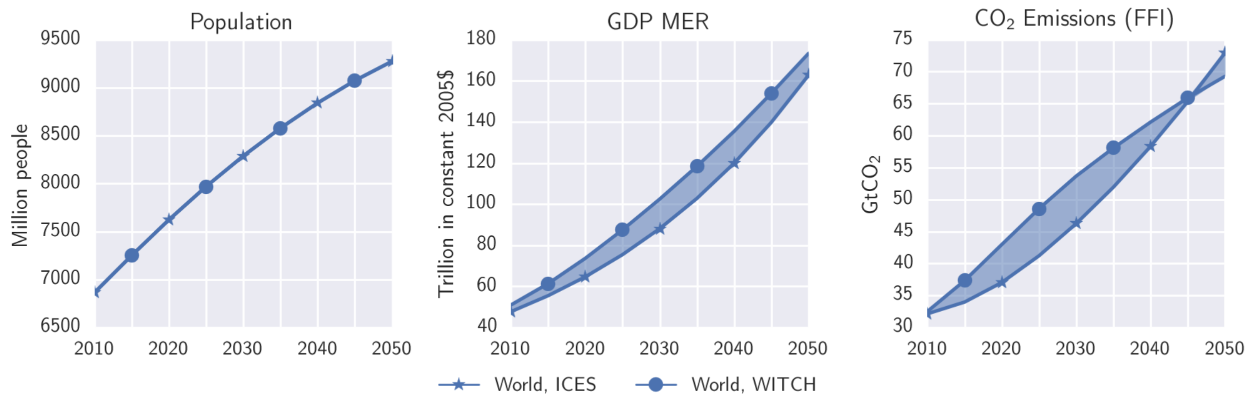


Figure 1: World Baseline Population (left), GDP (center) and CO_2 Emissions (excluding land use, land-use change, and forestry) (right)
FFI = fossil fuels and industry, GDP = gross domestic product, SEA = Southeast Asia

This becomes more evident when the baseline evolution of the economies of Indonesia and Southeast Asia are considered (Figure 2). ICES and WITCH are well harmonized in the growth trends for population and GDP. Population in Indonesia is projected to increase from 0.24 billion in 2010 to 0.29 billion in 2050; that in Southeast Asia, from 0.39 billion to 0.52 billion. Both areas are also showing strong GDP growth trends, with Indonesia's reaching roughly $5 trillion and Southeast Asia's reaching $7 trillion in 2050.

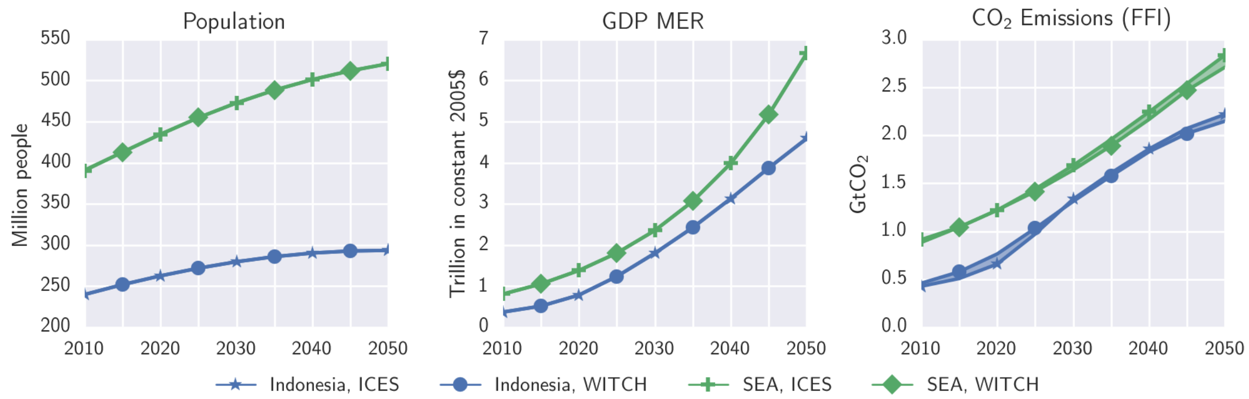


Figure 2: Indonesia and Southeast Asia Baseline Population (left), GDP (center) and CO_2 Emissions (excluding land use, land-use change, and forestry) (right)
FFI = fossil fuels and industry, GDP = gross domestic product, SEA = Southeast Asia

The two models agree in depicting a fossil fuel-based future until 2050 for the two regions, with increasing use of coal, oil, and gas and only a negligible role played by renewable energy sources.

Similarly, both models project a constant decline in both the energy intensity and carbon intensity of GDP, which is expected to be fostered by increased energy efficiency (Figure 3). This decline is more pronounced in WITCH than in ICES. According to WITCH, in 2050 the energy and the carbon intensity in Indonesia will be 71% and 60% lower than in 2010, respectively. In Southeast Asia, energy and carbon intensity are expected to decline 66% and 61% respect to 2010 levels, respectively. According to ICES, the energy and carbon intensities in Indonesia are projected to decline the 51% compared to the 2010 level. In Southeast Asia, energy intensity and carbon intensity are projected to decline roughly the 45% compared with 2010 levels. The models' differences are a consequence of both the richer portfolio of energy production technologies, and of the endogenous energy-efficiency improvement coupled with the perfect foresight and dynamic nature of the WITCH model. Ultimately, WITCH can support the same GDP as that of ICES, but it will entail a lower use of energy in general, and of fossil fuels, coal and oil, in particular.

Land-use emissions, as exogenous to both models, are consistently drawn from the International Institute for Applied Systems Analysis (IIASA) model cluster (Gusti et al., 2008), which combines the forestry model G4M and land-use model GLOBIOM. Attention was given to emissions from peatland, which in Indonesia accounts for almost half of total land-use emissions. Peatlands consist of deposits of plant residuals and water formed over thousands of years, usually in acidic conditions; the peat is drained during deforestation, setting off a process of oxidation and the risk of peat fires that have enormous emissions potential. Emissions can continue for decades after clearance; even if deforestation is falling, emissions would almost certainly increase because the rate of carbon loss from peat lags behind. The estimates for future emissions from peatlands assumed a lag of 25 years in the accumulation of deforested peatland (Hoijer et al., 2010), which were then converted into emissions with a specific coefficient of 1474 tCO2e/ha as suggested by Busch et al. (2011).

The baseline trends for land-use emissions (peatland and non-peatland) are declining as a result of declining deforestation estimated by the IIASA model cluster. As long as deforestation proceeds, this linkage is assumed to occur at a decreasing rate (Gusti et al., 2008; Hoijer et al., 2010). Accordingly, the emissions generated also decline.

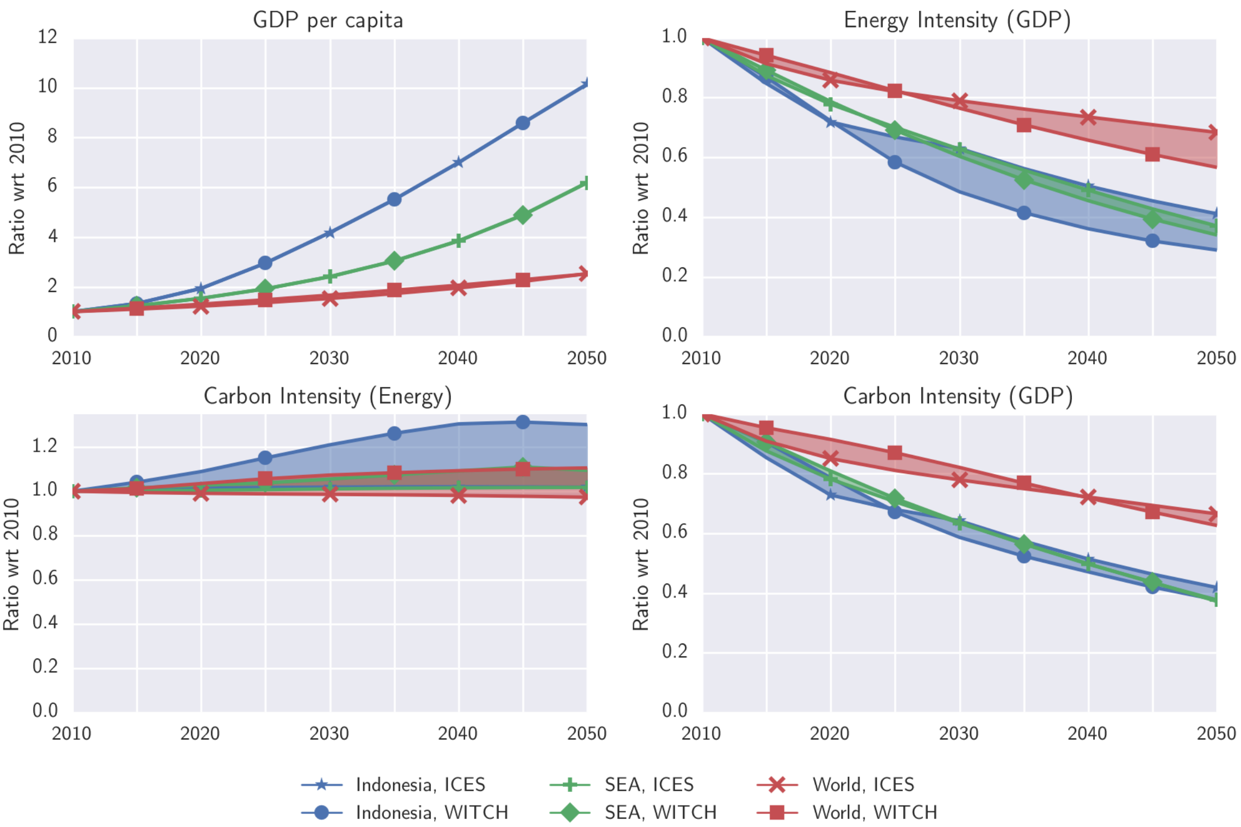


Figure 3: Baseline Indexed (2010=1) Per Capita GDP (top left), Energy Intensity of GDP (top-right), Carbon Intensity of the Energy Sector (bottom-left), Carbon Intensity of GDP (bottom right) in Indonesia, Southeast Asia, and World in the ICES and WITCH models

GDP = gross domestic product.

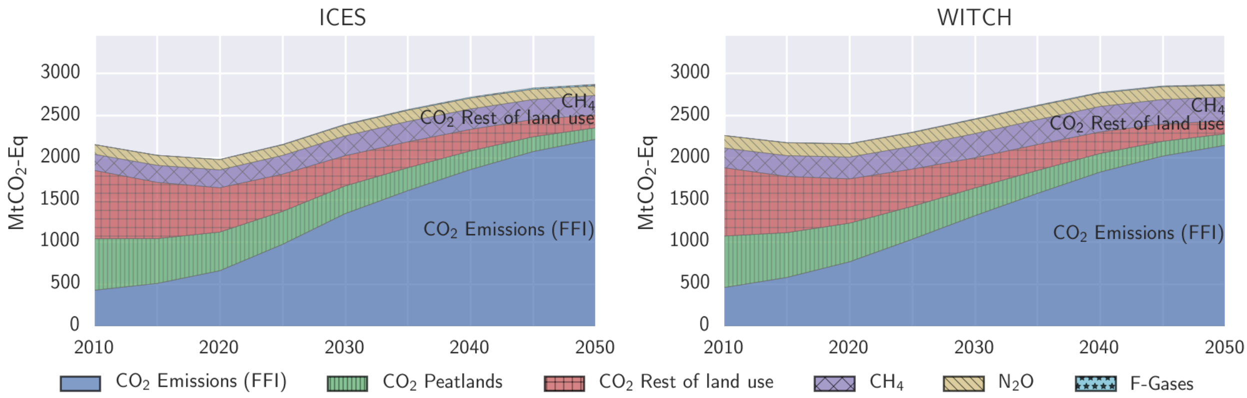


Figure 4: Indonesia Baseline GHG Emissions by Gas in the ICES and WITCH Models

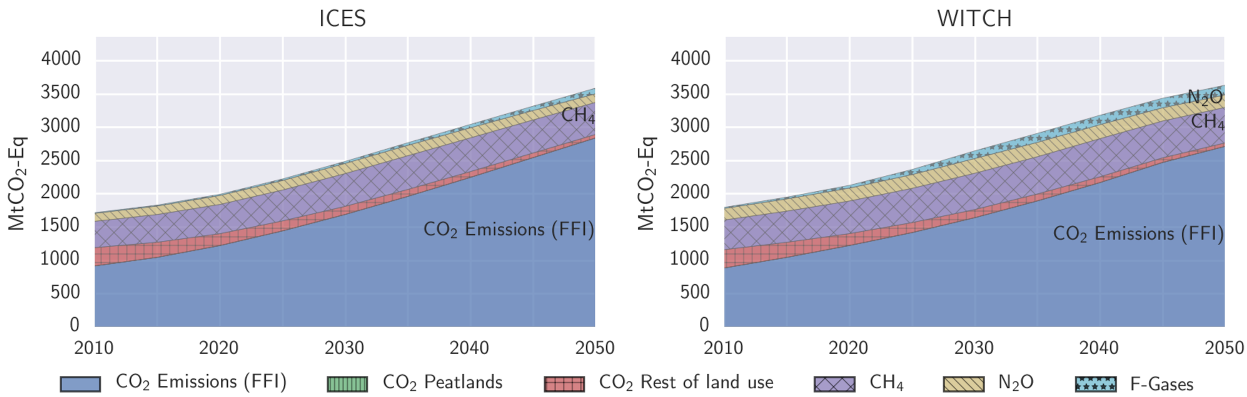


Figure 5: Southeast Asia Baseline GHG Emission by Gas in the ICES and WITCH Models

Baseline world trends for fossil fuel prices have also been harmonized across ICES and WITCH. They have been derived from simulations conducted with the WITCH model and developed in the context of the European Union Ampere project (Kriegler et al., 2014).

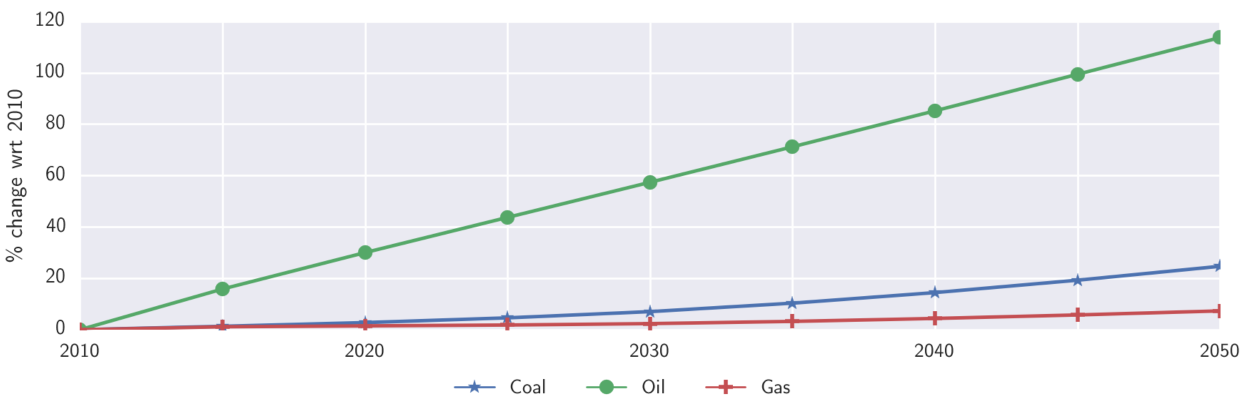


Figure 6: Baseline World Prices of Fossil Fuels

4. The climate scenarios

The intention of the scenarios modelled in this study is to represent alternative potential outcomes of the UNFCCC climate negotiations, and to identify the implications of these outcomes for Southeast Asia. The basic possibilities that are captured include:

1. Climate policies fail - Business as usual (climate action is not prioritized by any government)
2. International climate negotiations fail - Fragmented national climate policies (countries continue to pursue national climate actions at their current level of ambition)
3. International climate agreement reached with moderate ambition (a global climate agreement comes into place in 2020 with a moderate target)
4. International climate agreement reached with high ambition (a global climate agreement comes into place in 2020 with an ambitious target)

As current UNFCCC negotiations target the post 2020 period for implementation of a global climate agreement, the policy scenarios considered in this study have both a short-term and a long-term dimension. The first period focuses on policy objectives that the South East Asian countries aim to pursue by 2020 as stated in their respective official national plans. The second analyzes the implications of various GHGs emission reduction strategies to be deployed after 2020 until the end of the century, assuming different degrees of stringency and levels of global coordination.
To date, the only international expression of greenhouse gas emissions targets for developing countries in Asia is through the 2009 United Nations Framework Convention on Climate Change (UNFCCC) Copenhagen Accord, which covers the period until 2020. This periodic round of climate negotiations under the auspices of the UNFCCC aims to promote and facilitate dialogue on climate-change strategies among UN member countries. It exhorts the major world emitters to pledge voluntary climate-change policy commitments for the year 2020.[1] These pledges are generally expressed with reference to different baseline years or to the level of emissions in the absence of decarbonization actions (business as usual). Several countries or regions committed to two sets of targets: a more ambitious target known as "high Copenhagen pledge" and a less ambitious one known as "low Copenhagen pledge." Both targets are considered in this study. These Copenhagen pledges, expressed in terms of the 2020 policy scenarios, are described in Table 1.

Table 1: Copenhagen Pledges for 2020 Policy Scenarios

Region	Period of reference	Low Cop Pledges	High Cop Pledges
European Union	1990	-20%	-30%
Japan	1990	-25%	-
United States	2005	-17%	-
Russia	1990	-15%	-25%
Australia	2000	-5%	-25%
New Zealand	1990	-10%	-20%
Brazil	BAU	-36%	-39%
Mexico	BAU	-30%	-
Republic of Korea	BAU	-30%	-
Indonesia	BAU	-26%	-
Canada	2005	-17%	-
South Africa	BAU	-34%	-
People's Republic of China*	2005	-40%	-45%
India*	2005	-20%	-25%

BAU = business as usual, CoP = Conference of Parties.

[1] Annex I: http://unfccc.int/meetings/copenhagen_dec_2009/items/5264.php
Non-Annex I: http://unfccc.int/meetings/cop_15/copenhagen_accord/items/5265.php

Note: *on carbon intensity of gross domestic product.

Among Southeast Asian countries, only Indonesia came up with a pledge whose commitment falls within the Copenhagen Accord—a 26% reduction in GHGs with respect to baseline emissions. The rest of the countries are still formulating their climate change and energy policies that seek to promote decarbonization of their respective economic systems so as to reduce the environmental impact of intense fossil-fuel use.

Three long-term policy scenarios are assessed. The first is a fragmented scenario, which has been provided for benchmark comparison. It extrapolates to the end of the century the "low pledge" stringency of the Copenhagen Accord with respect to further carbon intensity improvements, and assumes that countries and regions will act domestically without the possibility of emissions trade. In this setting, carbon prices are not equalized across regions, leading to efficiency losses, in addition to the scenario not leading to the stabilization of the global climate.

The next two are long-term GHG concentration stabilization scenarios that aim by the end of the century to concentrations of GHG gases plus aerosols of two levels, namely at 500 ppm carbon dioxide equivalent (CO_2eq) and 650 ppm CO_2eq. The first and more stringent scenario, 500 ppm CO_2eq, would lead to a median temperature increase of 2°C with respect to preindustrial level by the end of the century; the second scenario, 650 ppm CO_2eq, to a median temperature increase of 2.4°C. The climate stabilization scenario at 500 ppm is assumed to follow the high Copenhagen pledges in 2020, while the climate stabilization scenario at 650 ppm is assumed to follow the low Copenhagen pledges.

The GHG concentration stabilization goals are implemented assuming full global cooperation in the form of an international quota system supported by global trading of grandfathered permits. Regional and country allowances are determined according to "contraction and convergence" criteria; that is, allowances are initially calculated considering the share of each country of total GHG emissions in 2020 (including land use and peatland), which then linearly tend to a per-capita criterion that is fully implemented in 2050.

In the climate stabilization scenarios, emission reductions that are generated by avoided deforestation produce credits that can be traded in the carbon market, provided that a country or region emits less than its allocated target. In the fragmented scenario, countries can use emissions from avoided deforestation to comply with their domestic targets, but cannot trade them.

As the role of REDD in future carbon markets is still not decided and the performance of REDD is not well understood, different assumptions on the feasibility of REDD activities are introduced. This is particularly important for Indonesia as well as also more generally relevant to global climate policy in the context of the potential supply of REDD reduction from Latin American countries. In a "Higher REDD cost" case, the cost of implementing REDD activities is assumed to increase by 150% with respect to that used as the standard in the models. This specific increase takes into account, in addition to opportunity costs, the transaction costs, potential project failures, and leakage that could result from overoptimistic reference levels or from REDD activities that simply displace deforestation or substitution effect. In the "No REDD" case, REDD is excluded altogether. Table 2 summarizes the seven policy scenarios considered.

Table 2: Definitions of the Policy Scenarios in the Present Study

ICES-WITCH Joint scenario matrix		**POLICY STRINGENCY**			
		BAU	**No International Climate Agreement**	**Mid ambition International Climate Agreement**	**High ambition International Climate Agreement**
			Low Copenhagen Pledges in 2020 and extrapolation thereafter	**Low Copenhagen** Pledges in 2020 and long-term GHG concentration at **650** ppm CO2 eq in 2050	**High Copenhagen** Pledges in 2020 and long-term GHG concentration at **500** ppm CO2 eq in 2050
REDD potential	Full REDD	1	2 (Fragmented)	3	4
	Low REDD			5	6
	No REDD			7	8

BAU = business as usual, eq = equivalent, GHG = greenhouse gas, ppm = parts per million, REDD = reduced emissions from forest degradation and deforestation.

5. Results

5.1 Emissions pathways

Greenhouse gas (GHG) emissions in a business- as-usual scenario are expected to increase through mid-century. This trend is projected to persist both at the global level and also for Indonesia and Southeast Asia. As shown in Figure 7, the 650 scenario depicts a global stabilization of emissions, while the 500 case represents a more pronounced emission reduction of around 40% by mid-century.

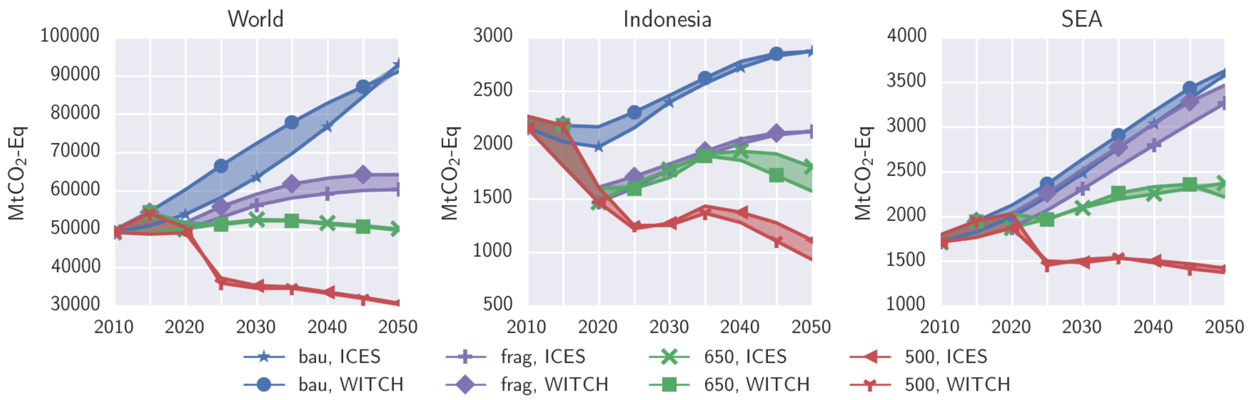


Figure 7: GHGs Emission Pathways for the World, Indonesia, and Southeast Asia
BAU = business as usual, frag = fragmented (policy)

For the two regions of interest, the fragmented policy implies two different patterns. For Indonesia, the scenario suggests a modest but non-negligible slowdown of emissions, whereas for Southeast Asia, that policy is assumed to reduce emissions only marginally. The stabilization policies would require a more significant reduction, especially when approaching 2050. For Indonesia, however, emissions are expected to have already significantly abated by 2020 as the targets of its Copenhagen pledge take effect.

These emission reductions are achieved via three main effects triggered by carbon markets: (i) increasing the efficiency of energy usage, (ii) replacing carbon-intensive fuels with cleaner alternatives, and (iii) reducing land-use emissions. Figure 8 reports sources of reductions under the stabilization scenarios. Prior to 2040, when REDD is included in the scenarios, it accounts for more than half of abatement in Indonesia under both global stabilization scenarios, and accounts for about 10%–15% abatement for the rest of Southeast Asia by 2030. About half of emissions abatement aggregated across both regions through the mid-2030s arises from REDD. In Indonesia, the presence of REDD also increases abatement substantially, particularly in the period around 2030 and the 650 ppm scenario, where abatement is doubled. REDD makes a greater contribution to emission reduction than renewable energy in Indonesia for the entire period and in the rest of Southeast Asia prior to 2040.

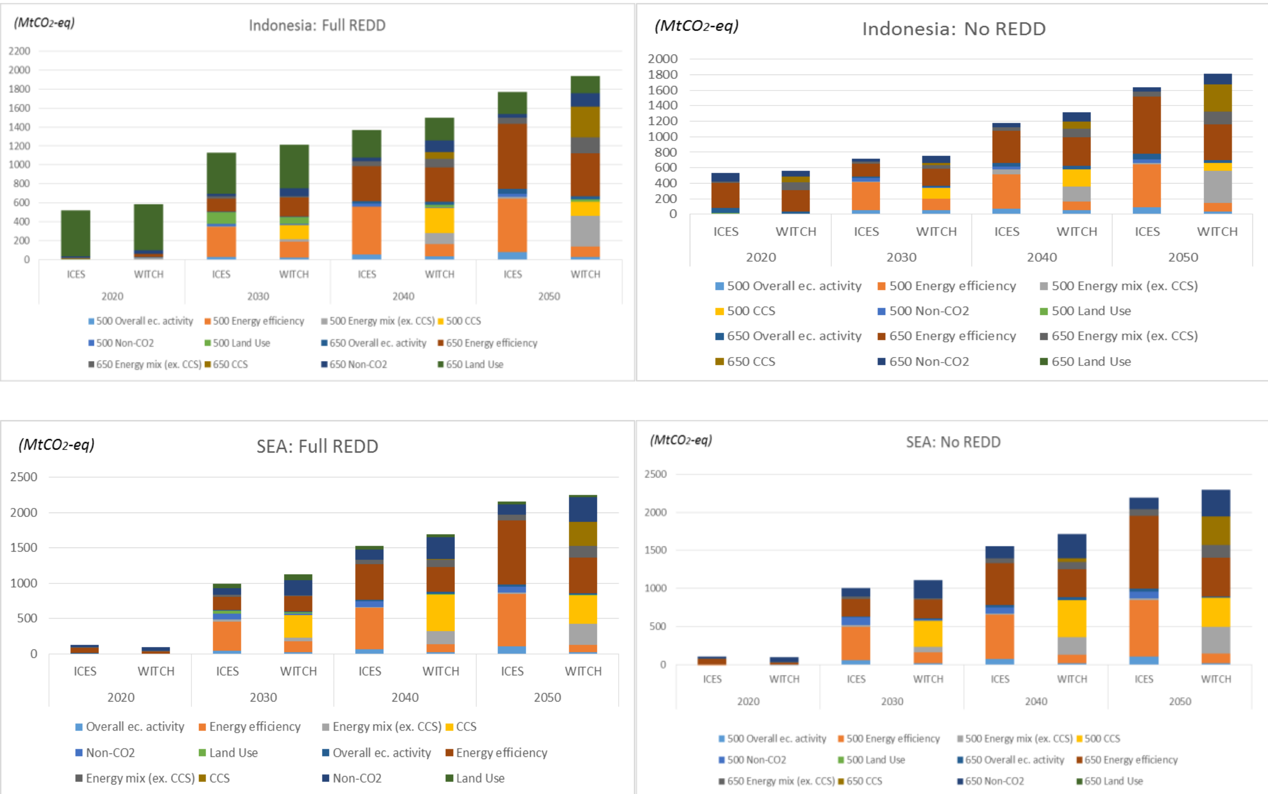


Figure 8 - Emission Reduction by Source under Stabilization Scenarios

The largest single source of cumulative emission reductions over 2010–2050 is energy efficiency gains, under all scenarios and models when emissions are aggregated across Indonesia and the rest of Southeast Asia. This is particularly pronounced in the rest of Southeast Asia and under ICES, where it is the main mechanism for the energy sector to reduce emissions.

In ICES, energy efficiency is the source of a rising share of emission reduction over the period, whereas in WITCH, its share is generally stable or declining in all cases other than Indonesia in the presence of REDD.

Emission reductions attributable to fundamental changes in energy production technologies only become dominant in 2050 under 650 ppm stabilization modeled in WITCH. Over the longer term, more advanced "backstop" technologies that are not yet economically viable and with uncertain development potential come into play. One such advanced "backstop" technology is carbon capture and storage (CCS), in which emitted GHGs are dissolved in a solvent and transported for underground storage. Another is advanced biofuel, which permits the use of agricultural residues, or microbes for fuel with zero net emissions.

Under 500 ppm stabilization, emission reductions from these technologies occur more quickly. The combination of CCS and substitution of renewable sources (termed "energy mix" here) for fossil fuel energy becomes dominant in Indonesia after 2040 and in the rest of Southeast Asia after 2030 both under WITCH. ICES finds similar energy sector shares of emission reductions to WITCH, but generally relies on increased energy efficiency to substitute for the role of CCS and more renewable sources. Renewable energy contributes less to emission reduction than does CCS when present in the models. In the rest of Southeast Asia, renewables

also contribute less than non-CO2 reductions, which principally take place in agriculture, in all periods under 650 ppm stabilization and prior to 2050 in the 500 ppm stabilization. Renewable energy begins to play as great a role as CCS when present in Indonesia only in 2050 under the 500 ppm stabilization scenario.

5.3 Land use emissions

Figure 9 provides an overview of net land-use emissions for the world, for Indonesia, and for the rest of Southeast Asia. Reducing emissions from land use via REDD is critical to emissions abatement, especially in through 2030. Global land-use emissions fall to nearly zero by 2030 in the 500 ppm scenario, and are significantly mitigated in the other scenarios. A similar pattern is found for Indonesia and the rest of Southeast Asia, although the pattern is more pronounced in Indonesia. For Indonesia, land-use emissions by 2020 are halved with respect to BAU as a result of its Copenhagen pledge. The quantity of Indonesia's emission reductions from REDD is relatively insensitive to a higher costing for REDD (termed "Low REDD" in the figure). For Indonesia and the rest of Southeast Asia, land-use emissions are expected to fall below 200 MtCO2 and 50 MtCO2 in 2030, respectively, and close to zero by mid-century.

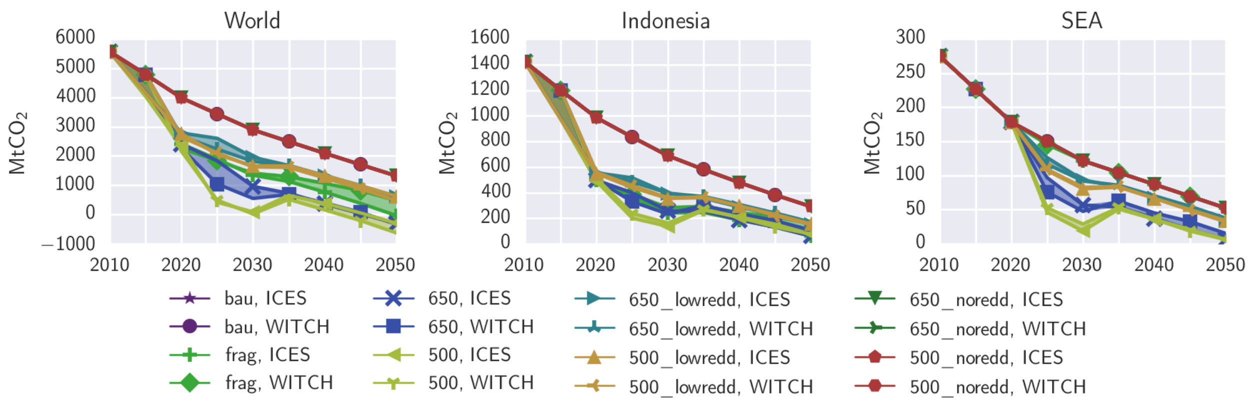


Figure 9 – Land use emissions

5.4 Policy Costs

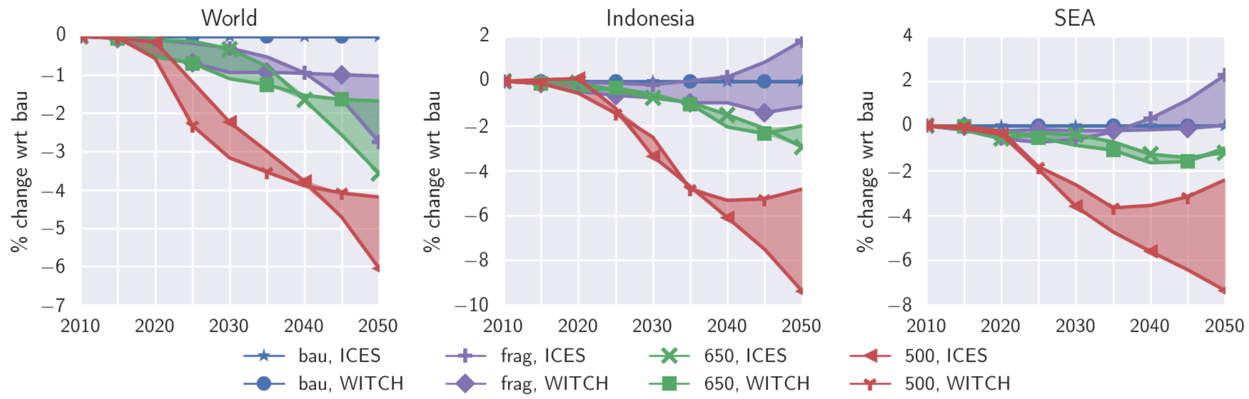
Figure 10 presents the effects of the climate policy scenarios on GDP. As can be seen in the contrast between scenarios with and without REDD, policy costs through 2035, especially in Indonesia, greatly depend upon avoided forest destruction. In the presence of REDD, 500 ppm stabilization leads to positive effects on GDP in WITCH through 2030, even if REDD is high cost, whereas the absence of REDD causes GDP to experience relatively large drops to comply with emissions targets. This is particularly true through 2020, as the country tries to fulfil its Copenhagen pledge through energy sector measures alone. Southeast

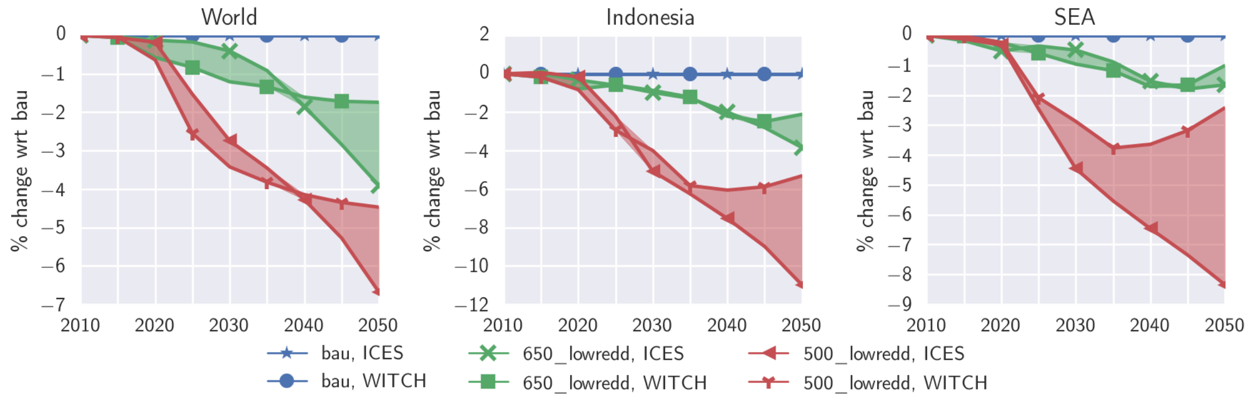
Asia is also somewhat sensitive to REDD through its effect on carbon permit prices, although the effect is smaller.

Globally, due to the inefficiency of a fragmented policy regime, the fragmented policy generates GDP losses similar to the 650 case despite achieving lower emission reductions. For Indonesia and Southeast Asia, both policies yield relatively small or even negative losses of output. The more aggressive stabilization policy, 500, comes at greater GDP cost but there is more disagreement among the models using it. In particular, there is a high divergence in costs after 2030, with ICES presenting larger GDP losses. This is due basically to the detailed and endogenous modelling of technological change in WITCH and to bottom-up and richer description of the energy sector. As a consequence, WITCH offers more flexibility in decarbonization than ICES and this flexibility has a direct implication for policy costs.

Figure 11 illustrates the cumulative discounted (at 5%) effects on GDP of the policy scenarios. Here it can be seen that the presence of efficient REDD can allow 2010-2050 policy costs for Indonesia to be reduced by more than 50% according to ICES and WITCH results for both levels of stringency. In the rest of Southeast Asia, REDD allows policy costs to be reduced by 15% or more.

With REDD in place, WITCH finds total costs to GDP that never exceed 2% of GDP for the period, while the cumulative costs are approximately 5% of GDP under ICES. The 650 stabilization costs less than 1% of GDP under WITCH and approximately 1.5% of GDP under ICES. Indonesia experiences higher costs to GDP under the fragmented scenario than under 650 stabilization, whereas Southeast Asia has lower costs under the fragmented scenario. Indonesia has lower decarbonisation costs than the rest of Southeast Asia.





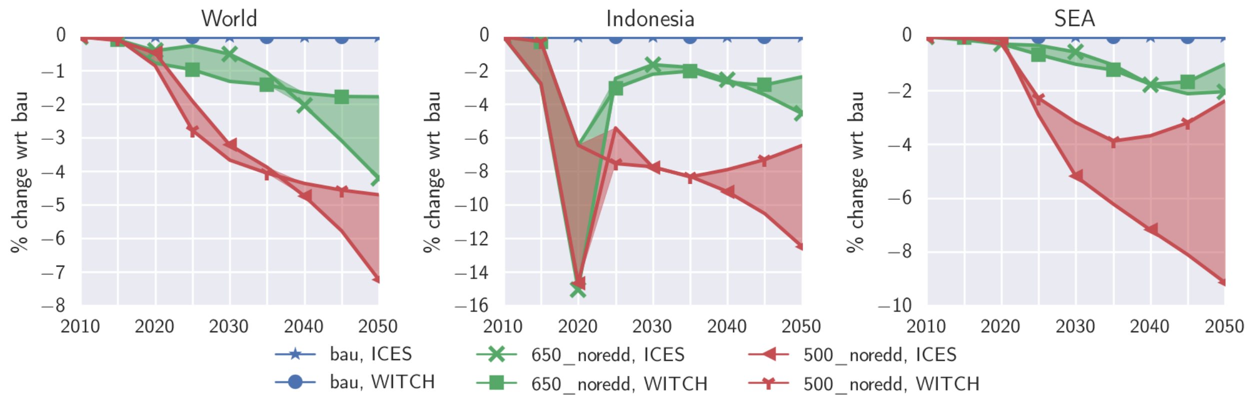


Figure 10. GDP losses
frag = fragmented (policy), GDP = gross domestic product, SEA = Southeast Asia.

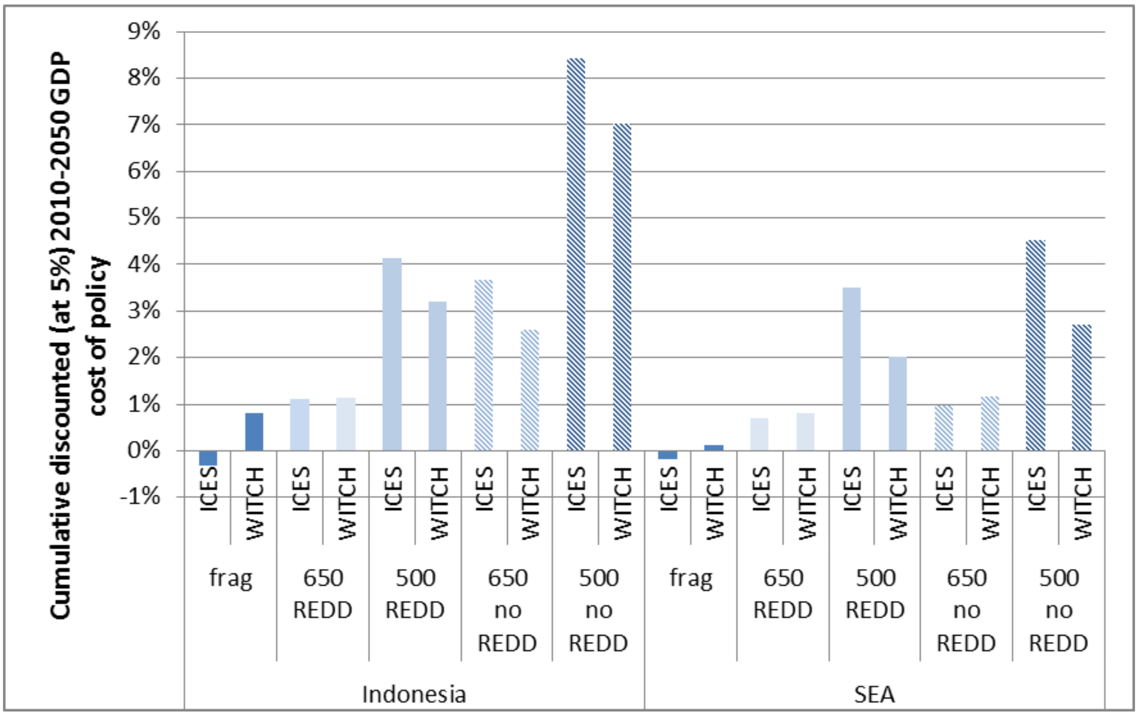


Figure 11. Cumulative GDP losses over 2010-2050 period (discounted at 5%)

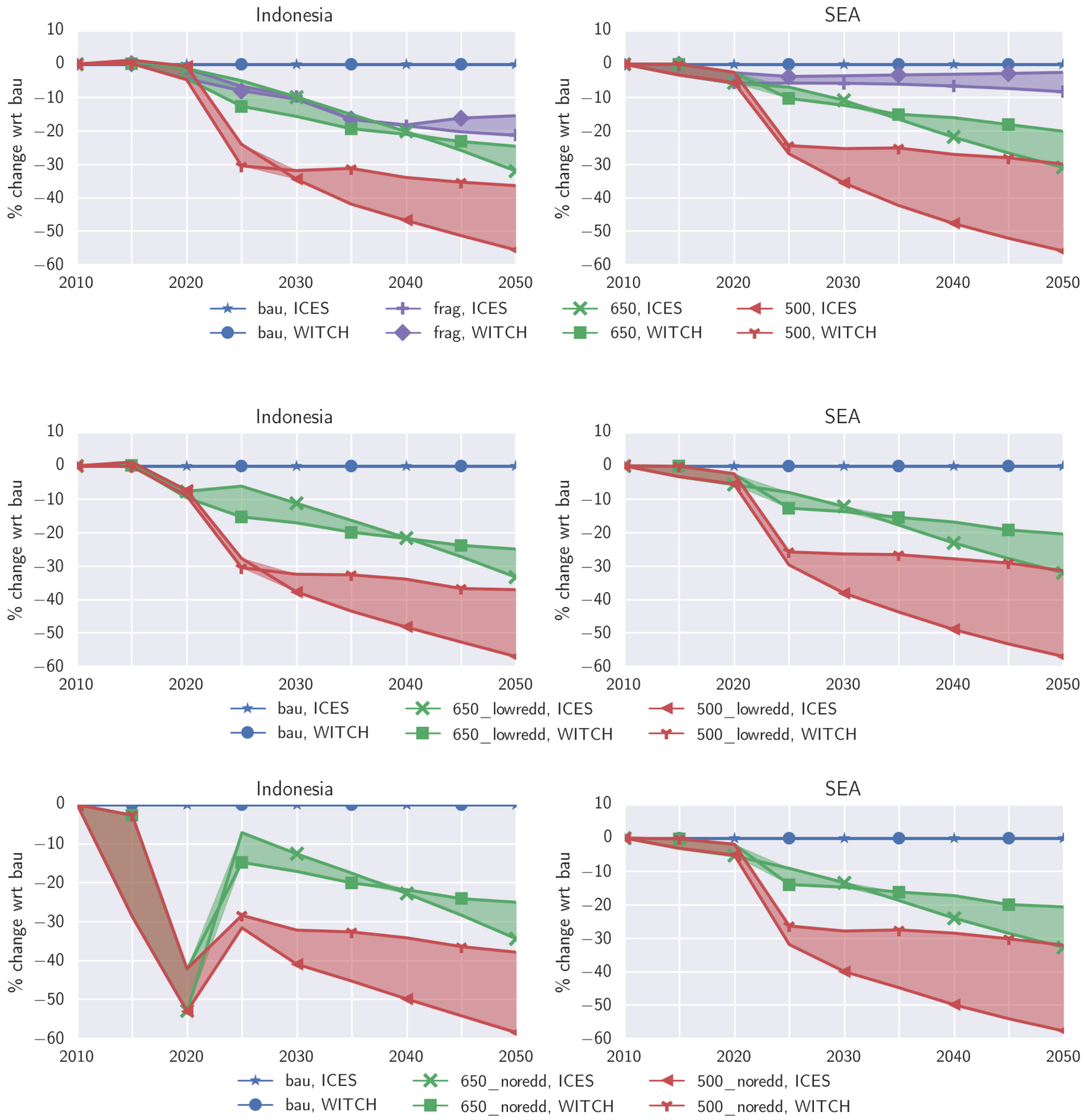
5.5 Transformations of the energy sector

Achieving the transformations depicted in previous sections will require commensurate changes in the way energy is consumed and produced. As highlighted in Figure 14, and as expected from previous discussion, energy consumption would be reduced with respect to business as usual in the climate policy scenarios in accordance with emissions target.

The fragmented scenario results in a decrease of 20% Indonesian energy consumption by 2050. However, the weaker commitments of the rest of Southeast Asia make this scenario much closer to the baseline. The more stringent 500 target requires considerable energy savings for both regions, especially in the ICES model.

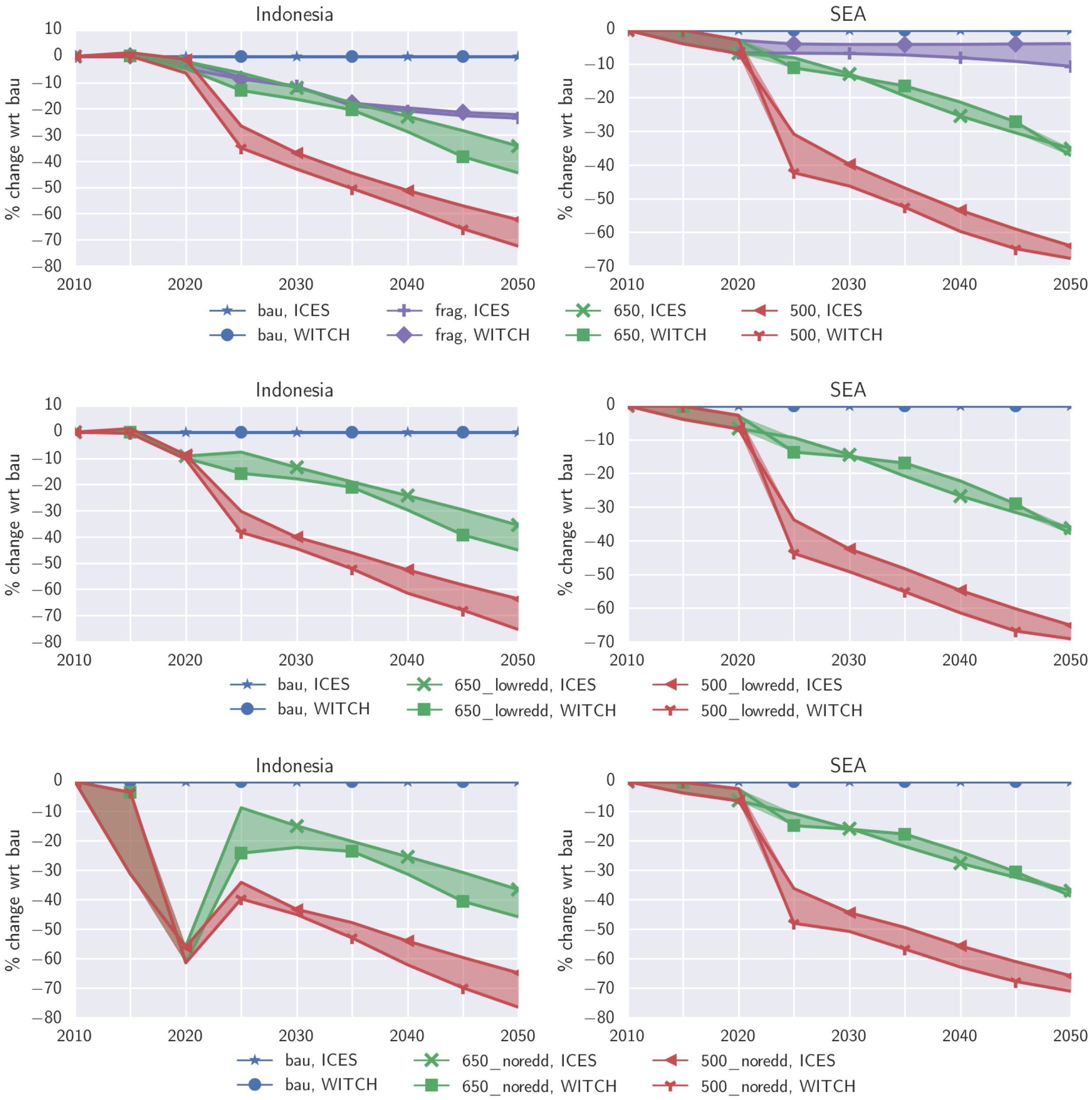
Figure 12 and Figure 13 chart the projected results for Indonesia and the rest of Southeast Asia, showing how they affect energy intensity and carbon intensity for various policy scenarios. The two models indicate different long-term behavior for the most stringent 500 scenario, with ICES achieving much higher energy-intensity reductions than WITCH to compensate for the lower substitutability of carbon-intensive sources with “cleaner” ones.

Both find that fuel substitution is an indispensable long-term strategy for achieving climate stabilization. If policies aimed at 650 parts per million (ppm) carbon dioxide (CO2) equivalent (eq) and 500 ppm CO2eq are adopted, carbon-intensity reductions of roughly 20 to 30% and 35 to 55% with respect to BAU are achieved by mid-century in Indonesia, respectively. In the rest of Southeast Asia, the values are similar at 20 to 30% under 650 stabilization and 30% to 55% under 500 stabilization.



BAU = business as usual, frag = fragmented (policy), SEA = the rest of Southeast Asia

Figure 12: Energy Intensity Projections for Indonesia and the rest of Southeast Asia



BAU = business as usual, frag = fragmented (policy), Mt CO_2-Eq = million tons carbon dioxide equivalent, SEA = the rest of Southeast Asia.

Figure 13: Carbon Intensity for Indonesia and the rest of Southeast Asia

Figure 15 portrays the evolution of the primary energy mix across scenarios and models. The figure illustrates a gradual transition toward cleaner forms of energy over time, particularly under the more stringent scenarios. In the most stringent scenario, Indonesian coal use is reduced by 65% from 2020 to 2035 and falls to 5% of the mix in 2050. Gas also declines slightly, with 30% of the mix in 2050. In contrast, oil remains significant, especially in ICES, as a share, but declines in absolute values, given that overall energy use falls. Similar trends are found for the rest of Southeast Asia, with a greater penetration of hydro and gas in the mix.

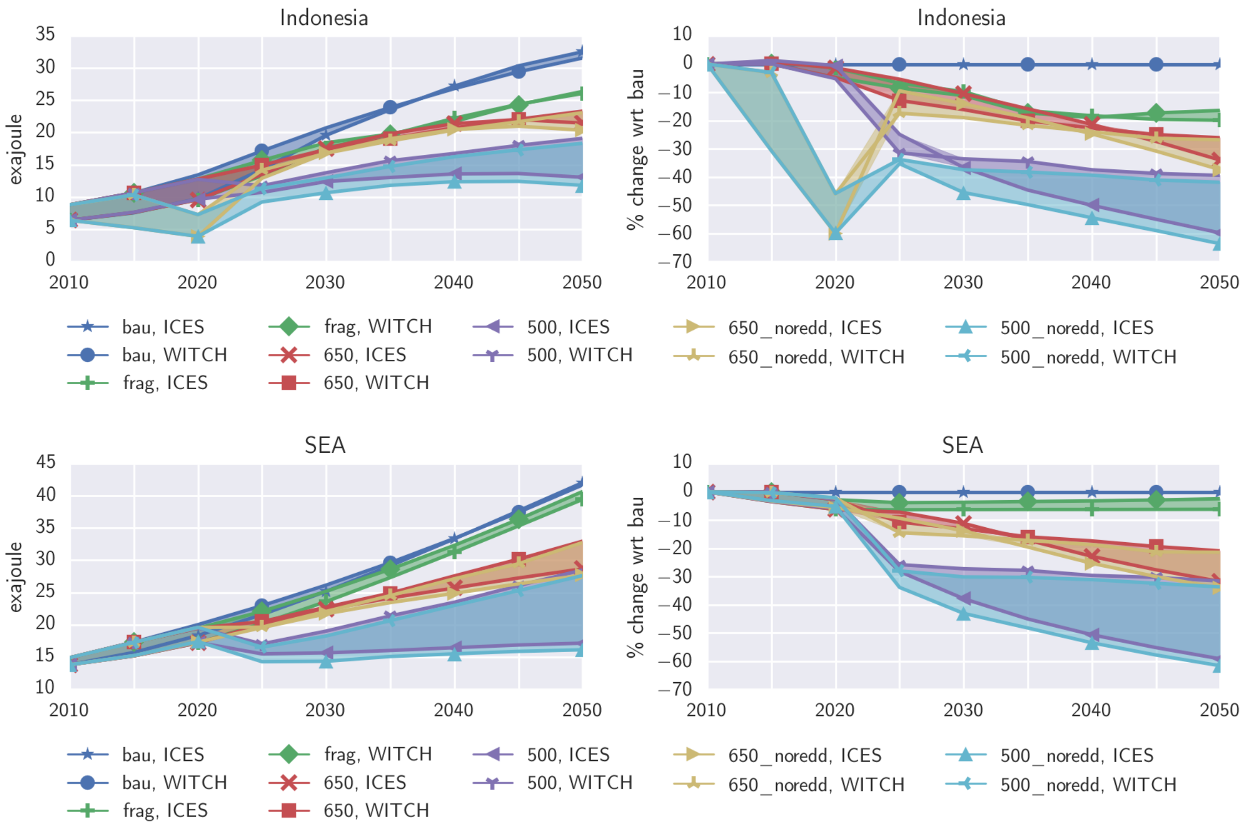
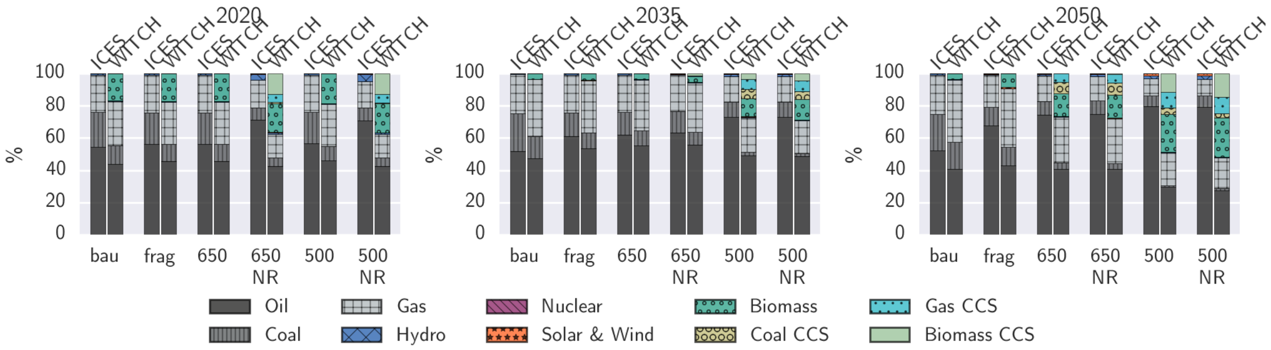


Figure 14: Primary Energy Consumption (full REDD)
BAU = business as usual, SEA = Southeast Asia.

In all WITCH scenarios, traditional biomass is phased-out in both Indonesia and the rest of Southeast Asia. In the baseline, it is replaced mainly by fossil fuels, but in a carbon-constrained world, fossil fuels are replaced by other cleaner sources, including modern biofuels (see Box 3 for an explanation of these), as well as non-biomass renewables, such as solar, wind, and hydropower. A portion of the fossil fuels is also expected to transition to carbon capture and storage (CCS), and this transition is much stronger under the 500 scenario than under 650, where CCS adoption is delayed. Under climate stabilization, CCS is adopted in the rest of Southeast Asia more rapidly than in the world primary energy mix, whereas in Indonesia, bioenergy expands more rapidly. In contrast, in ICES, due to the limited number of energy technologies available, both 650 and 500 policy scenarios induce reduction of total primary energy compared to the baseline.

Indonesia



Rest of Southeast Asia

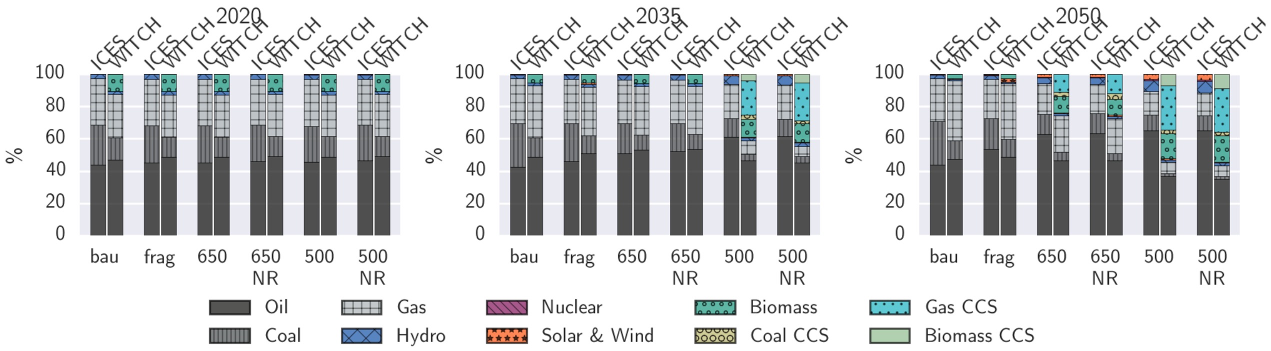
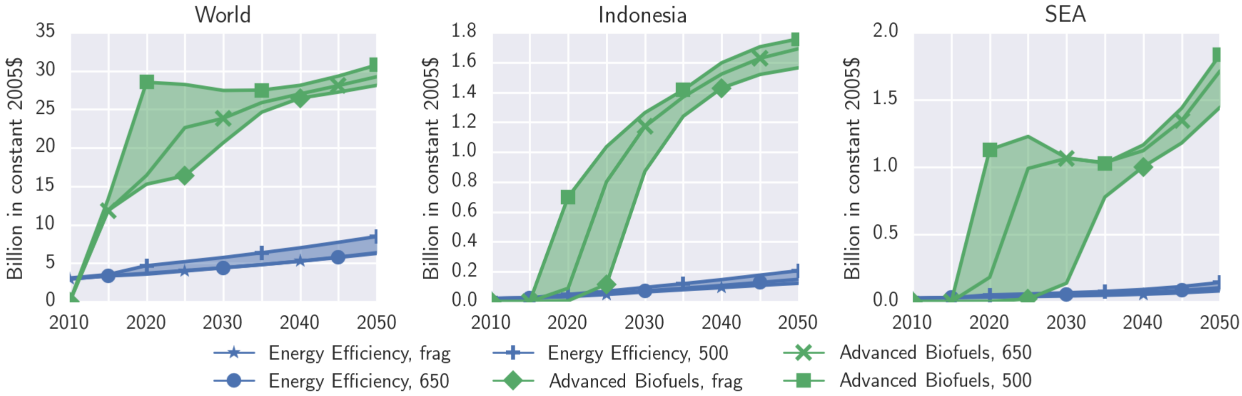


Figure 15: Energy Mix Projections under Climate Stabilization Scenarios

One key issue in climate policy is the extent of innovation needed to achieve climate objectives. The role of technological progress is a key factor in the feasibility of climate policies, given its enormous impacts on policy costs and implementation. Technical change is likely to respond endogenously to climate policies. In WITCH, this mechanism is modeled for two key decarbonization options: low-carbon fuel in the transportation sector (advanced biofuels) and carbon capture and storage.

Figure 16 shows the evolution of investments in clean energy research and development (R&D) for the world, as well as for Indonesia and the rest of Southeast Asia. Globally, R&D investments scale-up very rapidly, especially for low-carbon fuels, given the difficulty in decarbonizing the transportation sector. A failure to do so early enough may lock-in the energy system to more costly decarbonization pathways, especially when steeper emission reduction rates are required. Investments in energy efficiency would need to scale-up over time more gradually than advanced biofuels, reflecting the difference between marginal technological improvements of the former and the breakthrough innovation feature of the latter.



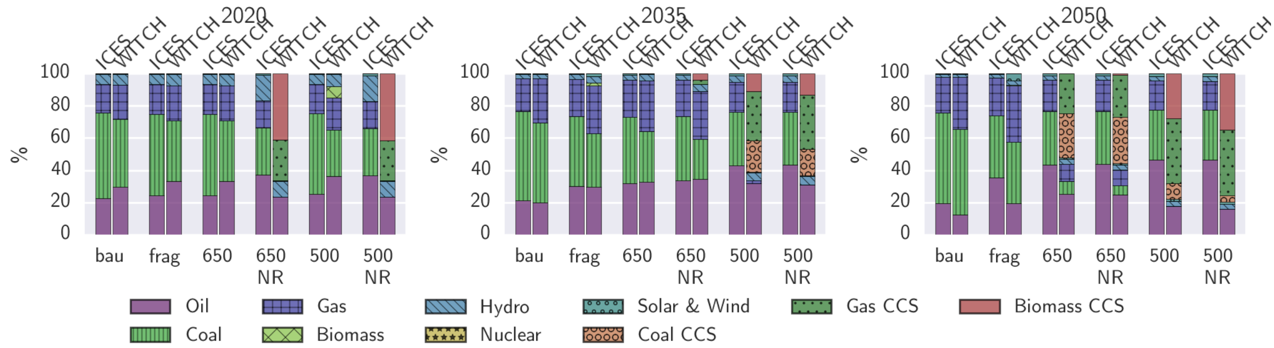
Frag = fragmented (policy), SEA = the rest of Southeast Asia.

Figure 16: Research and Development Investments under the WITCH Model for the World, Indonesia, and the rest of Southeast Asia

Regarding the regions of interest, the WITCH model indicates that both Indonesia and the rest of Southeast Asia benefit from their own R&D investments. Although these would be a fraction of global investments, they are crucial in equipping the rest of Southeast Asia with the knowledge necessary to absorb advances in technology. The different levels of global climate stabilization targets influence more the timing than the scale of R&D investment. The 500 scenario leads R&D investment to be advanced 10 to 15 years compared to the fragmented scenario. Even though this is a significant change from the status quo, such R&D figures remain below 0.05% of GDP through 2050.

Both models find moderate level of electricity production contraction under climate stabilization scenarios. WITCH projects that the electricity mix evolves from 80% - 90% sourced in 2010 from fossil fuels without CCS, to 50-70% of electricity from gas and coal combined with CCS in 2050 in the 500-ppm scenario (Figure 17). Natural gas potentially plays an important role in transitioning away from coal, which would become less than 10% of the electricity mix in 2050 under the 500 case. The use of CCS for power generation from modern biomass is included in the 500-ppm scenario, reaching 29% and 11% of electricity in Indonesia and SEA, respectively, by 2050.

Indonesia



Rest of Southeast Asia

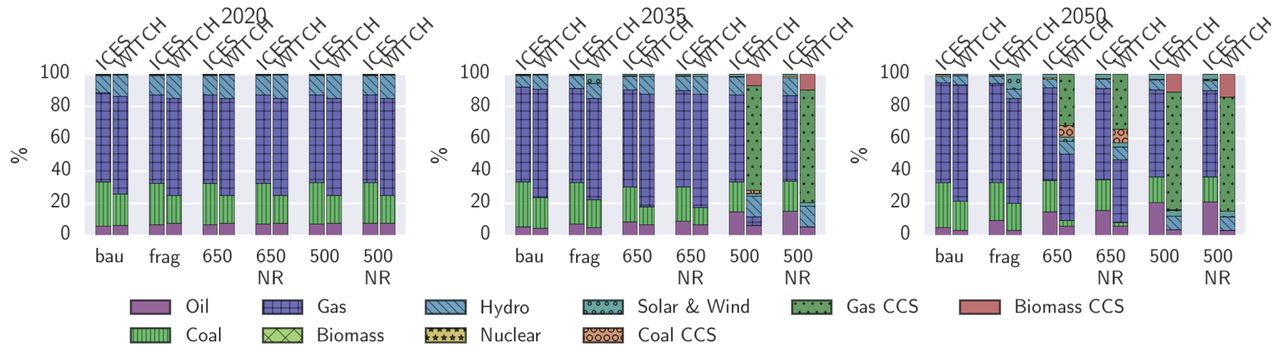


Figure 17: Electricity Mix Projections under Climate Stabilization Scenarios

5. Conclusions

Southeast Asia is particularly exposed to climatic changes and vulnerable to their adverse consequences, with expected economic losses that are much higher than the world average. Climate change is thus a development challenge for the region, especially in the light of the large share of the Southeast Asian population still living in poverty and employed in climate-sensitive sectors. At the same time, Southeast Asia is also fast becoming one of the world's important contributors to global warming, as it currently couples policies that encourage high levels of emissions and technical inefficiency with some of the world's most rapidly growing economies. Addressing the risks posed by climate change requires substantial mitigation and adaptation action.

To go beyond previous studies, a recursive-dynamic CGE model is used to capture and sectoral specificities and international trade effects of five Asian countries (Indonesia, Malaysia, Philippines, Thailand and Viet Nam), while a climate-environment-economic, hard-linked, dynamic optimization model is applied to represent long-term dynamics in technological improvement and abatement opportunities in the energy sector. Both models show that stabilizing global temperature at 1.5°C by the end of the century—below the target set by the international community to limit the probability of catastrophic and potentially irreversible effects—requires early action embedded in a global and coordinated effort to be effective.

The models find that to minimize long-term costs, Southeast Asian emissions need to decline by 20%–25% compared to the baseline in 2025 and by 60% by 2050. The associated costs in terms of GDP are quite similar in the two models up to 2030 and when REDD mechanisms are fully exploitable. After 2030, the cost pathways diverge substantially between the models with the ICES model generating higher policy costs. As an example, in the 500ppm scenario, the ICES model shows a GDP loss of 9.4% vs. 4.8% and 7.4% vs. 2.4% in Indonesia and Southeast Asia respectively.

Early action is required to cope with the lagged response of climate to emission reductions and to avoid insurmountable decarbonization cost spikes. For example, a 10-year delay in implementation of the 1.5°C target in WITCH leads to 2050 Southeast Asian GDP losses that are 60% higher than with no delay.

When long-term emission reduction needs are compared with domestic climate-change and energy targets for 2020, it emerges that some current targets are insufficient, particularly in the Southeast Asia region.

Decarbonization of the energy sector is found to derive from increased efficiency of energy use, replacement of carbon-intensive fuels with cleaner alternatives, and reduction in energy consumption. However, the relative importance of these three components depends largely on the availability of low-carbon technological options.

The development and availability of these advanced low-carbon energy technologies critically affect overall economic costs of climate stabilization. In the absence of advanced energy technologies, oil will become even more dominant as an energy source even under a global climate regime. Solar and wind energy will experience a strong increase in production, but their share in primary energy will remain low. The contraction in energy use needed to reduce emissions would most affect the energy-intensive sectors, followed by services and agriculture. However, if low-carbon technologies are developed and available, the 2050 gross domestic product (GDP) costs of decarbonization for the region could be reduced by 50%, with a peak in 2045, before declining.

Realizing the potential of advanced low-carbon energy sources to contain decarbonization costs requires up-front investment in research, with overall funding needs identified as $3.5 billion for the region under WITCH. Although this figure may appear to be large in absolute terms, it is only a small share of regional GDP, and has large payoff under global climate stabilization scenarios in terms of reduced policy costs.

If, in the longer term, technological development is fundamental, REDD is critical in the medium term, especially in Indonesia. Under a global climate agreement, the country could leave its medium-term energy consumption levels almost unchanged and concentrate emissions reduction on REDD actions without affecting its energy/industrial system. Those deforestation reductions can be made at low opportunity cost, as

Indonesia has large areas of unproductive degraded grasslands, where land demanding industries, such as plantation agriculture, could still be developed were natural forest clearance more limited. This would allow Indonesia to sustain negligible policy costs, while exporting hundreds of billions of dollars of carbon credits. In the medium term, this would lead to positive effects on consumption and living standards for Indonesia, as well as reduced policy costs for the region.

References

ADB *Key Indicators for Asia and the Pacific 2011*. 42nd edition, Asian Development Bank, Manila (2011a).

ADB *Long-Term Projections of Asian GDP and Trade*. Asian Development Bank, Manila (2011b).

ADB *The Economics of Climate Change in Southeast Asia: A Regional Review*. Asian Development Bank, Manila (2009).

Akashi O., Hijioka Y, Masui T, Hanaoka T, Kainuma M. "GHG emission scenarios in Asia and the world: The key technologies for significant reduction". *Energy Economics*, 34 (2012) S346-S358.

Anthoff, D., Nicholls, R.J., & Tol, R.S.J. "The economic impact of substantial sea-level rise". *Mitigation and Adaptation Strategies for Global Change* 15 (2010): 321-335.

Avetisyan, Misak, A. Golub, T. Hertel, S. Rose and B. Henderson, "Why a Global Carbon Policy Could Have a Dramatic Impact on the Pattern of the Worldwide Livestock Production" *Applied Economic Perspectives and Policy* (2011): 1–22

Blanford G.J., Rose S. K., Tavoni M. "Baseline projections of energy and emissions in Asia". *Energy Economics* 34 (2012): Supplement 3, S284–S292.

Bohringer, C., Fisher, C. and K.E. Rosendahl "The global effects of subglobal climate policies". The B.E. *Journal of Economic Analysis & Policy* 10 (2010): (2 (Symposium)), Article 13.

Bohringer C., Rutherford T. and Tol R., "The EU 20/20/20 targets: an Overview of the EMF22". *Energy Economics* 31 (2009): 268–273.

Bosello, Francesco, Eboli, Fabio and Pierfederici, Roberta, "Assessing the Economic Impacts of Climate Change". *Review of Environment, Energy and Economics* (2012): ,http://dx.doi.org/10.7711/feemre3.2012.02.002

Bosello, Francesco and Parrado, Ramiro, "Climate Change Impacts and Limited Market-driven Adaptation" *Review of Environment, Energy and Economics* (2014): http://dx.doi.org/10.7711/feemre3.2014.09.004

Bosello, F., Eboli F., Parrado R. and Rosa R. "REDD in the Carbon Market: A General Equilibrium Analysis". *FEEM Working Paper* (2010):142.

Bosello, F., Lazzarin, M., Roson, R. and R.S.J. Tol "Economy-wide estimates of climate change implications: sea-level rise", *Environment and Development Economics* 37 (2007):549–571.

Bosello, F., Roson, R. and R.S.J. Tol "Economy wide estimates of the implications of climate change: human health" *Ecological Economics*, 58 (2006): 579-591.

Bosetti, V., Tavoni, M., De Cian E. and Sgobbi A., "The 2008 WITCH Model: New Model Features and Baseline". *FEEM Working Paper* (2009) No. 85.2009.

Bosetti, V., Massetti, E. and Tavoni, M. "The WITCH Model. Structure, Baseline, Solutions". *FEEM Working Paper* (2007) No. 10.2007.

Burniaux, J.-M., Truong, T.P. "GTAP-E an energy-environmental version of the GTAP model". *GTAP Technical Papers* (2002): No. 16. Center for Global Trade Analysis, Purdue University, West Lafayette, Indiana, USA 47907-1145.

Busch, J., Lubowski, R., Godoy, F., Steininger, M., Yusuf, A., Austin, K., Hewson, J., Juhn, D., Farid, M., Boltz, F. "Structuring economic incentives to reduce emissions from deforestation within Indonesia*". Proc. Natl. Acad. Sci*. USA 2012, 109, 1062–1067.

Calvin, K., Clarke. L., Krey, V., Blanford, G., Jiangd, K., Kainuma, M., Kriegler, E., Luderer, G., Shukla, P.R., "The role of Asia in mitigating climate change: Results from the Asia modeling exercise*". Energy Economics*, 34 (2012a): (Supplement 3) S251-S260.

Calvin, K., Fawcett, a., Kejung, J., "Comparing model results to national climate policy goals: Results from the Asia modeling exercise", *Energy Economics*, 34 (2012b): Supplement 3, S306-S315.

Calzadilla, A., Rehdanz, K., Tol, R. "The Economic Impact of More Sustainable Water Use in Agriculture: A CGE Analysis". Research Unit Sustainability and Global Change (2008): FNU-169. Hamburg University.

Chaturvedi V., Waldhoff S., Clarke L., Fujimori S. "What are the starting points? Evaluating base-year assumptions in the Asian Modeling Exercise". *Energy Economics* 34 (2012): S251-S260.

Ciscar, J., A. Iglesias, L. Feyen, L. Szabó, D. Van Regemorter, B. Amelung, R. Nicholls, P. Watkiss, O.B. Christensen, R. Dankers, L. Garrote, C.M. Goodess, A. Hunt, A. Moreno, J. Richards, and A. Soria "Physical and economic consequences of climate change in Europe" *Proceedings of the National Academy of Sciences of the United States of America* (2011): 108(7), 2678-2683.

Corruption Eradication Commission "Integritas Sektor Publik Indonesia 2012: Fakta Korupsi Dalam Layanan Publik". Jakarta (2013): Corruption Eradication Commission.

Darwin, R. F. and Tol, R. S. J. "Estimates of the Economic Effects of Sea Level Rise". *Environmental and Resource Economics* 19 (2001): 113-129.

Deke, O., Hooss, K. G., Kasten, C., Klepper, G., Springer, K. "Economic Impact of Climate Change: Simulations with a Regionalized Climate-Economy Model". Kiel Institute of World Economics, Kiel (2002): 1065.

Dixon P., Rimmer M. "Dynamic general equilibrium modeling for forecasting and policy". North Holland (2002).

DNPI *Indonesia's greenhouse gas abatement cost curve*. (Jakarta: National Council for Climate Change 2010).

Dowling P., Russ P., "The benefit from reduced energy import bills and the importance of energy prices in GHG reduction scenarios". *Energy Economics* 34 (2012): S429-S435

Eboli, F., Parrado, R. and R. Roson "Climate Change Feedback on Economic Growth: Explorations with a Dynamic General Equilibrium Model". *Environment and Development Economics* 15 (2009): 515 -533.

Eliasch, Johann *Climate Change: Financing Global Forests*" (Norwich, UK: The Stationery Office 2009).

Energy Modeling Forum 21, John Weyant and Francisco C. de la Chesnaye. Multi-Greenhouse Gas Mitigation and Climate Policy. *The Energy Journal* (2006).

European Commission *Package of implementation measures for the EU's objectives on climate change and renewable energy for 2020*. Commission Staff working document SEC (2008) 85 II.

European Commission *Analysis of options to move beyond 20% greenhouse gas emission reductions and assessing the risk of carbon leakage*. Commission Staff working document SEC (2010) 650.

FAO "Global Forest Resources Assessment 2000". Main report, *FAO Forestry paper* 140 (2001).

FAO "Global Forest Resources Assessment 2005: Progress towards sustainable forest". management". *FAO Forestry paper* 147 (2006).

FAO *Global forest resources assessment 2010 country reports* (Rome: Food and Agriculture Organization, 2010)

Golub, Alla., Thomas Hertel, Huey-Lin Lee, Steven Rose, Brent Sohngen "The opportunity cost of land use and the global potential for greenhouse gas mitigation in agriculture and forestry," *Resource and Energy Economics* 31 (2010): pp 299-319.

Golub, Alla., B. Henderson, T. Hertel, S. Rose, M. Avetisyan, B. Sohngen "Effects of GHG Mitigation Policies on Livestock Sectors". *GTAP Working Paper* No.62 (2010).

Gusti, M., Havlik, P., Oberstenier, M. "Technical description of the IIASA model cluster", International Institute for Applied System Analysis (2008).

Hafner, S. "Trends in maize, rice, and wheat yields for 188 nations over the past 40 years: a prevalence of linear growth" *Agriculture, Ecosystems & Environment*. (2003): 97(1–3): 275-283.

Hanaoka, T., Kainuma, M. "Low-carbon transitions in world regions: comparison of technological mitigation potential and costs in 2020 and 2030 through bottom-up analyses", *Sustainability Science* (2012): Volume 7, Issue 2, pp 117-137.

Hoa, N. T., Gomi, K., Matsuoka, Y., Fujino, J., Kainuma, M., Shrestha, R. M.: Sustainable Low-carbon development towards 2030 in Vietnam, available at http://2050.nies.go.jp/LCS, February 2010.

Hooijer A, Page S, Canadell JG, Silvius M, Kwadijk J, Wosten H, Jauhiainen J "Current and future CO2 emissions from drained peatlands in Southeast Asia". Biogeosciences (2010): 7:1-10.

IEA *World energy outlook 2009* (Paris: International Energy Agency 2009).

IEA *World energy outlook 2010* (Paris: International Energy Agency 2011).

IEA *World energy outlook 2011* (Paris: International Energy Agency 2012).

IEA *Dataset: World - Renewable and Waste Energy Statistics* Data extracted on 18 Sep 2013 13:12 UTC (GMT) from OECD iLibrary.

IPCC *Climate Change 1995. Economic and Social Dimensions of Climate Change, Contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change* Bruce, J.P., Lee., H., Haites, E.F. (eds.), (Cambridge, UK: Cambridge University Press 1996).

IPCC *Climate Change 2001: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change* McCarthy, J., Canziani O.F., Leary, N.A., Dokken, D.J., White, K.S. (eds), (Cambridge, UK: Cambridge University Press 2001).

IPCC *Climate Change 2007: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson (eds) (Cambridge, UK: Cambridge University Press 2007)

IPCC *Climate Change 2014: Mitigation of Climate Change*. Contribution of Working Group III to the fifth assessment report of the intergovernmental panel on climate change. (Cambridge: Cambridge University Press, 2014).

Kindermann GE, Obersteiner M, Sohngen B, Sathaye J, Andrasko K, Rametsteiner E, Schlamadinger B, Wunder S, Beach R, “Global cost estimates of reducing carbon emissions through avoided deforestation”. *Proc. Natl. Acad. Sci*. (2008) 105(30):10302-10307.

Kriegler E, Tavoni M, Aboumahboub T, et al. “What does the 2°c target imply for a global climate agreement in 2020? the limits study on durban platform scenarios”. *Climate Change Economics* (2013): 04:1340008. doi: 10.1142/S2010007813400083

Kriegler E., Weyant J.P., Blanford G.J., Krey V., Clarke L, Edmonds J., Fawcett A., Luderer G., Riahi K., Richels R., Rose S.K., Tavoni M., van Vuuren D. P. “The role of technology for achieving climate policy objectives: overview of the EMF 27 study on global technology and climate policy strategies”. *Climatic Change* (2014): Volume 123, Issue 3-4, pp 353-367.

Labriet M., Kanudia A., Loulou R. “Climate mitigation under an uncertain technology future: A TIAM-World analysis”. *Energy Economics* 34 (2012): S366-S377

Luderer. G., Pietzcker, R., Kriegler, E., Haller, M., Bauer, N. “Asia's role in mitigating climate change: A technology and sector specific analysis with ReMIND-R”. *Energy Economics* 34 (2012): S378-S390.

Luderer G., Pietzcker R.C., Kriegler E., Haller M., Bauer N. “Asia's role in mitigating climate change: A technology and sector specific analysis with ReMIND-R”. *Energy Economics* 34 (2012): (Supplement 3), S378-S390.

Massetti, E. and M. Tavoni “A Developing Asia emission trading scheme (Asia ETS)”. *Energy Economics* 34 (2012): (Supplement 3), S436–S443.

McKinsey *Pathways to a Low-Carbon economy. Version 2 of the global greenhouse gas abatement cost curve* (Seattle: McKinsey and Company 2009).

Michetti M., Parrado R. “Improving Land-use modelling within CGE to assess Forest-based Mitigation Potential and Costs”. *Feem Working Paper* (2012): 2012.019.

Ministry of Energy, *Thailand’s renewable energy and its energy future: opportunities and challenges* (Bangkok: Ministry of Energy 2009).

Mi R., Ahammad H., Hitchins N., Heyhoe E. “Development and deployment of clean electricity technologies in Asia: A multi-scenario analysis using GTEM”. *Energy Economics*, 34 (2012): (Supplement 3), S399-S409

Narayanan, G.B. and T.L. Walmsley, Eds. *Global Trade, Assistance, and Production: The GTAP 7 Data Base* (Purdue University: Center for Global Trade Analysis 2008).

Nelson, G.C., Rosegrant, M.W., Palazzo, A., Gray, I., Ingersoll, C., Robertson, R., Tokgoz, S., Zhu, T., Sulser, T.B., Ringler, C., Msangi, S., and You, L. “Food Security, Farming, and Climate Change to 2050: Scenarios, Results, Policy Options” *International Food Policy Research Institute* (2010).

Nguyen Thai Hoa, Kei Gomi and Yuzuru Matsuoka “A scenario for Sustainable Low-carbon Development in Viet Nam towards 2030” (2010).

Nordhaus, W. “The Stern Review on the Economics of Climate Change” (2007).

Nordhaus, D. W, J. Boyer *Warming the World: Economic Models of Global Warming* (The MIT Press 2000).

Office of the President of the Philippines, “National Climate Change Action Plan 2011-2028”. Climate Change Commission (2011).

Okagawa, A., Masui, T., Akashi,O., Hijioka, Y., Matsumoto, K., Kainuma,M. "Assessment of GHG emission reduction pathways in a society without carbon capture and nuclear technologies", *Energy Economics*, 34 (2012): (Supplement 3), S391–S398.

Olz, S., Beerepoot, M. *Deploying Renewables in Southeast Asia: Trends and Potentials* (Paris: International Energy Agency/OECD 2010).

Orecchia, Carlo, and Ramiro Parrado (2013), "A Quantitative Assessment of the Implications of Including Non-CO2 Emissions in the European ETS". FEEM Working Paper No. 100.2013.

Paltsev S., Morris J., Cai Y., Karplus V., Jacoby H., "The role of China in mitigating climate change". *Energy Economics*, 34 (2012): (Supplement 3), S444-S450.

Paltsev, S., Reilly, J.M., Jacoby, H.D. and K.H. Tay "How (and why) do climate policy costs differ among countries?", in Schlesinger, M., Kheshgi, H., Smith., J., de la Chesnaye, F., Reilly, J.M., Wilson, T. and C. Kolstad (eds.) "Human induced climate change: An interdisciplinary assessment" Cambridge: Cambridge University Press, 2007.

Pant, H., Tulpule, V. and B.S. Fisher, "The welfare consequences of emission trading with pre-existing taxes" ABARE Conference Paper (2004): 04.05.

Phdungsilp, A., Wuttipornpun, T., "Analyses of the decarbonizing Thailand's energy system toward low-carbon futures" *Renewable and Sustainable Energy Reviews* 24 (2013): 187–197.

Philippine Climate Change Commission "National Framework Strategy on Climate Change 2010-2022" (2010).

Rogelj J., M. Meinshausen and R. Knutti, "Global warming under old and new scenarios using IPCC climate sensitivity range estimates", *Nature Climate Change* (2012): DOI: 10.1038/NCLIMATE1385

Ronneberger, K., Berrittella, M., Bosello, F. and R.S.J. Tol, "KLUM@GTAP: introducing biophysical aspects of land use decisions into a general equilibrium model. A coupling experiment", *Environmental Modelling and Assessment* 14 (2009): 2.

Rose, S., Finn, S., Scheele, E., Mangino, J., Delhotal, K., "Detailed greenhouse gas emissions data for global economic modeling". Washington DC, US Environmental Protection Agency, 2007.

Rose, S.K., Avetisyan, M., and Hertel, T. W, "Development of the Preliminary Version 7 Non-CO2 GHG Emissions Dataset", *GTAP Research Memorandum* No. 17 (2010).

Rose SK, et al. "Land-based mitigation in climate stabilization". *Energy Economics* 34 (2012): 365–380.

Roson, Roberto and van der Mensbrugghe, Dominique, "Climate Change and Economic Growth: Impacts and Interactions". *University Ca' Foscari of Venice, Dept. of Economics Research Paper Series* (2010): No. 07_10 .

Saveyn, B., Paroussos, L., Ciscar, JC., "Economic analysis of a low carbon path to 2050: A case for China, India and Japan, Energy Economics". *Energy Economics*, 34 (2012): (Supplement 3), S451–S458.

Shrestha R.M., Shakya S.R., "Benefits of low carbon development in a developing country: Case of Nepal". *Energy Economics*, 34 (2012): (Supplement 3), S503-S512.

Thepkhun, P., Limmeechokchai, B., Fujimori, S., Masui, T., Shresta, R., "Thailand's Low-Carbon Scenario 2050: The AIM/CGE analyses of CO2 mitigation measures" Energy Policy 62 (2013): 561–572.

van Vuuren, D.P “The representative concentration pathways: an overview”. Climatic Change (2011): 109:5–31.

Vinluan R. M. “Preliminary Low Carbon Policies and Targets”, Presentation for the 3rd Regional Consultation Meeting of the Asian Development Bank’ project “Strengthening Planning Capacity for Low Carbon Growth in Developing Asia” (2012),

United Nations, Department of Economic and Social Affairs, Population Division (2011). World Population Prospects: The 2010 Revision, CD-ROM Edition.

World Bank *World Development Indicators 2012*. Washington, D.C., The World Bank. April 2012.

WRI (World Resources Institute) *Climate Analysis Indicators Tool* (CAIT), version 9.0. Washington DC 2012.

Appendix

The ICES Model: Basic Structure

ICES is a recursive-dynamic CGE model. It solves recursively a sequence of static equilibria linked by endogenous investment determining the growth of capital stock from 2004 to 2050. The calibration year is 2004. As in all CGE models, ICES makes use of the Walrasian perfect competition paradigm to simulate adjustment processes, although the inclusion of some elements of imperfect competition is also possible.
Industries are modeled through representative firms, minimizing costs while taking prices as given. In turn, output prices are given by average production costs. Production functions are specified via a series of nested CES functions. Domestic and foreign inputs are imperfect substitutes, according to the so-called "Armington" assumption.

The Economy

A representative consumer in each region receives income, defined as the service value of national primary factors (natural resources, land, labor, and capital). Capital and labor are perfectly mobile domestically, but immobile internationally. Land and natural resources are industry-specific. The income is used to finance three classes of expenditure: aggregate household consumption, public consumption, and savings (see Figure 18). The expenditure shares are generally fixed, as the top-level utility function has a Cobb-Douglas specification.

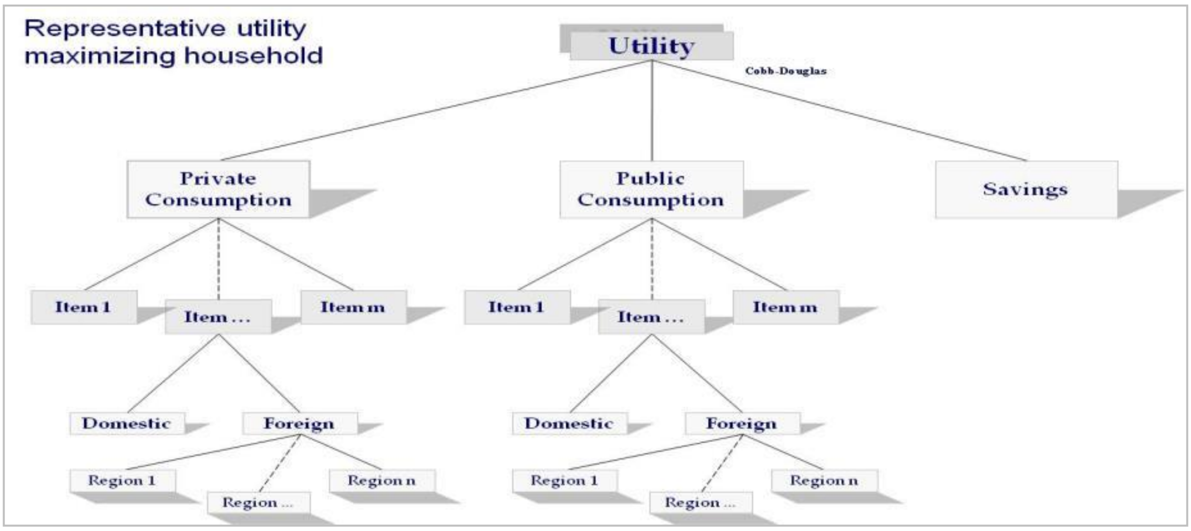


Figure 18: ICES Model Nested Consumption Function

Public consumption is split in a series of alternative consumption items, also according to a Cobb-Douglas specification. However, almost all expenditure is actually concentrated in one specific industry: non-market services.

Private consumption is analogously split in a series of alternative composite Armington aggregates. These postulate the imperfect substitutability across domestic and imported commodities. However, the functional specification used at this level is the Constant Difference in Elasticities form: a non-homothetic function, which is used to account for possible differences in income elasticities for the various consumption goods.

Investment is internationally mobile: savings from all regions are pooled and then investment is allocated so as to achieve equality of expected rates of return to capital. As a result, savings and investments are equalized at the world, but not at the regional, level. Because of accounting identities, any financial imbalance mirrors a trade deficit or surplus in each region.

The ICES production tree, represented by each node in the tree, combines single or composite factors of production in a constant elasticity of substitution (CES) production function.

All sectors use primary factors such as labor and capital-energy, and intermediate inputs. In some sectors (fossil fuel extraction industries and fishery), primary factors include natural resources (e.g., fossil fuels or fish) and land. The nested production structure depicted in Figure 19 is the same across all sectors, and diversity in production processes as well as technologies is captured through sector-specific productivity and substitution elasticity parameters.

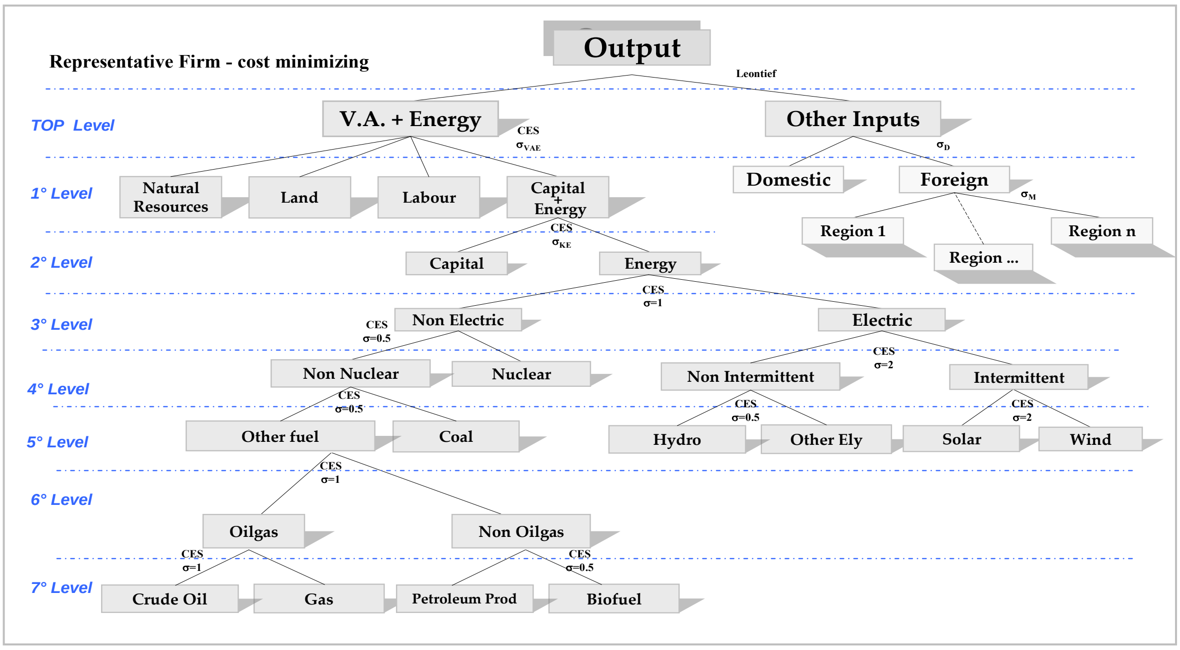


Figure 19: ICES Model Nested Production Function

The regional specification singles out Indonesia and considers "rest of Southeast Asia" (SEA thereafter). This allows more specific analysis of the economic implications of medium- and long-term decarbonization policies in these country/region. Most relevant international players, globally and in the area, have been also distinguished to highlight trade patterns and policy spillover effects from the region. The production tree emphasizes energy-producing sectors, given that they are the major industries impacted by mitigation/decarbonization policies. The depiction of agriculture and of "other industries and services" remains less detailed, although agriculture singles out the timber sector, which can be more directly affected by deforestation patterns.

Table 3: Regional and Sectoral Detail of the ICES Model

Countries/Regions		
Organisation for Economic Co-operation and Development (OECD)	**Non-OECD**	**Developing Asia**
United States (USA)	Economies in transition (TE)	Indonesia
WEURO (15 European Union Member States)	Middle East and North Africa (MENA)	Malaysia
EEURO (12 European Union Member States)	sub-Saharan Africa (SSA)	Philippines
KOSAU (Republic of Korea,	South Asia (SASIA)	Thailand

South Africa, Australia)		
CAJANZ (Canada, Japan, Australia, New Zealand)	India	Viet Nam
	People's Republic of China (PRC)	Rest of Southeast Asia (EASIA)
	Latin America (LACA)	
Sectors		
Agriculture/Land Use	***Energy***	***Others***
Rice	Coal	Heavy Industry
Other Crops	Crude Oil	Light Industry
Vegetables and Fruits	Natural Gas	Services
Livestock	Petroleum Products	
Timber	Nuclear	
	Hydro	
	Solar	
	Wind	
	Other Electricity	
Biofuels		

The Energy Sector

Renewable energy sources (hydro, solar, wind) are stand-alone sectors providing electricity to the rest of the economic system. The intermittency of solar and wind is accounted for by low substitution with other energy sources, which limits their penetration over time in the energy mix.

Biofuels are transformation sectors processing the output of the agricultural "Other Crops" sector and selling output (biofuels) to the "Services" sector that includes retail sale of automotive fuels. Nuclear energy is an alternative option for base-load energy, along with coal but with lower substitution than between coal and other fossil fuels (oil, gas), so that it is represented in a nest above coal.

Other GHGs and Land Use

Avoided deforestation is introduced as an additional abatement option. Country-specific equations link different carbon prices to different abatement levels that can be accomplished by REDD practices. The parameterization of these equations derives from the International Institute for Applied Systems Analysis (IIASA) model cluster (Gusti et al., 2008) prepared for the Eliasch (2008) report. The cluster model, however, does not specify REDD abatement opportunities for Indonesia, only for Southeast Asia as a whole. Country abatement has been estimated by downscaling Southeast Asia data proportionally to the national share of emission from deforestation in the regional total.

Avoided deforestation, triggered by sufficiently high carbon prices, impacts agriculture, forestry, and pasture land use. In particular, lower deforestation might imply a lower expansion of land for farming and grazing. This effect is also considered, and the relation between lower emissions from REDD, lower number of hectares deforested, and lower expansion of agricultural land has been estimated by coupling the data from the IIASA cluster model with those of UN FAO (2006, 2001). In particular, to calculate the amount of land entering large-scale agriculture after deforestation, the parameters from UN FAO (2001) are applied. According to the FAO study, around 10% of deforestation in Africa was due to conversion to this type of land use, while for Latin America and Asia these were 46% and 30%, respectively.

In the simulations, the forest land-using sectors (agriculture and timber) are compensated to reduce deforestation. In other words, it is assumed that avoided deforestation takes place only if it is profitable. This is done in the model through a subsidy to land-using industries equal to the value of the avoided emissions from REDD.

In Indonesia, a large share of deforestation emissions is associated with peatland drainage following clearance of deep peat swamp forests. Peatlands are deposits of plant residuals and water formed over thousands of years, which contain thousands of tons of carbon per hectare. The peat is drained during deforestation, setting off a process of oxidation, as well as a risk of peat fires, which have enormous emissions potential. Emissions can continue for decades after clearance and even if deforestation is falling, aggregate emissions may continue to increase, as the rate of carbon loss from peat has a lagged effect. Accordingly, reducing deforestation of peat swamp forests will also reduce the specific peatland emissions. In addition, it is possible to abate peatland emissions with specific measures implemented directly on already deforested peatland areas, such as peatland restoration and rehabilitation, fire prevention, and water management.

To account for this deforestation-associated source of emissions, both ICES and WITCH explicitly consider peatland emissions in Indonesia as part of total emissions (see section 5 for the relative baseline assumptions), drawing on parameters on peatland deforestation and emissions reported in Busch et al., (2011), with emissions assumed to take place over a 25-year timeframe. The country abatement potential has also been tailored to capture the opportunities that might come either from reduced deforestation in peatland areas or from peatland restoration and rehabilitation, fire prevention, and water management of peatland deforested areas. The first was modeled by increasing Indonesian emission reduction potential from REDD proportionally to the share of deforested land on peatland over total deforested land, while the second was implemented through an aggregated marginal abatement cost curve for peat rehabilitation using information reported in DNPI (2010).

The model is updated with sectoral emissions from CO2 CH4, N2O, PFCs, HFCs, and SF6 derived by Rose et al. (2010). A further extension is the introduction of a carbon market involving all GHGs and not only CO2. This feature allows the possibility of exploiting lower-cost abatement options in non-CO2 gases or emitting sectors.

The WITCH Model: Basic Structure

WITCH, the World Induced Technical Change Hybrid model, is an optimal growth model of the world economy. For this study, Southeast Asia has been split into two subregions: Indonesia and the rest of Southeast Asia. This moves the regional disaggregation of WITCH to 14 regions, increasing the detail of the solution.

Regions interact with each other through the presence of economic and environmental global externalities. For each region, a forward-looking agent maximizes the intertemporal social welfare function, strategically and simultaneously with other regions. The intertemporal equilibrium is calculated as an open-loop Nash equilibrium, but a cooperative solution can also be implemented. Through the optimization process regions choose the optimal dynamic path of the control variables, namely investments in different capital stocks, in research and development, in energy technologies, and consumption of fossil fuels.

WITCH is termed a hard-link hybrid model because the energy sector is fully integrated with the rest of the economy, and therefore investments and the quantity of resources for energy generation are chosen optimally, together with the other macroeconomic variables of the model. The model is a hybrid because the energy sector features bottom-up characteristics, in which a broad range of different fuels and technologies can be used in the generation of energy. Energy production is organized in electric and non-electric sectors; the modeled primary energy sources include oil, gas, coal, uranium, hydro, wind and solar, and bioenergy. The substitutability across sectors is regulated via nested CES functions calibrated on 2005 values and previous econometric studies. The energy sector endogenously accounts for technological change, with considerations for the positive externalities stemming from learning by doing and learning by researching. Overall, the economy of each region consists of one final good, which can be used for consumption or investments, one electric sector, representing a wide range of power generation options, and a non-electric energy sector, aggregating the demand from transportation, industry, and residential services but distinguishing across fuels (Figure 20).

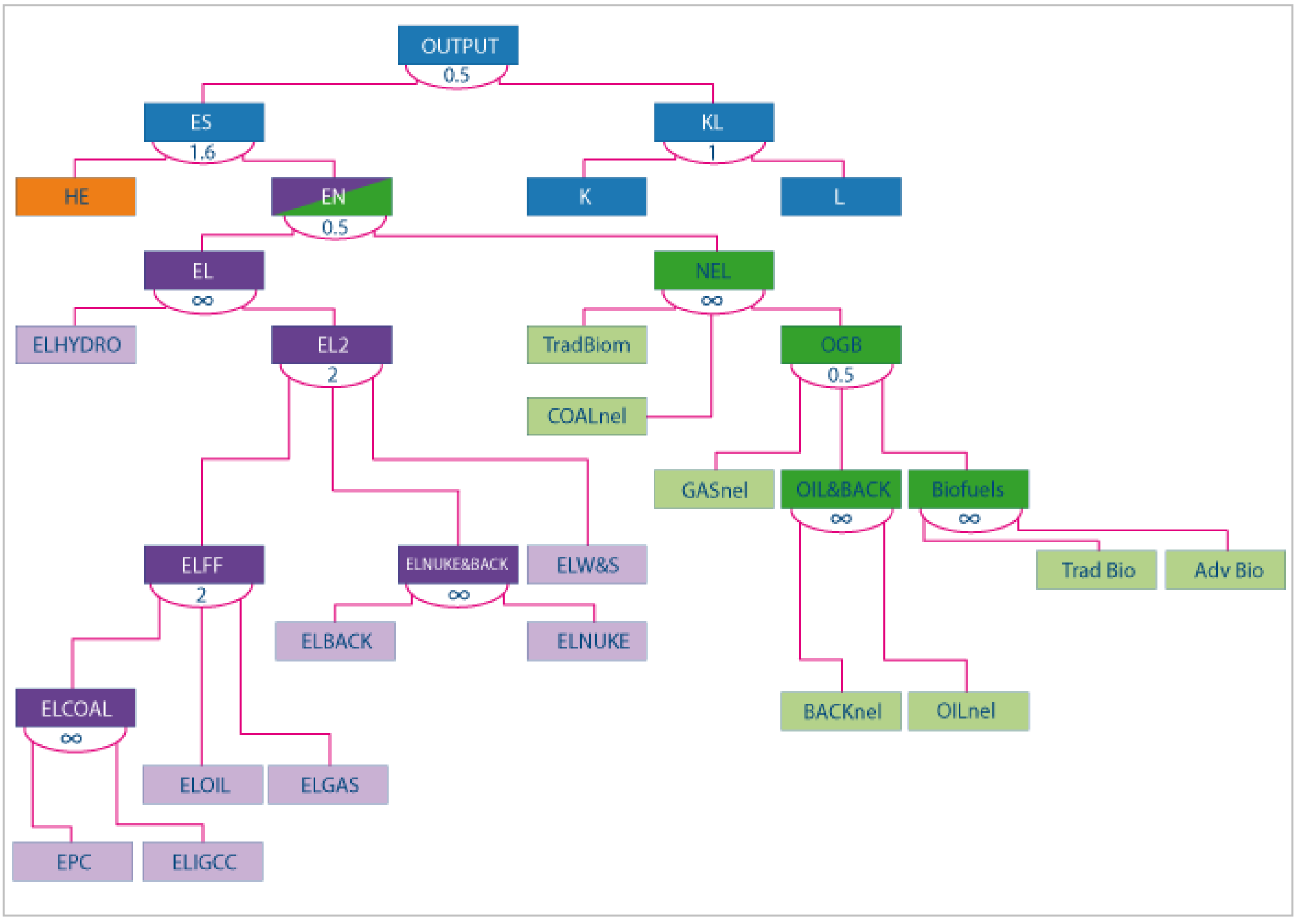


Figure 20: The WITCH Optimal Growth Model of the World Economy Structure

The length of the time horizon (from 2005 to 2100 with five-year steps), the regional dimension, and the game theory set up make the WITCH model suitable for the assessment of intertemporal and strategic aspects of climate change policies.

The Economy

As typically found in intertemporal optimal growth models, the production side of the economy is very aggregated. Each region produces one single commodity that can be used for consumption or investments. The final good (Y) is produced using capital (K_C), labor (L) and energy services (ES). In the first place capital and labor are aggregated using a Cobb-Douglas production function. This nest is then aggregated with energy services with a constant elasticity of substitution (CES) production function.

The optimal path of consumption is determined by optimizing the intertemporal social welfare function, which is defined as the log utility of per capita consumption, weighted by regional population. The pure rate of time preference declines from 3% to 2% at the end of the century, and it has been chosen to reflect historical values of the interest rate.

Energy services, in turn, are given by a combination of the physical energy input and a stock of energy efficiency knowledge. This way of modeling energy services allows for endogenous improvements in energy efficiency. Energy efficiency increases with investments in dedicated energy R&D, which build up the stock of knowledge. The stock of knowledge can then replace (or substitute) physical energy in the production of energy services.

Energy used in final production is a combination of electric and non-electric energy. Electric energy can be generated using a set of different technology options; non-electric energy also consists of different fuels. Fuel consumption and investments in different technologies are the result of each region' optimization. In other words, each region will choose the optimal intertemporal mix of technologies and R&D investments in a strategic way. Next section describes in detail the energy sector.

The Energy Sector

Despite being a top-down model, WITCH includes quite a wide range of technology options to describe the use of energy and the generation of electricity. Energy is described by a production function that aggregates factors at various levels and with different elasticities of substitution. The main distinction is among electric generation and non-electric consumption of energy.

Electricity is generated from a series of traditional fossil fuel-based technologies and carbon-free options. Fossil fuel-based technologies include natural gas combined cycle (NGCC), fuel oil and pulverized coal (PC) power plants. Coal-based electricity can also be generated using integrated gasification combined cycle (IGCC) production with CCS. Low-carbon technologies are hydroelectric and nuclear power and renewable sources such as wind turbines and photovoltaic panels (Wind&Solar).

Many technology features are represented for each: yearly utilization factors, fuel efficiencies, investment, and operation and maintenance (O&M) costs. For CCS, supply costs of injection and sequestration reflect site availability at the regional level, as well as energy penalty, capture and leakage rates. IGCC-CCS competes with traditional coal, so that it replaces it under a sufficient carbon price signal. For nuclear power, waste management costs are also modeled, but no exogenous constraint is assumed, contrary to most models. Hydroelectric power evolves exogenously to reflect limited site availability. Potential breakthroughs in power generation technologies are modeled by introducing backstop technologies, which are a compact representation of a portfolio of advanced technologies that can substitute for nuclear power.

Energy consumption in the non-electric sector is based on traditional fuels (traditional biomass, oil, gas, and coal) and biofuels. In order to account for food security concerns, overall penetration of biofuels is assumed to remain modest over the century. The consumption of oil can be substituted with a carbon-free backstop technology, which may be next generation biofuels or carbon-free hydrogen. As a consequence, the backstop technology is mostly thought of as an abatement option for the transport sector.

The cost of electricity generation is endogenous and it combines capital costs, O&M expenditures, and the expenditures for fuels. The price of fossil fuels and exhaustible resources (oil, gas, coal, and uranium) is also endogenously determined by the marginal cost of extraction, which in turn depends on current and cumulative extraction, plus a regional mark-up to mimic different regional costs. The use of fossil fuels generates CO_2 emissions, which are computed by applying stoichiometric coefficients to energy use.

Other GHGs and Land Use

Beyond CO_2, WITCH features all the main Kyoto gases, including CH_4, N_2O, as well as short- and long-lived fluorinated gases. These are modeled through marginal abatement cost curves for each gas, which are region specific and are derived for the base year (2005) from the assessment of the Environmental Protection Agency of the USA. Technical change allows these curves to shift over time. Moreover, CO_2 emissions from land-use change and forest management are also modeled via marginal abatement cost curves. These also include the potential from REDD and are derived from several sources, including the GLOBIOM model developed at IIASA (Eliasch, 2008) and the Global Timber Model developed by Sohngen (Energy Modeling Forum 21, 2006). Particular attention has been devoted to represent the mitigation opportunities in the land-use and forestry sectors, which play a key role in the definition of the GHG mitigation potential of the Southeast Asia and Indonesia.

Emissions from peatlands, according to a harmonized protocol with the ICES model, were added to the land-use baseline emissions for Indonesia, the REDD abatement curve was modified accounting for the relation between avoided emissions from deforestation and emission reductions from avoided peatlands, and a MAC curve was implemented for modeling explicit abatement options related to peatlands management as described in previous section.

Endogenous Technical Change

One of the main features of the WITCH model is the characterization of endogenous technical change. Albeit difficult to model, technological innovation is key to the decoupling of economic activity from environmental degradation. The ability to induce it using appropriate policy instruments is essential for a successful climate agreement, as highlighted also by the Bali Action Plan.

Both innovation and diffusion processes are modeled. WITCH distinguishes dedicated R&D investments for enhancing energy efficiency from investment aimed at facilitating the competitiveness of innovative low-carbon technologies in both the electric and non-electric sectors (backstops). R&D processes are subject to technological progress and technological spillovers. Specifically, international spillovers of knowledge are accounted for to mimic the flow of ideas and knowledge across countries. Finally, experience processes via Learning by Doing are accounted for in the development of niche technologies, such as renewable energy (Wind&Solar) and backstops.

Model Solution

The game theory set up of the model makes it possible to capture the noncooperative nature of international relationships. Free riding behavior and strategic inaction induced by the presence of a global externality are explicitly accounted for in the model. Climate change is the major global externality, as GHG emissions produced by each region indirectly affect all other regions through the effect on global concentrations and thus global average temperatures. The model features other economic externalities that provide additional channels of interaction. Energy prices depend on the extraction of fossil fuels, which in turn is affected by consumption patterns of all regions in the world. For oil, regional production patterns are also taken into account, and an iterative process adjusts the world oil price so that consumption and production are globally balanced. International knowledge and experience spillovers are two additional sources of externalities. By investing in energy R&D, each region accumulates a stock of knowledge that augments energy efficiency and reduces the cost of specific energy technologies. The effect of knowledge is not confined to the inventor region but can spread to other regions. Finally, the diffusion of knowledge embodied in Wind&Solar experience is represented by learning curves linking investment costs with world, and not regional, cumulative capacity. Increasing capacity thus reduces investment costs for all regions.

These externalities provide incentives to adopt strategic behavior, both with respect to the environment (e.g., GHG emissions) and with respect to investments in knowledge and carbon-free but costly technologies. In order to represent strategic behavior, the model is solved as a noncooperative game. The solution is found when all regions’ strategies are a best response to other regions’ best responses. An iterative algorithm is solved recursively and yields an Open Loop Nash Equilibrium.

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