Costa Rica - Assessing Climate Mitigation Pathways to Support NDC Implementation

Final Report: Assessment of Mitigation Measure to Achieve NDC Goals

Prepared for

World Bank and PMR Costa Rica

By

DecisionWare Group LLC
Policy Analysis for
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Acronyms

AdvTech	Set of improved, better, and advanced demand devices controlled by the model technology quality uptake constraints
AT	Analysis Team
AXLS	Analytics Excel workbook
BAU	Business-as-Usual (Baseline) scenario
BCCR	Central Bank of Costa Rica
BY	Base Year (template)
CO_2	Carbon Dioxide
CO2eq	Carbon Dioxide equivalent
COM	Commercial sector
CR	Costa Rica
DCC	Directorate of Climate Change
DSE	Dirección Sectorial de Energía
DWG	DecisionWare Group LLC
EB	Energy balance (template)
EE	Energy Efficient devices
FEC	Final Energy Consumption

GFE	Gross Final Energy
GW	Gigawatts
GWh	Gigawatt Hours
GHG	Greenhouse Gas
ICE	Instituto Costarricense de Electricidad (Costa Rica main electric company)
IND	Industrial sector
INDC	Indicative National Determined Contribution
INEC	Instituto Nacional de Estadística y Censos
km/yr	Kilometers per year
kt	Thousand metric tons
LCV	Light Commercial Vehicles
LDV	Light Duty Vehicles
MAC	Marginal Abatement Curve
MARKAL	MARKet Allocation
MEI	Mitigation Effectiveness Indicator
MINAE	Ministry of Environment and Energy
Mpkm	Million passenger-kilometers
Mt	Million metric tons
Mtkm	Million ton-kilometers
NAMA	Nationally Appropriate Mitigation Action
NDC	National Determined Contribution
NT	New technology (template)
PJ	Petajoules
PJa	Petajoules per annum
PMR	Partnership for Market Readiness
PP	Power Plant
RE	Renewable Energy
REDD+	Reducing Emissions from Deforestation and Forest Degradation
RES	Reference Energy System
RSD	Residential sector
S_	Scenario (template)
SUP	Supply (template)
SUV	Sport Utility Vehicle
t	Ton (Metric)
T&D	Transmission and Distribution
TIMES	The Integrated MARKAL-EFOM System (the successor to MARKAL)
TIMES-CR	TIMES model for Costa Rica
TRN	Transportation sector
UC	User constraints (template)
UNFCCC	United Nations Framework Convention on Climate Change

1 Executive Summary

1.1 Overview

Costa Rica has set very ambitious Greenhouse Gas (GHG) mitigation goals in its Nationally Determined Contribution (NDC) with the aspiration of reaching net carbon-neutrality later in this century. Achieving these goals, especially given the country's already low carbon intensity, will require aggressive policies and actions, particularly with respect to fossil fuel use in the transportation and industry sectors.

Under the leadership of the Ministry of Environment and Energy (MINAE) and other ministries and the support of the Partnership for Market Readiness (PMR) in Costa Rica, a project was designed to develop improved analytical tools and capabilities to assist the government of Costa Rica in determining viable pathways to achieve the emission reduction commitments made in its NDC. A secondary goal was to establish the in-country capacity that will allow continuous improvements and ongoing application of the methodology to examine new issues, options, technologies and policies as circumstances dictate to inform future NDC and policy developments. Furthermore, the resulting platform was also designed to be readily applicable, transferable and reproducible by PMRs in other countries.

The study team worked with local experts and key stakeholders to:

- Identify policies and measures politically, technically, and economically viable for Costa Rica;
- Develop a country-specific energy systems model with validated input parameters and resulting ***Baseline scenario***;
- Develop a ***Planned policy scenario*** to assess existing and proposed mitigation policies and actions;
- Develop ***Enhanced policy scenarios*** necessary for Costa Rica to achieve its NDC targets, and
- Build **local capacity** to take over stewardship and ongoing use of the national energy planning platform.

1.2 Analytical Framework for NDC Pathway Design

The core analytical framework employed is the TIMES (see www.iea-etsap.org) modelling platform, which is the most widely used least-cost optimization methodology employed around the world to inform energy policy and strategic planning. The TIMES-Starter, which consists of an integrated full-sector energy system model that employs best practices and is built upon a peer-reviewed database, was transformed into a comprehensive energy system planning model for Costa Rica (TIMES-CR) by adopting local data and reflecting local knowledge to the fullest extent possible. The Analysis Team (AT), assembled to support the implementation and take over stewardship of the model, has provided the latest data and reviewed critical model assumptions and results to ensure the model properly represents the Costa Rica energy system.

The basic structure of the TIMES-CR model is illustrated in Figure 9. Primary energy supplies in Costa Rica consist of imported fossil fuels and a variety of domestic renewable energy sources. These are characterized by cost-supply curves that define how much is available at a particular price in each year. Power plants and fuel processing plants convert the primary energy sources into final energy carriers, such as electricity and biofuels that are used in the demand sectors. These plants are characterized by their investment and operating cost, efficiency and other performance parameters. The model contains five main demand sectors: Agriculture, Commercial, Industry, Residential and Transportation. End-use devices characterized by investment and operating cost, efficiency and operating parameters deliver end-use services (such as lighting, cooling, cooking, industrial process heat and motor drive, passenger and freight travel) that correspond to the economic activities in the country. For most devices there are Existing, Standard, Improved, Better and Advanced options. The base year demands for useful energy services are calculated based on the existing devices and the efficiency of that stock. Future demands for useful energy services are projecting from these base year values in accordance with sector-specific drivers, such as GDP growth, GDP per capita growth, industrial production projections, space cooling growth expectations, etc.

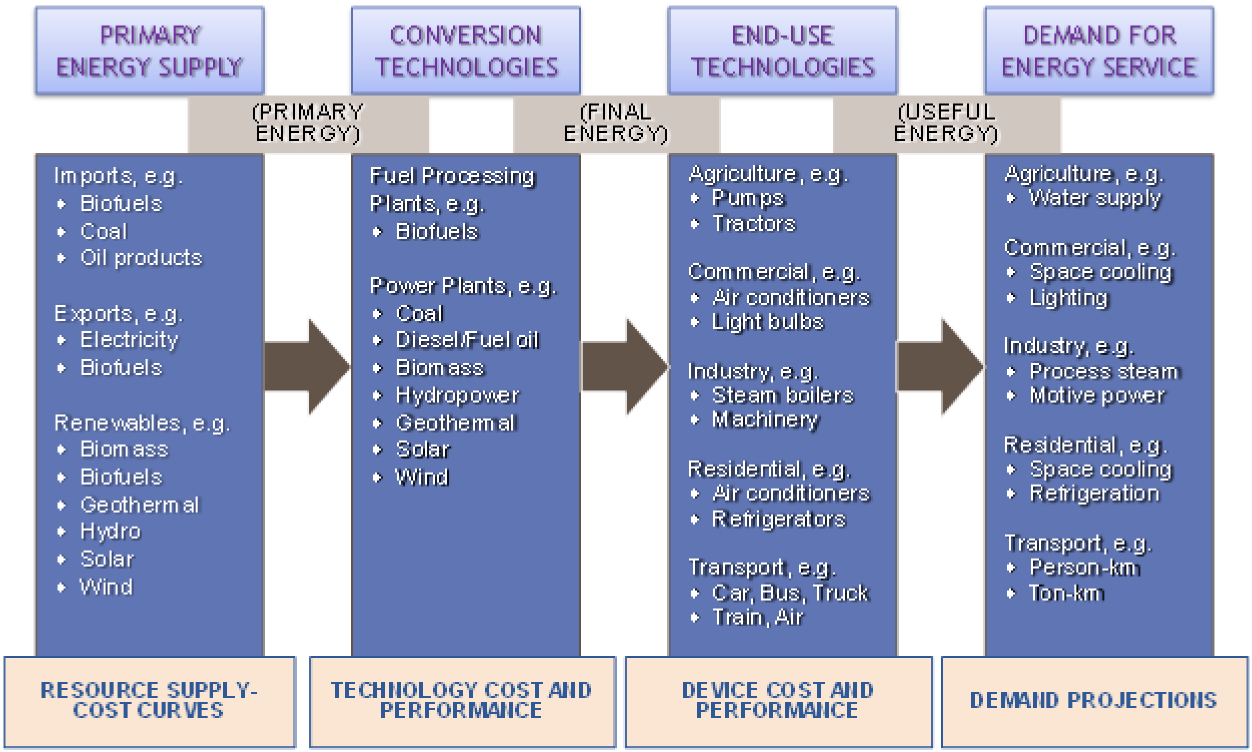


Figure 1: TIMES-CR Model Overview

Once the underlying energy system is properly depicted, calibrated (to reproduce the first year energy balance) and a Baseline (or business-as-usual) scenario determined, the model was used to analyze a wide range of alternative mitigation policies and measures, as well as conducting sensitivity analysis to inform the design a robust least-cost roadmap for realizing the country's NDC aspirations.

1.3 Baseline Scenario Emissions

Figure 31 shows the energy system GHG emissions from the Baseline scenario by sector and gas. Hydro and geothermal power plants were given CO_2 eq. emission factors based on ICE data. The methane and nitrous oxide emissions from the energy system come from incomplete combustion of fuels in the different energy sectors, and their CO_2 equivalent emissions are shown from all energy sectors. Overall energy sector related GHG emissions growth is 58% between 2015 and 2050, with Transport and Industry sectors accounting for over 93% of the total growth.

Costa Rica's NDC ambitions were translated into a calculated 2050 target for the energy sector, based on the 2050 per capita emission goal of 1.19 tons, which results in a 60% reduction in energy sector emissions from the Baseline. This is quite aggressive, and innovative policies and measures along with a strong national commitment will be needed to achieve this goal.

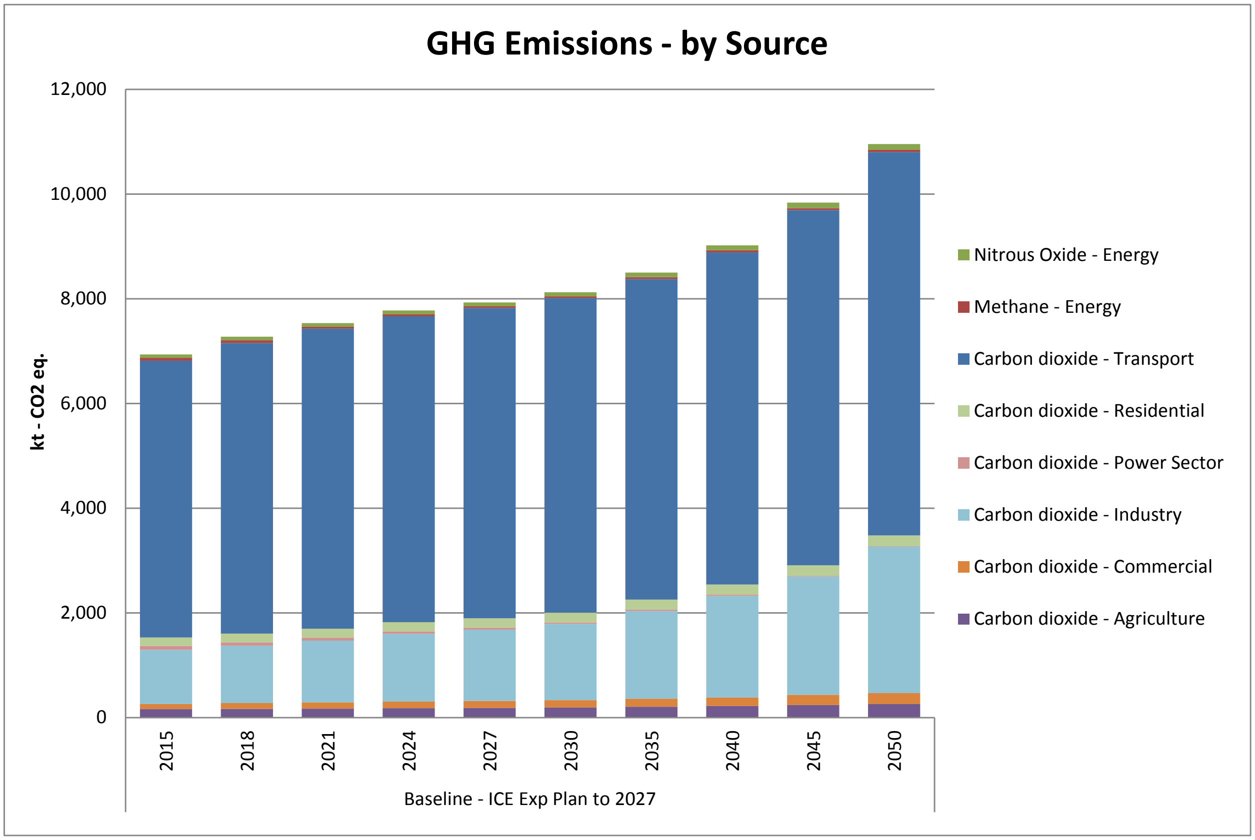


Figure 2: Baseline GHG Emissions

1.4 GHG Mitigation Measures

A comprehensive set of GHG mitigation measures for Costa Rica was identified from existing policy documents by the PMR, in consultation with the Directorate of Climate Change (DCC), for consideration as possible options to help realize the NDC goals of the country. Review of the initial list of mitigation measures identified over 75 energy-related measures that were candidates for evaluation using TIMES-CR. The set of Planned policy measures were first examined individually, then combined by sector, and finally included with all other Planned measures to determine their combined impact. The energy sector portion of the NDC GHG target was then imposed on the Planned policy measures indicating a shortfall in terms of meeting the reduction target, so additional measures were added and the results examined to identify the Enhanced measures and critical policies needed to achieve the country's NDC goals.

The impacts of the mitigation measures and policies were quantified using specific metrics that characterize the technical, economic and environmental changes each policy produces. These metrics are the total or cumulative amount over the entire planning horizon (2015-2050), and their definitions are shown in Table 20. These cumulative metrics are used because they integrate the changes occurring over the entire planning horizon, which better represents the impacts compared to the results from any particular year.

Table 1: Cumulative Analysis Metrics and Definitions

Metric	Definition
System Cost (2015$M)	Net present value of all costs for energy system investments, operating costs and fuel expenditures
Primary Energy (PJ)	Primary energy used
Electricity Generation (GWh)	Electricity generation
Final Energy Consumption (PJ)	Energy consumed in all demand sectors
Power Plant Builds (GW)	New power plants built
Electricity Investment (2015$M)	Lump sum investment in new power plants
Demand Device Purchases (2015$M)	Purchases of demand devices
Fuel Expenditures (2015$M)	Fuel expenditures
GHG Emissions (kt CO2 eq.)	GHG emissions
Mitigation Effectiveness Indicator (MEI) (2015$/t)	Change in energy system cost divided by cumulative emission reduction

1.5 Planned Policy Measures

The Planned policies and measures were analysed according to the following sectors: Supply and Power, Building and Industry Efficiency, and Transport. GHG levy and GHG cap scenarios were also examined; the latter to ensure the NDC target is met and determine exactly what that entails.

Supply and Power Sectors: Nine specific Supply and Power sector measures were examined. The two most significant measures are to increase the Renewable Energy (RE) share of Gross Final Energy (GFE) use from 56% in 2015 to 70% in 2050, and to set targets for biofuels to reach the levels of 50% biodiesel, 30% biogasoline, and 20% biojetfuel by 2050 across all sectors. The RE Share of GFE measure realizes over 46 Mt of GHG emission reductions, but increases new power plant builds by 38% (1.5 GW) and new power plant investment by over 60% (US$8.9 B). The Biofuels Target results in a 15% reduction in GHG emissions (50 Mt), while increasing fuel expenditures 11% by displacing diesel, gasoline, jet fuel and kerosene with their biofuel equivalents. Other measures that are cost-effective and result in meaningful emission reductions are Improving Distribution Efficiency and Electricity Storage, which collectively reduces emissions 1.1 Mt. Although the RE Share of GFE measure and the Biofuels Target yield the biggest reductions, they are expensive (resulting in high ARCs), when not combined with efficiency measures. This highlights the importance of simultaneously examining the entire set of energy sector measures as part of determining a robust cost-effective NDC pathway. All Supply and Power sector measures produce over 56 Mt of cumulative emission reductions.

Efficiency in Buildings and Industry: Fourteen specific measures and 23 scenarios (including combinations and sensitivity runs) were used to examine efficiency in Buildings (commercial and residential) and Industry, which includes agro-industries. In general, GHG emission reductions from Buildings are small because most of the energy savings are in the form of electricity, which is largely decarbonized in Costa Rica. Although the Building efficiency measures produce only 2.8 Mt of cumulative emission reductions, the measures (e.g., LED public lighting, appliance standards, building retrofits) are mostly quite cost-effective (highly negative ARCs) and are necessary to facilitate more switching from conventional fuels to electricity without overly increasing generation requirements or the cost to consumers. Industry measures that are most effective reduce fossil fuel use through improved equipment efficiency, and fuel switching to electricity, biomass residues and biofuels. The combined Industry measures produce 10.3 Mt of cumulative emission reductions.

Transport Sector: Sixteen specific measures and 23 scenarios were used to examine the Transport sector. The measures cover vehicle technology improvement, mode-shifting for passenger and freight transport, as well as cap and levy measures. Most of the individual measures achieve less than 10 Mt in GHG emission reductions. Measures that exceed that level allow 50% and 90% of all new vehicles to be using advanced technologies (e.g., hybrid and plug-in electric) by 2050. The combination of non-levy Transport measures produces more GHG reductions (42 Mt) than the low GHG levy for the Transport sector (34 Mt), but less than the high GHG transport levy (64 Mt). The 25-50% GHG Cap in 2030/2050 is feasible and produces almost 66 Mt of emission reductions, while resulting in a minimal (0.04%) change in the energy system cost thanks to the higher permitted uptake of advanced vehicles. Thus, the transformation of the Transport sector is critical to being able to achieve the NDC goals, and the key measures necessary are summarized in Table 2.

Table 2: Key Transportation Measures

Measure	Outcome
25/50% share of hybrid in LDV new vehicle stock by 2030/50	Reduces cumulative GHG emission by less than 0.1% (286 kt) as hybrids are not forced and the model does not find them cost-effective over the long run.
25/50% share of electric in LDV new vehicle stock by 2030/50	Reduces cumulative GHG emission by 4.2% (13.7 Mt) due to a 1.5% drop in fossil fuel use, and reduces system cost by $US928 M confirming that electric vehicles are cost-effective, especially after 2030.
5% shift of passenger transport to non-motorized modes (cycling, walking) by 2030	Achieves a 6.1 Mt reduction in GHG emissions, cuts fuel expenditures by $US2.5 B and reduces energy system cost by over 2.7% (US$6.2 B).
Reduce GHG emissions from the transport sector by 25%/50% by 2030/50	Results in GHG emission reduction of 66 Mt owing to aggressive uptake of advanced vehicle technologies and access to biofuels and electricity. Change in system cost is minimal as fuel cost savings offset increased vehicle and power plant costs.
Levies on emissions from the transport sector - $10/ton in 2021 increasing to $150/ton (Low) and $300/ton (High) in	Without advanced technology access, both levies achieve relatively little GHG emission reductions (1.5 Mt). Where 90% advanced technology penetration is allowed, the Low levy achieves over 10% reduction in cumulative emissions (33.7 Mt), but increases system cost by 1.2% as the

2050	fuel cost savings does not fully offset the increased vehicle and power plant costs plus the levy. The High levy achieves an 11.6% (37.8 Mt) reduction in cumulative GHG emissions which indicates that there are diminishing returns for going much beyond a levy of $150/t.

Overall GHG Levies: The Low GHG Levy starts at $10/t in 2021 and increases linearly to $150/t CO2 eq. in 2050, and the High GHG Levy starts $10/t in 2021 and increases linearly to $300/t CO2 eq. in 2050. As seen in the transport sector, a system-wide GHG levy does not achieve significant emission reductions without incentivizing advanced demand device technologies. However, with incentives the emission reduction increases dramatically, and the energy system cost decreases because of the cost-effectiveness of the advanced demand devices more than covers the cost of the more expensive devices and increased power sector investments needed to achieve the GHG emission reductions.

The Low levy with advanced demand devices reduces GHG emissions by 59 Mt while only increasing energy system cost by 1% (US$2.2 B). The High Levy with advanced technology incentives increases emission reductions to 65 Mt, while increases energy system cost by 4.5%, which again indicates that there are diminishing returns for going much beyond a levy of $150/t. Note that the cost of the levy is charged against the energy system, but that revenue could be used to subsidize lower income households, incentivize energy efficiency, fund infrastructure for mode shifting, or support other measures that benefit the energy system. For example, the Low levy with advanced technology incentives raises US$6.8 B (net present value). However, neither levy reaches the reduction levels set in the NDC.

GHG Target Cases: Three system-wide GHG emission target measures were examined – 40%, 50% and 60% below the Baseline in 2050. The 60% case represents the energy systems share of the NDC target for 2050, and the 40% and 50% cases are sensitivity analyses to understand how the energy system responds to the GHG cap. Each target was examined with incentives for advanced devices and with and without biofuels. The two 40% target cases both generate over 88 Mt in cumulative emission reductions between 2015 and 2050, and the 50% target case with biofuels achieves 107 Mt of emission reductions. However, the 50% case without biofuels and both 60% reduction scenarios are not achievable, unless supplemented by Enhanced measures as discussed in the next section. Although the two 40% target cases generate similar emission reductions, without biofuels the energy system cost increases about 12.5% compared to a 3.2% increase for the case with biofuels. This is because without biofuels the model needs to use more expensive electric vehicles and generate more electricity from renewables to get emission reductions in the transport sector.

All Planned Measures: The All Planned policies scenario integrates the planned Supply and Power, Building and Industry Efficiency and Transport sector measures while incentivizing advanced technologies and permitting biofuels. Figure 39 shows the MEI and level of reduction achieved for each bundle. The All Planned policies combination achieves over 103 Mt of cumulative GHG emission reductions at an acceptable MEI of $62/Mt, compared to 2.8 Mt for All Building Efficiency Measures, 10.3 Mt for All Industry Efficiency Measures, 42 Mt for the Transport & Biofuels Combination, and 56.4 Mt for All Supply & Power Measures. Biofuels are a common measure between the latter two scenarios, and these overlapping measures are primarily why the All Planned policies scenario is less than the sum of the components.

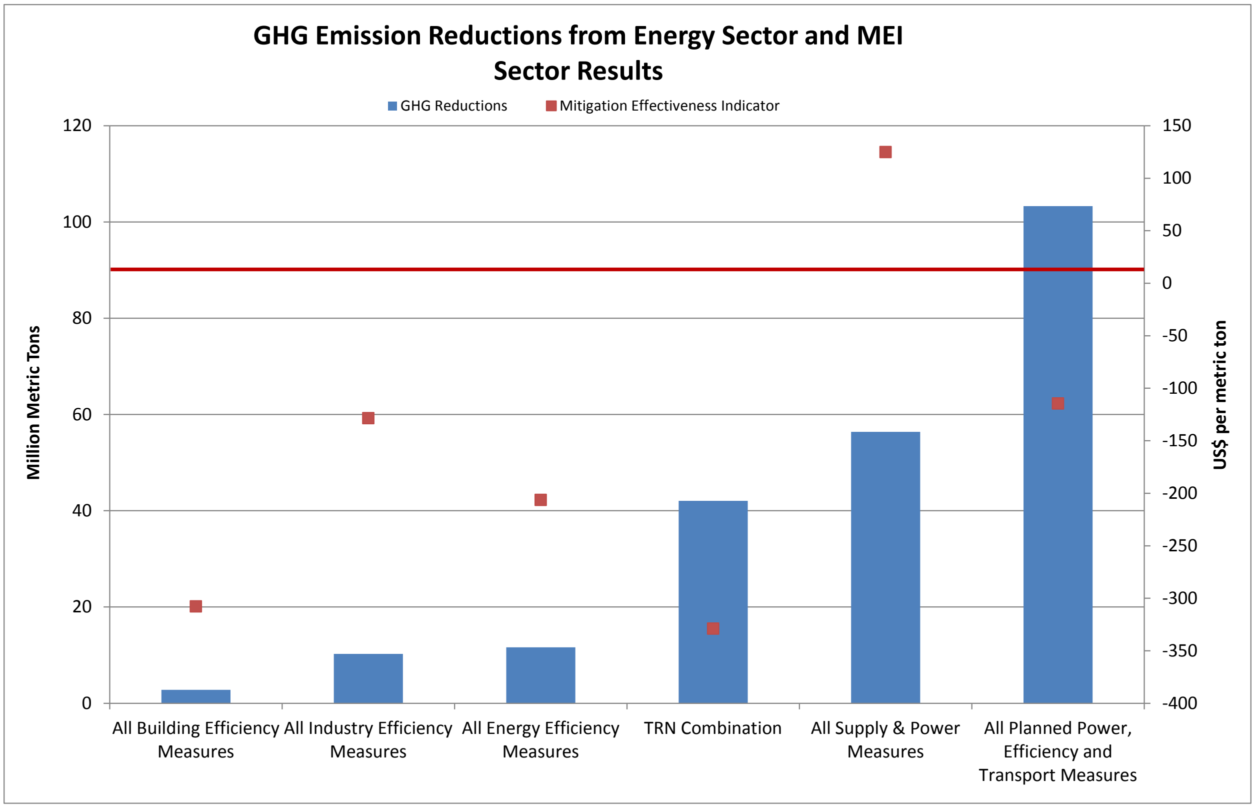


Figure 3: GHG Emissions and MEI for Sectoral and All Planned Policies Scenarios

Table 26 shows the sectoral breakdown of GHG emission reductions achieved by the Planned policies. The Transport and Industry sectors account for 97% of all reductions (78% and 19% respectively).

Table 3: 2015-2050 Cumulative GHG Emissions by Sector (kt CO2 eq.)

Emissions	Source	Baseline - ICE Exp Plan to 2027	All Planned Measures	Reductions Achieved by Planned Measures
Carbon dioxide	Agriculture	7,655	5,910	1,745
	Commercial	5,682	5,474	208
	Industry	64,589	45,515	19,074
	Power	1,219	1,217	3
	Residential	6,910	5,616	1,294
	Transport	230,581	149,632	80,949
Methane	Entire Energy sector	1,440	1,417	23
Nitrous Oxide	Entire Energy sector	3,238	2,932	306
Total	**Entire Energy sector**	**321,314**	**217,713**	**103,601**

Figure 40 shows the breakdown of GHG emissions by gas and sector for the Baseline and All Planned policies scenarios. The 2050 GHG emission level from the energy sector is 5,207 kt CO2eg, compared to 11,066 kt in the Baseline, which is a 53% reduction. However, the GHG emissions reduction NDC target for the energy sector has been estimated to be 60% below the Baseline in 2050. Therefore, Enhanced policies needed to be identified that can cost-effectively fill the gap, as discussed next.

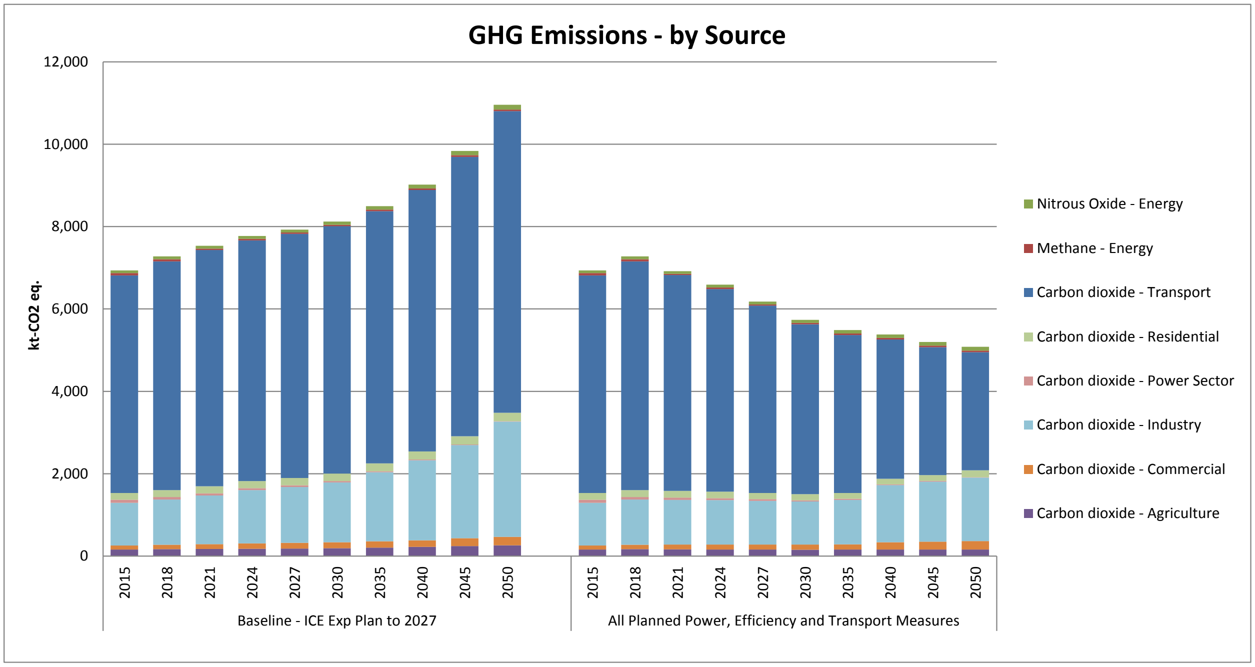


Figure 4: GHG Emissions for Baseline and All Planned Policies Scenarios

1.6 Enhanced Policies to Achieve the NDC Goals

Because the Planned policy measures fall short of achieving the reductions goals of the NDC, estimated as a 60% reduction from the baseline in 2050, additional Enhanced measures were considered. First, the Enhanced policy measures identified during the study were added to the All Planned policies scenario as the Planned and Enhanced run. Although this scenario increases the emission reduction in 2050 to 56%, a gap in GHG emission reductions remains to reach the NDC target. To help identify the additional Enhanced measures needed, the Planned & Enhanced policies were run the 60% GHG emission reduction target imposed in 2050, which forces the level of emission reduction needed to meet the NDC goal. Examination of how the GHG gap between the Planned & Enhanced policies and the NDC target run is eliminated provides an initial indication of what additional Enhanced measures are needed.

As shown in Figure 41, the Planned & Enhanced Measures with 60% target run (NDC target run) makes additional emission reductions starting in 2021 mostly from the Transport sector early, and the Industry sector later. This scenario achieves over 139 Mt in GHG emission reductions, while increasing energy system cost by 6.9% (almost $US16 B). Table 27 provides a breakdown of the additional emission and shows that 93% of the additional GHG emissions reductions needed to achieve the NDC target are found in the Transport and Industry sectors.

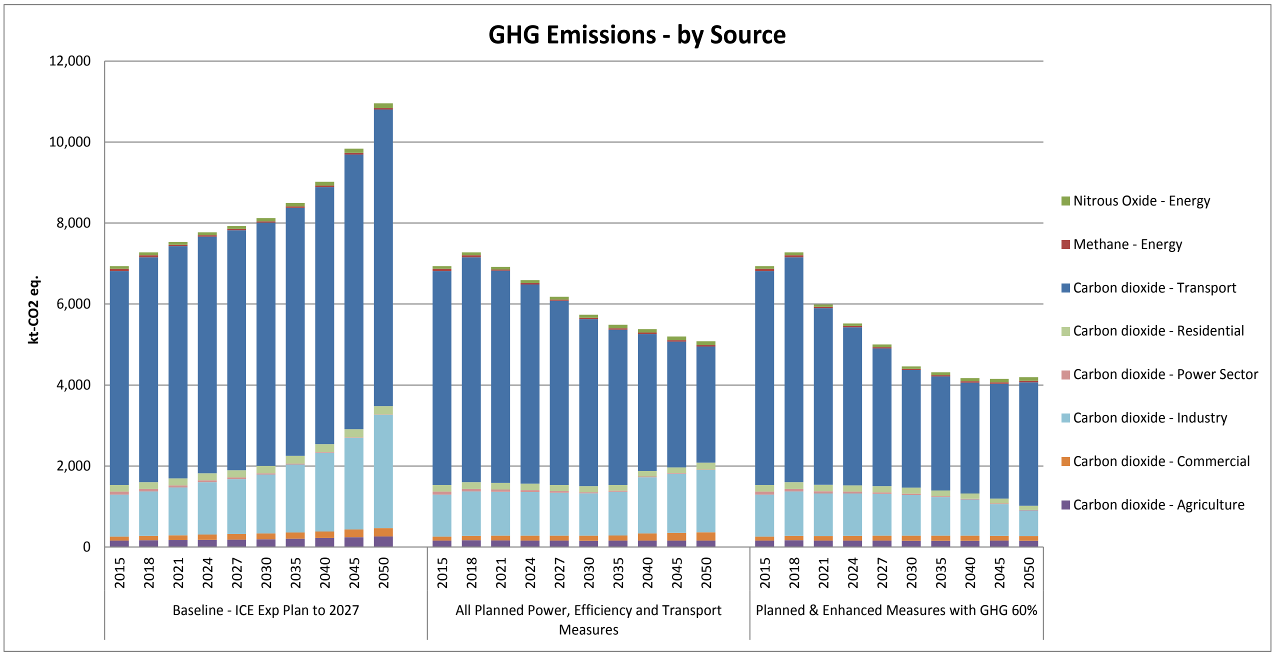


Figure 5: GHG Emissions for Planned Policy Measures without and with 60% GHG Target

Table 4: 2015-2050 Cumulative GHG Emissions from Enhamced Policy Runs (kt CO2 eq.)

Emissions	Source	Planned & Enhanced Measures	Planned & Enhanced Measures with GHG 60%	Additional Reductions Needed
Carbon dioxide	Agriculture	5,910	5,834	76
	Commercial	5,474	4,376	1,098
	Industry	45,165	34,076	11,089
	Power	1,217	1,217	0
	Residential	5,592	5,143	450
	Transport	144,462	127,844	16,618
Methane	Entire Energy Sector	1,404	1,357	46
Nitrous Oxide	Entire Energy Sector	2,879	2,682	198
Total	**Entire Energy Sector**	**212,103**	**182,528**	**29,575**

Figure 6 shows annual change in energy system cost by component for the NDC target run compared to the Baseline scenario. Most of the additional cost is driven by investment in high-efficiency demand devices, particularly up to 2035, with incremental investments in additional supply technologies starting in 2030. The savings in fuel expenditures grows over time such that the net system cost becomes negative after 2035.

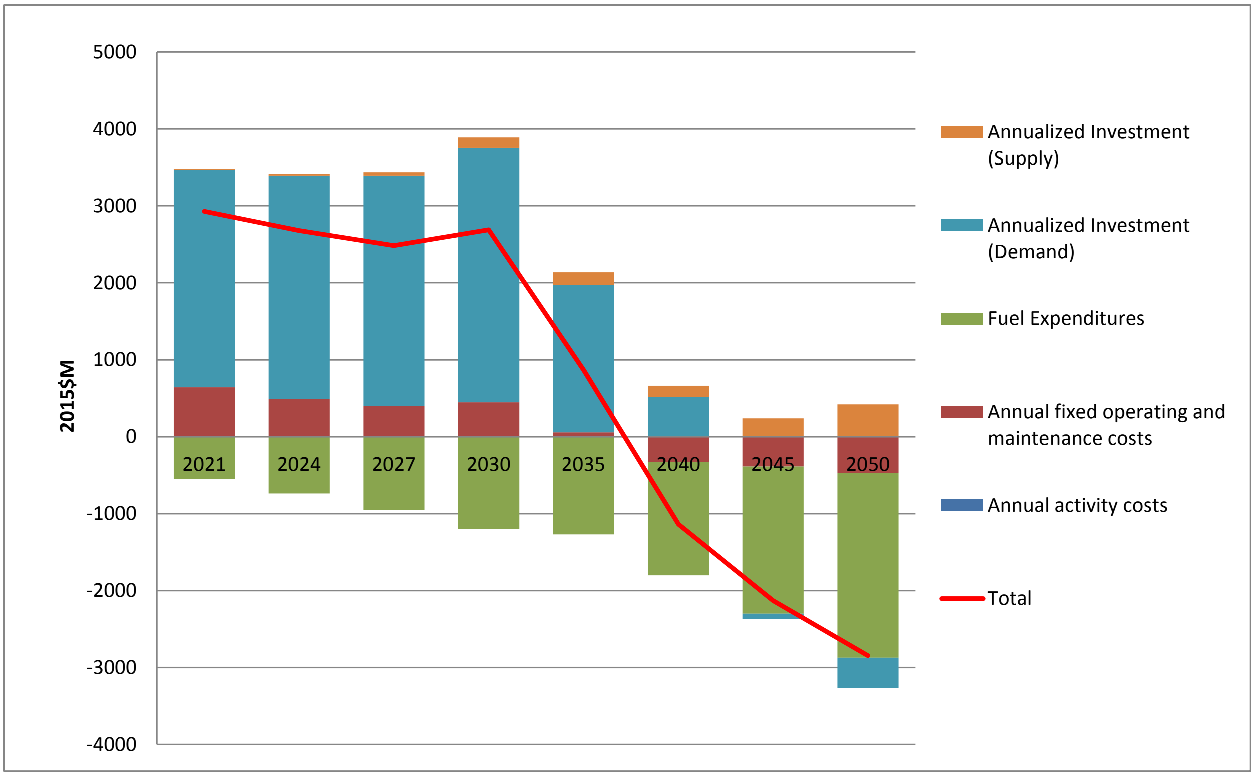


Figure 6: Annual Change in Energy System Cost by Component compared to Baseline

The NDC target run increases electricity generation in 2050 by 18%, highlighting the key role that the power sector needs to play by providing green electricity to drive the low carbon economy. Table 5 shows the change in power plant investment between 2015 and 2050. Note that red highlighted cell indicate negative changes and green one positive changes.

The Planned policies require a net added investment of $US933 M for new solar and wind plants with reduced investments for thermal, hydropower and biomass-fired generation. The identified Enhanced measures increase investments by $US2.9 B, primarily in run-of-river hydropower, geothermal and solar. This investment averages $US82 M per year. The NDC target adds an additional $US3.7 B, primarily in run-of-river hydropower, geothermal, wind and biomass-fired plants. The total added investment averages $US217 M per year.

Table 5: 2015-2050 Changes in Lumpsum Power Plant Investment ($US M)

Power plant Type	Planned - Baseline	Enhanced - Planned	NDC - Enhanced	NDC - Baseline
Biofuel-fired	-80	0.0	152	72
Geothermal	0.0	964	1,101	2,066
Hydro - Run of River	-216	2,520	1,865	4,169
Hydro regulated	0.0	0.0	0.0	0.0
Oil-fired	-338	143	194	0.0
Solar	937	387	11	1,335
Storage for Wind & Solar	0.0	5.3	1.3	6.6

Wind	630	-1,076	408	-37
Total	**933**	**2,945**	**3,733**	**7,612**

Table 6 shows the cumulative changes in FEC between the Baseline, Planned, Enhanced and NDC scenarios, with positive changes in green, while negative changes are red. The Planned measures reduce over 700 PJ, mostly from diesel and gasoline, while increasing use of biofuels and electricity. The Enhanced measures make small additional reductions in diesel and gasoline use, while continuing the increased use of electricity. However, to achieve the NDC goal, other fuels, particularly LPG and Other petroleum products (largely petroleum coke) need to be reduced, while electricity use increases significantly. Interestingly, some of the biofuel use in the Planned policy run is reduced in the NDC target run in favor of electricity, as higher efficiency Electric vehicles are favored over Hybrid vehicles.

Table 6: 2015-2050 Changes in Cumulative Final Energy Consumption (PJ)

Fuel	Planned - Baseline	Enhanced - Planned	NDC - Enhanced	NDC - Baseline
Agricultural residues	15.8	0.1	-25.7	-9.8
Aviation gasoline	0.0	0.0	-0.25	-0.25
BioDiesel	361	-10	-32	319
BioGasoline	184	-16	-92	76
BioJet-Kerosene	53	0.0	-52	1
Biogases	21	0.6	6	27.6
Coal	4.8	0.04	-6.5	-1.7
Diesel	-782	-21	-51	-853
Electricity	81	13	287	381
Fuel Oil	-61.8	0.01	-2.4	-64.2
Fuelwood	25.7	0.5	-1.3	24.5
Gasoline	-459	-50	-158	-667
Jet Fuel	-57	0.0	52.6	-4.5
Kerosene	-6.8	0.0	-0.1	-6.9
LPG	-32	3.1	-121	-149
Other Oil Products	-65.6	0.2	-68	-133.4
Renewables	13.3	0.6	0.7	14.6
Total	**-704**	**-79**	**-264**	**-1,047**

However, one of the concerns with liquid biofuels is size of the domestic resource and the likelihood of needing to import biofuels to meet the NDC goals. Based on the current estimates of domestic biofuels production, Figure 7 shows that the share of imported biofuels is highest in the Planned and Planned & Enhanced scenarios, with biodiesel reaching 63% and biojet-kerosene reaching 50% in 2050. Only Biogasoline is domestically produced in these scenarios. However, in the NDC target scenario, the biojet-kerosene imports are eliminated, and the biodiesel imports decrease to 52% in 2050.

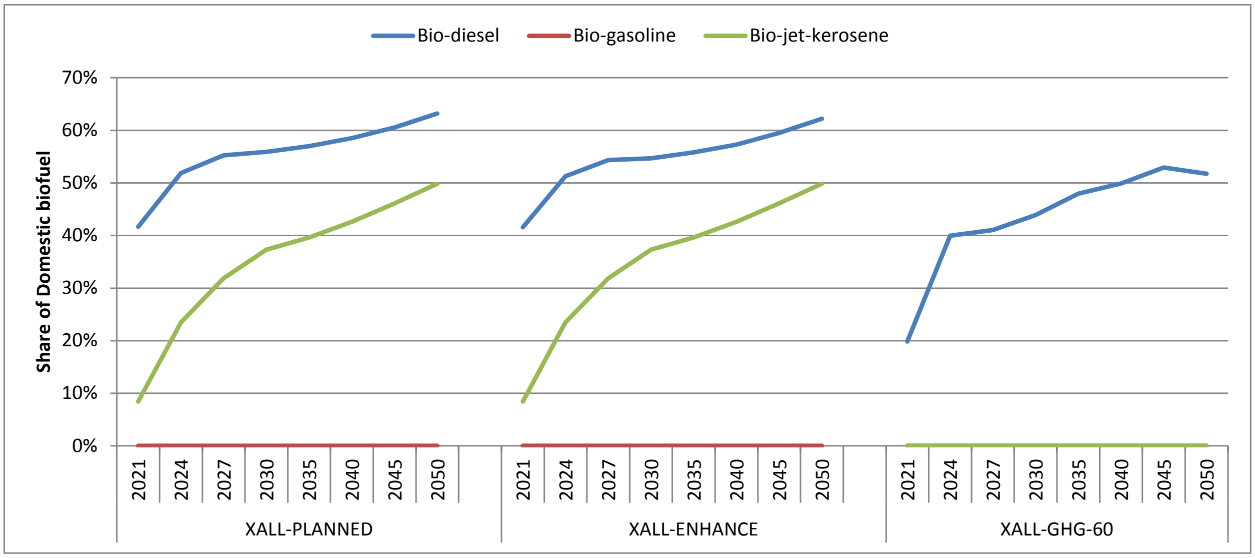


Figure 7: Share of Imported Biofuels

The key Planned and Enhanced measures necessary to achieving Costa Rica's NDC ambitions are discussed by sector below and summarized in Table 7.

Supply and Power Sector Measures: The key Planned measures for this sector include the RE Share of GFE, the Biofuels Target and the measures to expand solar resources beyond the Baseline. The known Enhanced measures increase capacity of geothermal, run-of-river hydro and solar while decreasing wind. To meet the NDC target, another 425 MW of run-of-river hydro is needed along with 400 MW of wind and geothermal and 80 MW of biomass-fired plants over what the Enhanced scenario delivers on its own.

Transport Sector Measures: For passenger transport, the Planned measures move Buses to Improved, Advanced and Hybrid options. But the NDC scenario shifts many of the Hybrid and Advanced buses to electricity and redirects biodiesel use to Trucks. The Planned measures move Minibuses into gasoline Hybrid and Electric vehicles, and to reach the NDC goal all minibuses shift to electric vehicles. The Planned measures move LDVs into Electric and Hybrid vehicles, while the known Enhanced measures continue the trend to Electric vehicles, and to meet the NDC target, all LDVs move to Electric (electric-only and plug-in hybrid) vehicles. The Planned measures move Taxis into Electric vehicles and Hybrids, and to reach the NDC goal almost all Taxis transition to Electric vehicles, although some Hybrids remain. Air transport is not impacted since most flights are international and emissions from international air transport are not included in national inventories.

For freight transport modes, the Planned measures shift Light trucks to Improved, Advanced and Hybrid types, and decreases gasoline, diesel and LPG consumption while increasing biodiesel use. The Planned measures also shift most demand to Heavy long-haul trucks, and to reach the NDC target, biodiesel use increases, along with continued shift to Improved long-haul trucks and Advanced short-haul trucks. Planned measures favor Improved and Hybrid technologies for Shipping and to meet the NDC target, most Ships are shifted to Hybrids. For Off-road vehicles, the Baseline scenario selects mostly Improved vehicles, and this trend is continued to reach the NDC target.

To summarize, the key Planned measures in the Transport sector include targets for Electric vehicles for LDVs, Taxis, Minibuses and Buses, public transit measures, and mode shifts from Truck to Rail. Needed Enhanced measures include increased incentives for Electric vehicles, especially for LDVs, Taxis, Minibuses and Buses, and to allow more liquid biodiesel use for Trucks of all classes, Shipping and Off-road. An important ancillary measure would be incentives to increase domestic biofuel production to avoid the need for imports.

Industry Sector Measures: Key Planned measures for the Industry sector include targets for utilization of biomass residues in the Agro-industry and measure to reduce fossil fuel use in Other (cement) sub-sector. Key Enhanced measures are needed to further decrease the use of LPG, fuel oil and petroleum coke. Additional measures should increase incentives for use of solid biomass and liquid biofuels, especially for process heat and steam generation and should develop a domestic biofuel market to support stable long-term pricing.

Building Efficiency Measures: Key Planned measures include incentives for advanced technologies for space cooling, water heating and cooking, LED public lighting, and public building efficiency retrofits. These measures (including appliance and building standards) achieve almost all the potential emission reductions in the sector. Enhanced measures are needed to increase Improved technologies for general lighting and cooling, and reduce LPG use for cooking.

Table 7: 2015-2050 Changes in Cumulative Final Energy Consumption (PJ)

Sector	Key Planned Measures	Enhanced Measures
Supply and Power	Increase RE share of GFE use from 56% in 2015 to 70% in 2050 Force biofuels to the following levels by 2050 across all sectors: Biodiesel-50%, biogasoline-30%, biojetfuel-20% Install 500 MW of centralized PV systems by 2050.	Add another 425 MW of run-of-river hydro 400 MW of wind and geothermal and 80 MW of biomass-fired plants
Transport	Incentivize advanced, hybrid and electric vehicles Improve share of Electric cars to 25% of New vehicles by 2030 (and 50% by 2050). Improve share of New Advanced Taxis, Buses and Mini-buses to 100% by 2030. Implement an Integrated Public Transport system 5% shift of passenger transport to Non-motorized modes by 2030	Shift all LDVs, minibuses and Taxis to Electric (electric-only and plug-in hybrid) vehicles Shift most Hybrid and Advanced buses to electricity and redirects biodiesel use to Trucks Improve urban mass transit plans to shift 5.4% of LDV demand to urban trains by 2030. Increase incentives to increase domestic biofuel production to avoid the need for imports.
Industry	Incentivize advanced demand devices Increase use of organic residues by Agriculture and Industry sectors. Increase bio-energy demand in Cement sector to 75% of all process heat demand to the Other sector by 2050.	Reduce fossil fuel share in Industry sectors to 25% by 2050. Increase incentives for use of solid biomass and liquid biofuels, especially for process heat and steam generation Develop a domestic biofuel market to support stable long-term pricing

Buildings	Incentivize advanced demand devices Transition to 100% LED Public Lighting by 2024. Appliance standards to transition Commercial & Residential devices to 100% improved, better and advanced techs by 2030. Efficiency retrofits for all Public Buildings by 2050	Incentives to increase Improved technologies for general lighting and cooling, and reduce LPG use for cooking.

1.7 Conclusions and Next Steps

This study has successfully constructed a TIMES-CR integrated full-sector energy planning model and performed a detailed, quantitative analysis investigating optimal strategies for Costa Rica to meet its ambitious NDC goals as cost-effectively as possible. Innovative metrics were used to assess the mitigation measures and actions to be undertaken, and recommendations on Enhanced policy measures necessary to do so were identified. This study has created a solid analytic foundation in Costa Rica for continued analysis of the policies that will effectuate the transition to the low carbon future envisaged in their NDC.

The Costa Rica PMR and AT are positioned to become leaders among developing countries on how sophisticated, well established, proven analytical methods can be applied to better inform decision-making and shape the country's energy future responsibly. The country is on the cusp of creating the in-country capacity needed to perform future analyses to evaluate GHG mitigation policies and measures on an ongoing basis, so as to be able to make stronger NDC commitments over time, as called for by the Paris Accord.

Given the accomplishments of this study, and the capacity built to date, a list of next steps was developed in discussion with the PMR and AT. The goal of the next steps is to cement the role of TIMES-CR as an integral part of the country's decision-making process and ensure that the necessary in-country skills to do so are in place. To accomplish this, the proposed next steps were organized into the following three categories:

- Enhancement of TIMES-CR;
- Advanced Capacity Building;
- Employing Advanced TIMES Modeling Techniques, and
- Application of TIMES-CR for Costa Rica NDC-2.

2 Background

Costa Rica set a very ambitious Greenhouse Gas (GHG) mitigation target in its Nationally Determined Contribution (NDC), "a maximum of 9,374,000 T CO2eq net emissions by 2030" and complemented it with an indicative long-term decarbonization pathway "with proposed emissions per capita of 1.73 net tons by 2030, 1.19 net tons per capita by 2050 and -0.27 net tons per capita by 2100" [1]. Achieving these goals, especially in a country with already relatively low carbon intensity such as Costa Rica, will require aggressive actions and policies, particularly in the fossil fuel use for transport and industry, as well as non-energy emissions from agriculture and waste.

Preliminary assessment work on existing and planned policies and actions in select sectors has been supported under the Partnership for Market Readiness (PMR) work program, which brings together more than 30 countries, providing funding and technical assistance for them to prepare and implement cost effective instruments, including carbon pricing policies, aimed at reducing global carbon emissions[2].

This project builds upon the work of the PMR in Costa Rica, and its relationship with Ministry of Environment and Energy (MINAE) and other ministries, and is designed to develop improved analytical tools and capabilities with the objective of assisting the government of Costa Rica in determining viable pathways to achieve the emission reduction commitments made in its NDC. The intended outcome is the development and application of a country-specific modeling framework, and the establishment of in-country capacity that will allow continuous improvements and ongoing application of the framework to examine new issues, options, technologies and policies as circumstances dictate. Furthermore, the resulting platform was also designed to be easily applicable, transferable and reproducible by PMRs in other countries.

The key objectives of this project are to work with local experts and key stakeholders to:

- Identify the policies and measures politically, technically, and economically feasible for Costa Rica;
- Develop a country-specific energy systems model with input parameters validated and the resulting ***Baseline scenario***;
- Develop a ***Planned policy scenario*** to assess existing and proposed mitigation policies and actions;
- Develop ***Enhanced policy scenarios*** necessary for Costa Rica to achieve its NDC targets comprised of additional plausible mitigation policies and actions, and
- Build **local capacity** to take over stewardship and ongoing use of the national energy planning platform.

The core framework employed is the TIMES (The Integrated MARKAL-EFOM System) modelling platform, as embodied in the new TIMES-Starter model[3]. TIMES is the most widely

[1] Costa Rica's Intended Nationally Determined Contribution, Government of Costa Rica, Ministry of Environment and Energy. 2015. Available at: http://www4.unfccc.int/Submissions/INDC/Published%20Documents/Costa%20Rica/1/INDC%20Costa%20Rica%20Version%202%200%20final%20ENG.pdf

[2] More information about PMR: https://www.thepmr.org/content/pmr-brochure-0

[3] https://iea-etsap.org/answer-times/TIMES-StarterModel_Guidelines%28v1.0%29.pdf

used least-cost optimization methodology employed around the world to inform energy policy and strategic planning. It was developed and is maintained, advanced and promoted by the International Energy Agency's Energy Technology Systems Analysis Program (IEA-ETSAP[4]), the longest running Implementing Agreement of the IEA. TIMES models are used in over 250 institutions in more than 70 countries, and TIMES is a proven and continually evolving modelling framework for assessing the least-cost evolution of an energy system under a wide range of energy, economic and environmental planning and policy issues.

The TIMES-Starter platform, developed by DecisionWare Group (DWG) on behalf of IEA-ETSAP, consists of an integrated full-sector energy system model that employs best practices, is built upon a peer-reviewed database, and provides a complete set of tools for managing and overseeing the effective application of the model.

The TIMES-Starter model has been transformed into a comprehensive energy system planning model for Costa Rica (TIMES-CR) by adopting local data and reflecting local knowledge to the fullest extent possible. The Analysis Team (AT), assembled by the PMR, has been providing the latest data and reviewing critical model assumptions and results to ensure the model properly represents the Costa Rica energy system. Members of the AT covering all key sectors of the energy economy are listed in Table 8.

Table 8: Current TIMES-CR Analysis Team Members[5]

Name	Organization	Role	Email
Dr. Jairo Quiros-Tortos	University of Costa Rica	Lead Coordinator	jairohumberto.quiros@ucr.ac.cr
J. Felipe De León	Costa Rica PMR	Advisor and government liaison	felipe@climatrader.com
Estiven González	Costa Rica PMR	Transportation and overall review	estivengj@gmail.com
Arturo Molina	Energy Sector Directorate (DSE)	Energy Balance, Buildings & Industry	amolina@dse.go.cr
Jorge Mario Montero	ICE Costa Rican Institute of Electricity	Electricity	JMonteroA@ice.go.cr
Catherine Salazar	Ministry of Transport (MOPT)	Transportation	csalazar@mopt.go.cr
Lil Moya Fernandez	MOPT	Transportation	lmoyafer@mopt.go.cr
Irene Alvarado Quesada	Central Bank of Costa Rica (BCCR)	Demand Projections	alvaradoqi@bccr.fi.cr
Johnny Aguilar	BCCR	Demand Projections	AGUILARMJ@bccr.fi.cr

This final report contains elements of the previous interim reports submitted as internal technical reports to the World Bank on Model Development, the Baseline Scenario, and the Preliminary Mitigation Analysis. Therefore, it summarizes all of the work performed under this project. Section 2 provides a summary of the TIMES-Starter model and how it was customized to create

[4] http://www.iea-etsap.org/.

[5] The PMR representative were heavily engaged in this phase of the undertaking, though are not expected to be ongoing members of the AT.

TIMES-CR, while Section 3 provides an overview of the TIMES-CR model structure and database. Section 4 provides a summary of the Baseline scenario results. Section 5 identifies the mitigation measures examined in this report. Section 6 examines some sensitivity analyses around the Baseline scenario, while Section 7 provides a comprehensive analysis of the cost and benefits of each measure by sector. Section 8 examines the results of the Planned and Enhanced Policy scenarios the gap between these scenarios and the NDC target scenario and identifies where the additional GHG reductions can most cost-effectively be found. Section 9 recommends policies by sector that could fill the gap in needed GHG reductions, and Section 10 provides conclusions and a list of next steps.

3 TIMES-Starter Model

The TIMES-Starter platform is comprised of an integrated full-sector energy system model that employs best practices, is built upon a peer-reviewed database, and provides a complete set of tools for managing and overseeing the effective application of the model. The model is assembled in a set of interactive Excel templates readily customized to a base-year energy balance, resource supply picture, power plant characteristics and end-use service demands that must be met over the planning horizon. It has a comprehensive model management platform that overseas all aspects of working with TIMES including integration of the Excel workbooks, Reference Energy System (RES) network diagramming, various technology views, job submission, along with results analysis tools including dynamic pivot tables and an interactive multi-case graphical comparison and metrics workbook to facilitate interpreting model results and their communication to decision-makers[6].

The components of the Starter platform are shown in Figure 8. There are seven categories of input templates, including the energy balance and electricity load curve, demand projections, resource supply and cost, existing technology characteristics and calibration, new technology characteristics, user constraints that help shape the baseline and policy scenarios, and the policy scenarios. These are read by the ANSWER-TIMES model management software and prepared as a least-cost optimization problem that is solved by GAMS, with the run results processed by the VEDA-BackEnd (VEDA-BE) software, which feeds the results to a Base-year Calibration workbook, and the Results Analysis workbook.

The TIMES-Starter model contains a fully documented, peer-reviewed database of current and future energy technologies and supply options that is derived largely from US Environmental Protection Agency (USEPA) and Department of Energy (DOE) data sources, augmented with European and other data sources to fill gaps or where better data exists. The TIMES-Starter model greatly facilitates moving from limited spreadsheet and accounting frameworks (e.g., LEAP, OSeMOSYS) to a more sophisticated decision support tool where assumptions and policy goals can be imposed to examine alternative least-cost pathways.

[6] Most all the results tables and figures in this report are extracted directly from this Results Analysis workbook

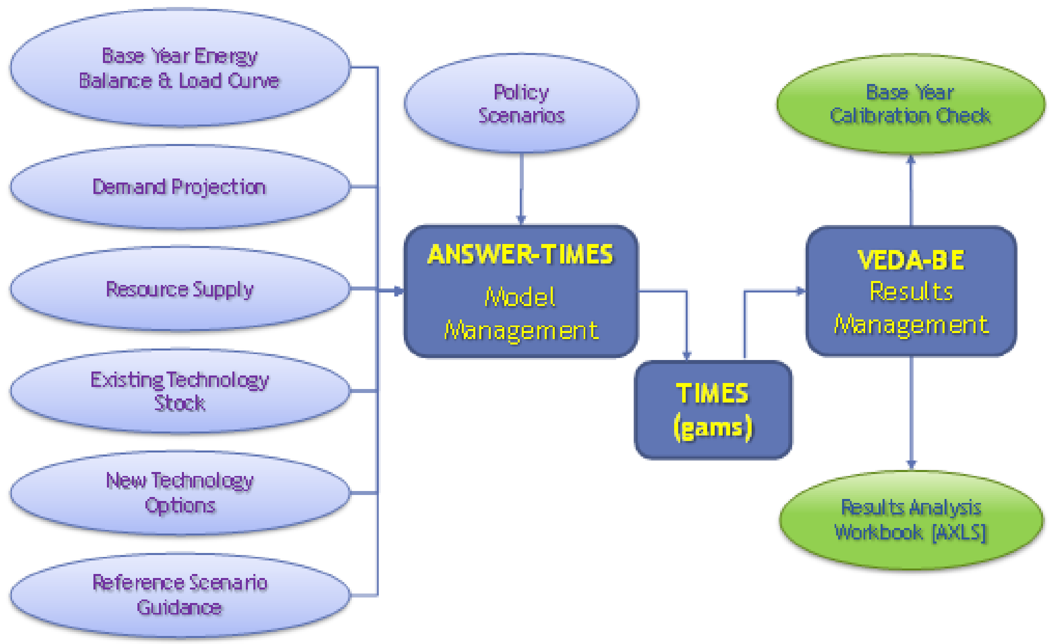


Figure 8: Components of the TIMES-Starter Platform

The TIMES framework also facilitates the analysis of a wide range of potential measures in order to determine which ones will be key to achieving the policy goals, and the merits of each can be examined in terms of their individual contribution to emission reductions, costs, and co-benefits as part of the determination of system-wide marginal abatement costs. In addition, the TIMES framework accurately integrates the impact of the individual measures, which is extremely important because no measure acts independently, rather each is part of an interconnected energy system, and when measures are combined they cannot be simply added owing to these system interactions. TIMES inherently captures all these complexities in a manner that is transparent for the user.

3.1 Customizing the TIMES-Starter for Costa Rica

A TIMES model requires a variety of input data, including:

- Energy Balance
- Useful Energy Demands and Energy Service Projections
- Detailed Costs on resources, technology investment, operating costs, fuel delivery
- Technology Characteristics, such as fuels in/out, efficiency, availability, technical life
- Resource supply steps, cumulative resources limits,
- Installed capacity of existing technologies, new investment possibilities
- Environmental Impacts, such as unit emissions per resource, per technology
- System and other parameters
- Discount rate, seasonal/day-night fractions, electric reserve margin

The TIMES-Starter model is a complete fully functional national TIMES model tied to an example energy balance, and the process of transforming it into a Costa Rica specific model followed the steps outlined in Table 9. This process was facilitated by data gathering meetings with key stakeholders in the energy sector and regular discussions with the AT.

Table 9: Adapting TIMES-Starter for Costa Rica

1.	Entered the 2015 base year energy balance and electricity hourly load curve.
2.	Used survey data where available, and expert judgement where not, to decompose sector fuel usage for each end-use demand.
3.	Tailored the model structure by eliminating commodities and processes not relevant to Costa Rica, and added others that were not initially in the TIMES-Starter model.
4.	Developed the season/day timeslices based on analysis of the electricity load curve to match the timing of electricity use in the various demand sectors to establish the load duration curve.
5.	Used ICE data to characterize the existing power sector configuration and base year operations.
6.	Used the TIMES-Starter database to characterize the existing technologies in each demand sector, augmenting with local data where available.
7.	Used expert judgment to set bounds for domestic resources and prices for primary energy resources not found in the US9r database.
8.	Developed useful energy demand projections using GDP, population, elasticity and other data provided by BCCR.
9.	Ran the TIMES-CR model and refined the base year calibration.
10.	Used the TIMES-Starter database to characterize the future technologies for each demand sector, and adjusted cost, efficiency and availability characteristics where local data was available.
11.	Adjusted the user constraints used to guide the Baseline scenario (rates of fuel switching, new technology penetration, and device shares).
12.	Reviewed and refined the Baseline scenario and developed sensitivity runs.

Once the TIMES-CR model was operational attention was turned to the representation of the various mitigation policies and measures that were to be analysed, with the steps employed noted in Table 10.

Table 10: Preparing for the Costa Rica NDC Analysis

1.	Identified current Planned and Enhanced policies (based on 14 local documents describing specific measures by sector).
2.	Developed scenario files for all Planned policies and analyzed these by sector.
3.	Refined scenario designs following review and discussion with the AT.
4.	Reviewed and refined the Planned policy scenario results.
5.	Modelled and ran a NDC target scenario.
6.	Identified gaps between the Planned policies and the NDC target scenarios.
7.	Identified Enhanced policy measures that would most cost-effectively close the gap between the planned policies and the NDC target.

3.2 Typical TIMES Model Results

The TIMES energy system model generator produces a large variety of results including:

- Total discounted energy system cost;
- Resources levels and marginal costs, if constrained;
- Levels of new and total installed capacity for supply and end-use technologies;
- Annual investments in new supply and end-use technologies;
- Annual fixed and variable operating and fuel costs for all technologies;
- Annual and season/time-of-day generation by power plants;
- Technology marginal cost, if constrained;
- Energy consumed by each technology (and sector), and marginal price (by season/time-of-day for electricity);
- Demand marginal costs and change in levels, if using elastic TIMES, and
- Emission level by resource/sector/technology for each period and marginal costs, if limited.

The VEDA-BE results handling tool allows the definition of user-defined sets that group the results as desired with clear descriptions for each entry that are then used to define tables which are presented as dynamic pivot tables that can be reconfigured and expanded to facility digesting and interpreting the detailed model results. The Results Analysis workbook (AXLS) is a scenario comparison graphing workbook that work in combination with VEDA-BE to greatly facilitate model review and more importantly dissemination of the results to policy advisors and decision-makers. Table 11 provides a summary of the main graphing sheets currently available in the AXLS for Costa Rica. Note that many of the end-use sector graphs are generated for each demand sector. Tables can be easily added to VEDA-BE and the AXLS as the need arises.

Table 11: Results Presentation Tables Available in the Starter Analytics Workbook

Area	Nature of the Results
Costs and Expenditures	Total discounted system cost (Objective Function)
	All system expenditures (fuel, investment, operation, etc.) summary table
	Annualized Investment expenditures by type
	Fixed and variable O&M and delivery expenditures by type
	Resource supply costs
	Fuel costs by sector
	Lump Sum Investments by type
	Investment expenditures by sector
	Energy (marginal) prices
	Electricity (marginal) price by timeslice
Energy Supply and Production	Energy production by fuel type
	Resource Supply by source (domestic/ imports)
	Imports by type
	Exports by type
	Biomass supply by type

	All renewables usage summary (electricity, heat, demand sectors)
Power Sector	Electricity generation by fuel group
	Fuel consumed in power plants by type
	New Power Plant capacity additions by fuel type
	Investments in power plants by fuel type
	Power Plant total installed capacity by type
	Electricity from Hydropower plants
	Electricity from renewables by type
End-use Sector	Energy consumption by demand sector and sub -sector
	Energy intensity by demand service
	Final energy by fuel group
	Renewable energy consumed in individual demand sectors
	Purchase of new devices and vehicles by type
	Amount of demand services meet by device and vehicle type
Emissions	GHG emissions by fuel & source (CO2, methane & nitrous oxide)
	CO2 Emissions by sector and sub-sector
	CO2 Emissions by fuel

4 TIMES-CR Model Structure

4.1 TIMES-CR Overview

The basic structure of the TIMES-CR model is illustrated in Figure 9. Primary energy supplies in Costa Rica consist of imported fossil fuels and a variety of domestic renewable energy sources. These are characterized by cost-supply curves that define how much is available at a particular price. Power plants and fuel processing plants convert the primary energy sources into final energy carriers, such as electricity, that are used in the demand sectors. These plants are characterized by their investment and operating cost, efficiency and other performance parameters. The model contains five main demand sectors: Agriculture, Commercial, Industry, Residential and Transportation. There is also a Non-energy/Other sector to fully align the model with the energy balance. End-use devices specific to each of the main demand sector are characterized by investment and operating cost, efficiency and operating parameters delivering end-use services (such as lighting, cooling, cooking, industrial process heat and motor drive, passenger and freight travel). For most devices there are Existing, Standard, Improved, Better and Advanced options. The base year demands for useful energy services are calculated based on the existing device stock and the efficiency of that stock. Future demands for useful energy services are projecting from these base year values in accordance with sector-specific drivers, such as GDP growth, GDP per capita growth, industrial production projections, space cooling growth expectations, etc.

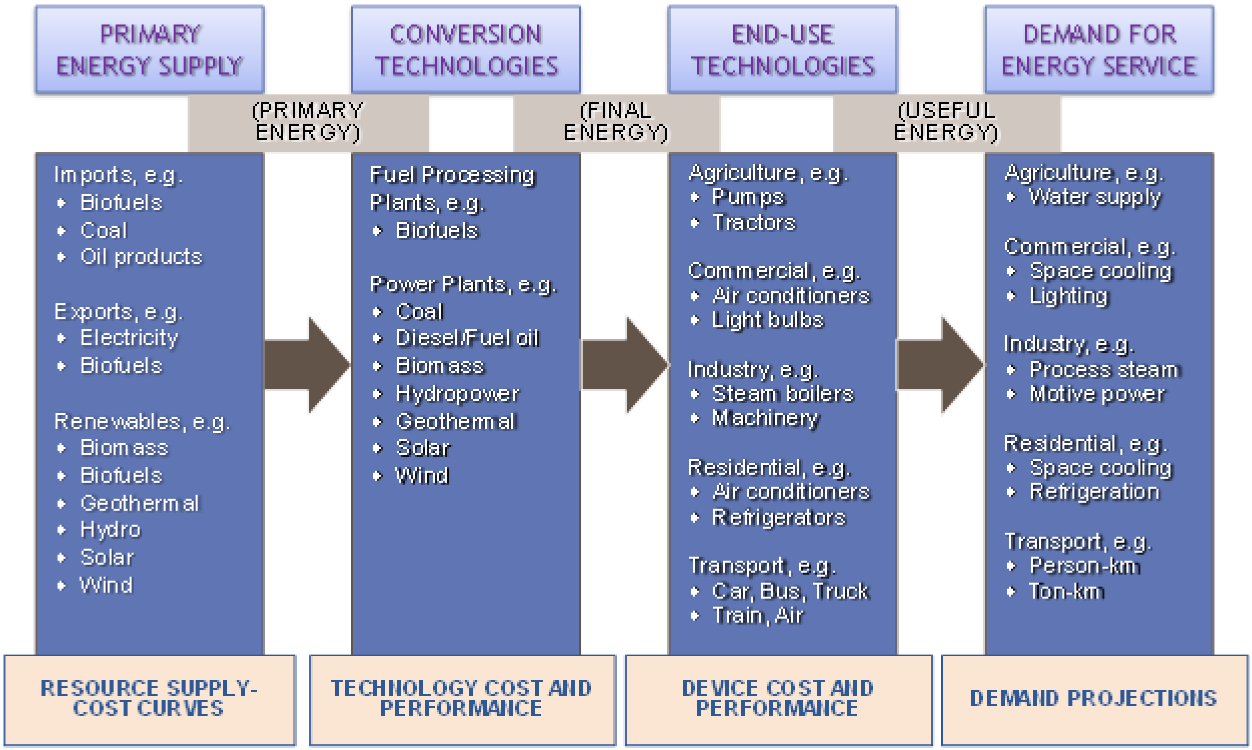


Figure 9: TIMES-CR Model Overview

TIMES-CR will solve for the least-cost energy system configuration that will meet the demand projections, adhering to in-country limits on resources and any additional policy constraints placed on the model. The total discounted system cost (the TIMES objective function) encompasses all costs arising from the production and consumption of energy including fuel expenditures, investments in power plants, infrastructure, purchases of demand devices and vehicles, and fixed/variable operating and maintenance costs associated with all technologies. In addition it may include policies such as carbon pricing instruments.

Figure 10 shows how the TIMES-CR model is organized in various sector-based “Smart” Excel input workbooks. These are VBA-enabled workbooks that assist with proper entry of the model data. There are interdependencies linking many of the workbooks, as explain in Appendix A. The six categories of input templates are summarized here and described in more detail in the sections that follow:

- 2015 energy balance (EB) is the source of all energy balance data;
- Demand projections (Demand-REF) start with the base year useful energy demands and use the various demand drivers to calculate useful energy demands in future years;
- Resource supply (SUP) provides costs and bounds for all domestic and imported resources;
- Base year (BY) template for each demand sector contain characteristics of all existing technologies and establish the base year calibration and “seed” useful energy demand of each sector;
- New technology (NT) templates for each sector contain the characteristics for new technology options by end-use application, sub-sector, or mode;

- User constraints (UC) for each sector help to shape the Baseline and policy scenarios limiting the allowed rates of fuel switching, new technology penetration, and device shares, and
- Policy scenarios (S_) contain the changed model inputs that characterize how a policy scenario differs from the Baseline.

These templates are read by the ANSWER-TIMES model management software and prepared as a least-cost optimization problem that is solved in GAMS. (TIMES is written in the GAMS modeling language). The TIMES-CR results are post-processed by VEDA-BE, which allows the development of customized sets and tables to enable the user to easily create dynamic pivot tables most useful for reviewing and analyzing model results. Finally, the DWG Results Analysis graphing workbook (AXLS) provides dynamic comparison of scenarios in graphs and tables ready for use in presentations and reports.

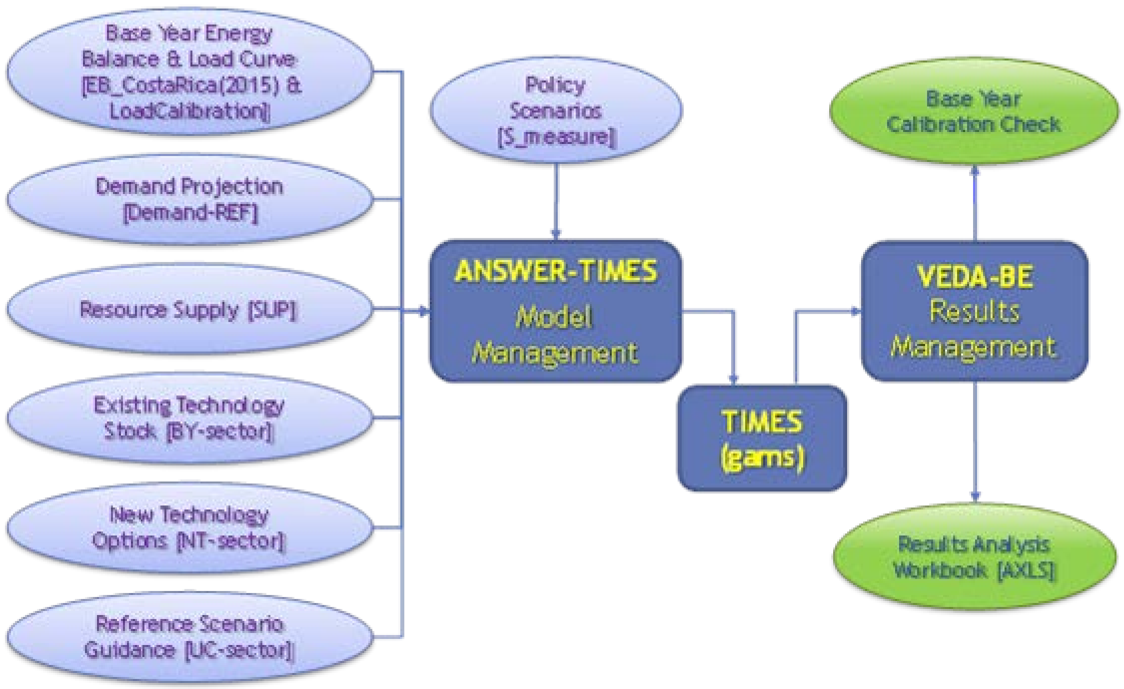


Figure 10: Overall Structure of the TIMES-CR Model

4.2 TIMES-CR Description

This section provides a snapshot of the current TIMES-CR underlying structure, or Reference Energy System (RES), which is the graphic depiction of all the inter-dependent commodities and processes in the Costa Rica energy system network. The summaries that follow are designed to provide an overview of how each sector of the model is structured and provide context for the discussion of the Baseline scenario and the design of the Mitigation Measures (MM) in the next sections.

In TIMES-CR, the units for most energy and demands are Petajoules (PJ) with their capacity in PJ/annum (PJa), other than the power sector where capacity is expressed in Gigawatts (GW).

However, in the transportation, the units for demands are either million passenger-kilometers (Mpkm) or million ton-kilometers (Mtkm). All emission units are Million metric tons (Mt).

4.2.1 Naming Conventions

The TIMES-CR model relies on the strict use of naming conventions for all commodities and processes that serve to both organize the information thereby making it easy to recognize each component, as well as facilitate the assembly of the VEDA-BE (and AXLS) reporting tables. Table 12 shows the naming convention for energy commodities. A similar approach is used for emission commodities and all processes. These naming conventions allow the use of consistent rules for creating customized sets of commodities or processes that do not need to be updated when new processes or commodities are added to the model, according to the Root and Sector components of the name. Table 12 also shows an example of how the supply of renewable hydropower for electricity would start as SUPRNWHYD and be transformed into PWRRNWHYD for use at the power plant. A similar approach is used for all sectors.

Table 12: TIMES-CR Commodity Naming Conventions

Energy Carrier Root	Description	Energy Carrier Qualifier	Description
BIO	Biomass	ANT	Anthracite
COA	Coal	PSF	Biomass (primary solid fuel)
GAS	Natural Gas	BIT	Bituminous
NUC	Nuclear	BRI	Briquettes
OIL	Oil and Oil Products	CCO	Coke
RNW	Renewables	COI	Crude
Other	Can be added as needed	DSL	Diesel
		FOI	Fuel Oil
Energy Sector	**Description**	GEO	Geothermal
AGR	Agriculture sector	GSL	Gasoline
COM	Commercial sector	HYD	Hydro
IND	Industrial sector	JET	Jet Fuel
PWR	Electric Generation	KER	Kerosene
RSD	Residential sector	LFG	Landfill Gas
SUP	Supply & Imports/Exports	LIG	Lignite
TRN	Transportation sector	LNG	Liquefied Natural Gas
Supply of renewable hydropower would start as SUPRNWHYD and would be transformed to PWRRNWHYD for consumption at the power plant.		LPG	Liquefied Petroleum Gas
		MSW	Municipal Solid Waste
		NAT	Natural Gas
		RBG	Bagasse
		RCC	Coffee husk
		SOL	Solar
		WAS	Waste
		WIN	Wind
		URN	Uranium
		Others	Can be added as needed

Similarly, naming conventions for technologies look to identify aspects of the sector, demand service (e.g., heating, cooling, lighting, etc.), nature of the technology or device type (furnace, air conditioner, light bulb, etc.), the fuel consumed, and quality of the device). For example, residential cooling devices would have their names built using the conventions below, resulting in RCBELCRST for a standard room air conditioner. The specific naming conventions for each sector are defined on the Setup tab for each sector base year template.

- Sector: R - Residential
- Service: C - Cooling
- Building Type: B - Households
- Fuel: ELC - Electricity
- Device Type C/R/H - Central/Room air conditioner/Heat pump
- Device Quality ST/IM/BE/AD- Standard/Improved/Better/Advanced

4.2.2 Global Parameters

The TIMES-CR model is currently designed with a 2015 Base Year and 3-year periods to 2030, with 5-year periods to 2050. The model can easily be run for different period intervals in the future. Commodities are generally tracked at an annual level, except for electricity which is modeled at the time-slice level. Following analysis of the 2015 hourly load curve, the associated TIMES-CR load duration curve is structured with 12 time-slices: three seasons (wet, dry1 and dry2) and four divisions of the day (day, day peak, night peak and night). Two dry seasons were selected because of changes in the capacity factors for wind and solar that occurs between these two parts of the total dry season.

4.2.3 Primary Energy Supply

Figure 11 shows a simplified RES diagram for supply of primary energy carriers to the power and demand sectors. All the first-year values for the supply processes come from the 2015 Energy Balance. The naming conventions determine how the energy carriers are transferred to each sector through distribution (exchange or "X") processes that rename the energy carrier for each sector (e.g., SUPOILFOI is change to INDOILFOI for use by the industry sector). These distribution processes are also used to track emissions (by fuel type) and apply sector fuel price adjustments (e.g., delivery costs, cross-subsidies).

As the diagram shows, imported oil products go to every demand sector, while biofuels (domestic and imported) are available to all sectors except Other/Non-energy. Solar energy is available to the Power, Commercial, Industry and Residential sectors, while solid biomass is available to the Power, Industry and Residential sectors. Coal is available to the Power and Industry sectors, and hydropower, geothermal, and wind are only available to the Power sector. Domestic solid biomass availability is limited to published estimates[7] and domestic liquid biofuels estimates were based on AT expert judgement, while imported biofuels are unlimited, but at a 10 percent higher cost.

[7] "Waste Agricultural Biomass (WAB) for Energy: Resource Utilization and Greenhouse Gas Emission Reduction in Costa Rica", The Ministry of Agriculture and Livestock in partnership with the FITTACORI Foundation and the Bioenergy Research and Technology Transfer Program, 2014.

The minimum data needed for each resource supply is an upper limit and a price for that amount of annual supply. All energy carriers have a 1st year upper limit, which is set according to the Energy Balance as part of the calibration. In addition, future supply limits have been defined for all sources that are limited based on available resource potential studies for domestic supplies[8] and importation infrastructure limits when appropriate. The future price for a given amount of supply is based on the latest IEA projections for world energy prices, with adjustments for local delivery or domestic supply costs. The resource limits grow linearly from their 2015 energy balance value to the 2050 limit. Domestic resource supply limits are primarily used for biomass resources, and Table 13 shows the domestic biomass energy resource annual limits for 2050 for the bio-energy categories used in TIMES-CR. Resource supply limits are not used for solar, wind, hydropower and geothermal. Instead technology limits are used control how much of these resources can be utilized.

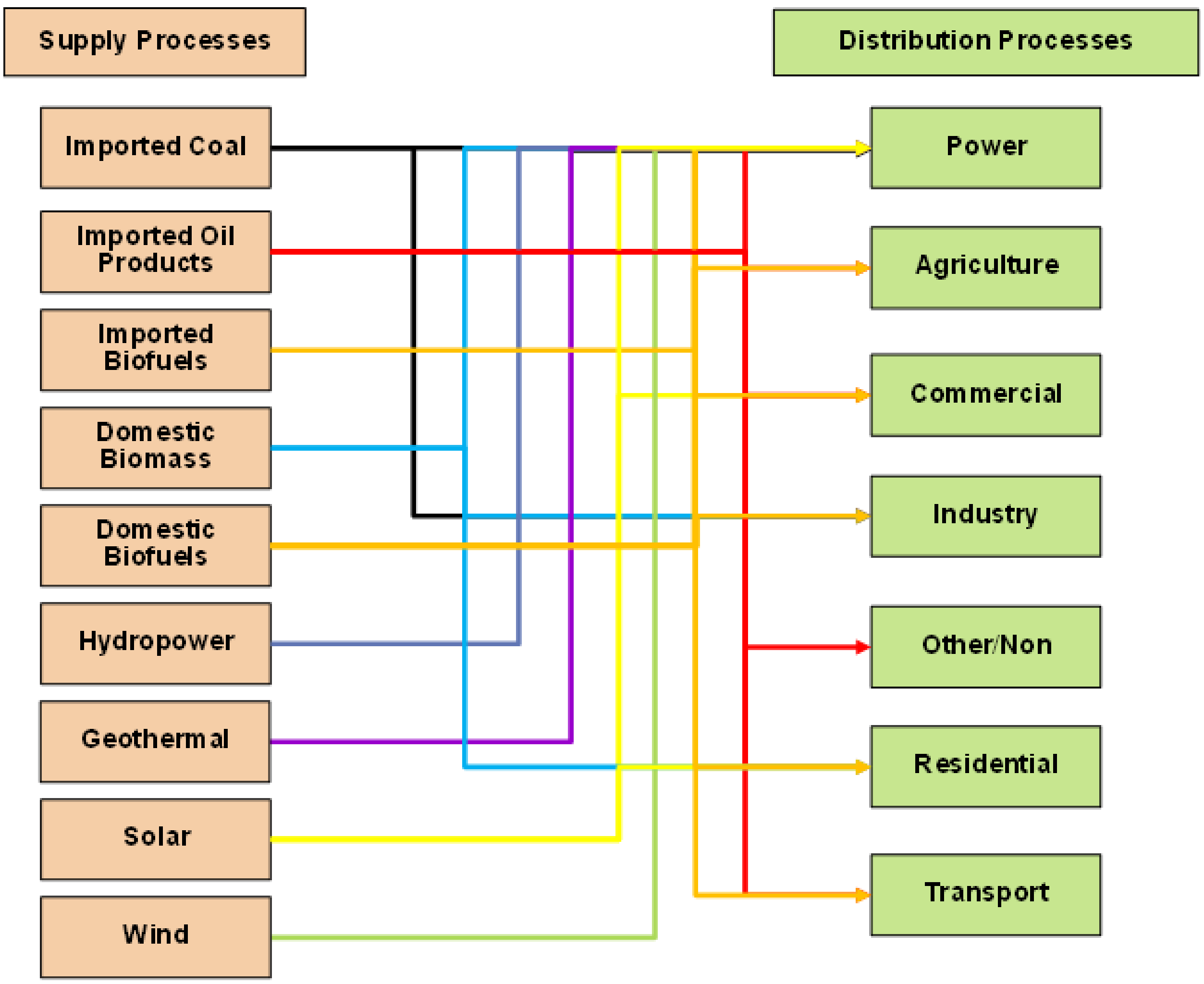


Figure 11: RES Diagram for Primary Energy Supply

[8] "Uso de los residuos agrícolas orgánicos como fuente de energía: aprovechamiento de recursos y reducción de gases de efecto invernadero en Costa Rica. Producto 1: Evaluación de la generación de residuos agrícolas orgánicos (RAO) en Costa Rica e identificación de sector Prioritario", Preparado por: Dr. Oscar Coto Chinchilla, Presentado a: FITTACORI, 2013.

Table 13: Biomass Resource Limits in 2050

Bio-energy Type	Data and Assumptions	Resource Limit in 2050 (PJ)
Firewood	Increased by 100% due to growth in Wood Products industry subsector, which uses fuelwood for Steam.	22.11
Biogases	Assume 50% availability of Coffee pulp, mucilage, manure and palm oil waste	4.02
Bio-gasoline	Based on added sugar cane production of 4.4 million tons yielding 130 liters of ethanol per ton	12.26
Bio-jet-kerosene	20% of current jet fuel/kerosene use	1.59
Bio-diesels	20% of current diesel use	8.48
Bagasse	Assumes a doubling of production	22.54
Coffee Husk	50% increase is proportional to growth in Coffee sector	0.56
Other organic residues	Assume 50% availability for energy	14.36

4.2.4 Power Sector

Figure 12 shows the RES diagram for the Power sector, depicting the primary energy sources that are consumed by various power plant technology types to produce grid electricity that primarily goes to the demand sectors. Imports and exports to/from neighboring countries are also modelled. The power sector is organized into existing power plants, as specified in the Energy Balance and ICE data[9,10,11], and new power plant options that are available to meet future needs.

Numerous types of power plant technologies are modelled, including three kinds of hydro plants – regulating (seasonal storage capacity), dam (daily storage capacity), and run-of-river (no storage capacity); several types of thermal and biomass based power plants, along with central PV as well as building distributed PV systems for both residential and commercial buildings. The distributed PV systems directly feed the distribution grid to the residential and commercial demand sectors, avoiding grid losses. Table 14 provides a complete list of the current and future plant options, with upper bounds on the potential new capacity by 2050 that are partially derived from the ICE Expansion Plan, with adjustments based on input from the AT.

[9] "Generación y demanda. Informe Anual. Centro Nacional de Control de Energía". Instituto Costaricense de Electricidad 2015. Available at: https://appcenter.grupoice.com/CenceWeb/CenceDescargaArchivos.jsf?init=true&categoria=3&codigoTipoArchivo=3008

[10] "Plan de expansión de la transmisión 2014 – 2025", Instituto Costarricense de Electricidad, 2015

[11] "Plan de expansion de la generación eléctrica. Periodo 2014-2035", Instituto Costarricense de Electricidad, 2014.

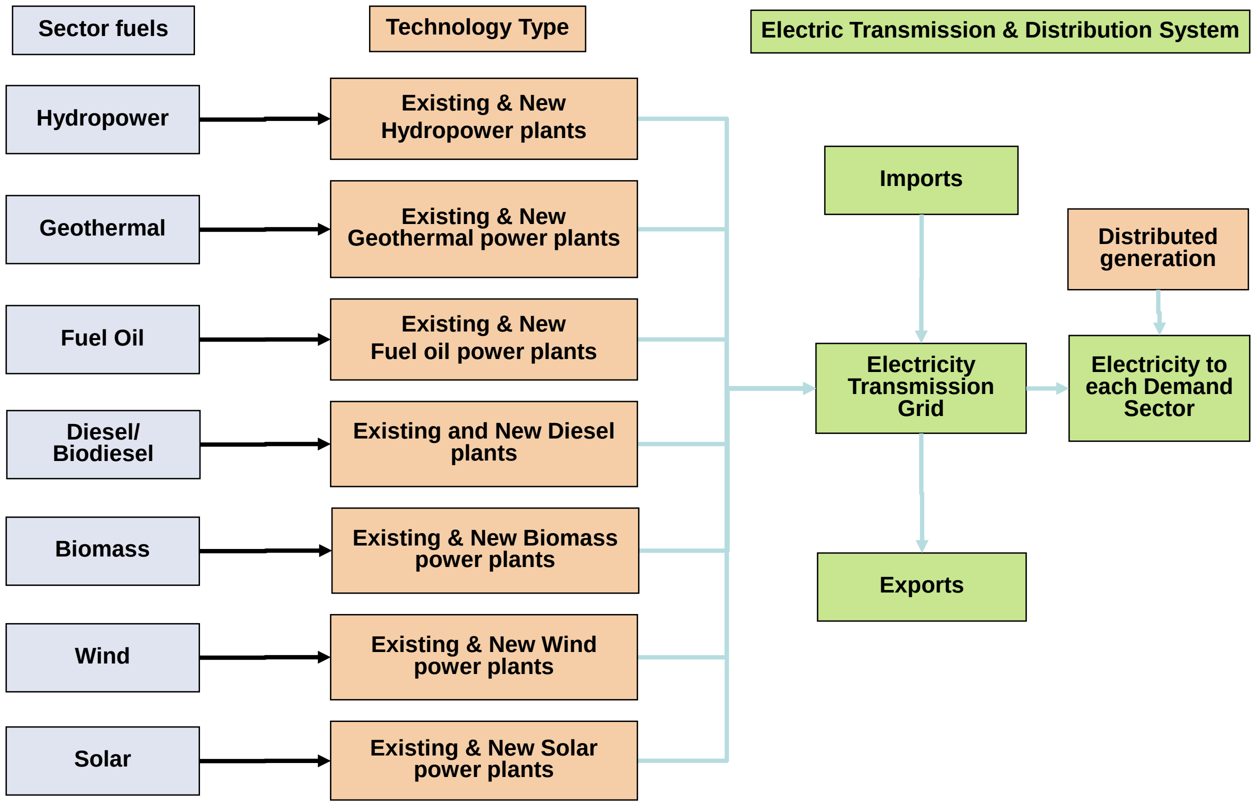


Figure 12: Power Sector RES

Table 14 : List of TIMES-CR Power Plants

Fuel Type	Technology Type	2015 Installed Capacity (GW)	2050 New Capacity Limits (GW)
Biogases	Engine/Reciprocating	0	0.05
Biogases	Gas turbine	0	0.05
Biogases	Steam turbine	0	0.01
Bagasse	Steam turbine	0.04	0.25
Other organic residues	Steam Turbine	0	0.1
Hydro	Regulating	0.363	0.5
Hydro	Dam	0.324	0.65
Hydro	Run-of-River	1.248	0.75
Hydro	Run-of-River Generic	0	0.5
Geothermal	Steam Turbine	0.217	0.25
Geothermal Generic	Steam Turbine	0	0.45
Wind	On-shore	0.278	0.15
Wind Generic	On-shore	0	1.00
Thermal/Diesel	Reciprocating engine	0.024	0.09
Thermal/Diesel	Gas turbine	0.344	0.27
Thermal/Coal	Steam turbine	0	0.00
Thermal/Fuel Oil	Reciprocating engine	0.227	0.30
Thermal/gas	Gas turbine	0	0.00
Solar	Photovoltaic	0.001	0.10

Solar Generic	Photovoltaic	0	0.50
Solar RSD Bldg	Photovoltaic	0	0.10
Solar COM Bldg	Photovoltaic	0	0.10

Electricity production and consumption are modelled at the time slice level to properly account for baseload, intermediate and peaking capacity requirements. All electricity demands are apportioned according to the season and day time slices when the demands occur, and electricity generation for solar, wind, and hydropower are apportioned according to the season and day time slices where the production occurs.

4.2.5 Demand Sectors Summaries

There are five (5) main demand sectors broken out in TIMES-CR: Agriculture, Commercial, Industry, Residential and Transportation. Each sector is further divided into the main end-use services essential to meet these demands. A non-energy/other sector is also defined to complete the full mapping of the 2015 energy balance. As with the Supply and Power sectors, the specific data sources used to develop each sector are identified in the BY, NT and UC model input data templates for each sector.

The following sections describe the basic RES structure of each demand sector, including the fuels, technologies and end-use services provided. A decomposition approach, as documented in each BY template, was used to move from the final energy consumed by each sector as reported in the energy balance to the device level characteristic needed to meet the end-use service demands.

4.2.5.1 Agriculture

The Agriculture sector consists of three end-use services as shown in Figure 13. Diesel, gasoline and electricity are the key energy carriers supplied to the sector, and both biodiesel and biogasoline are made available to the sector as blended fuels with diesel and gasoline for possible use in the future. The other energy carriers are largely used for other services. There are over 30 technologies that describe the Existing technologies, along with Standard and Improved quality new technology options[12].

[12] "Balance Energético Nacional de Costa Rica 2015". Dirección Sectorial de Energía, 2015.

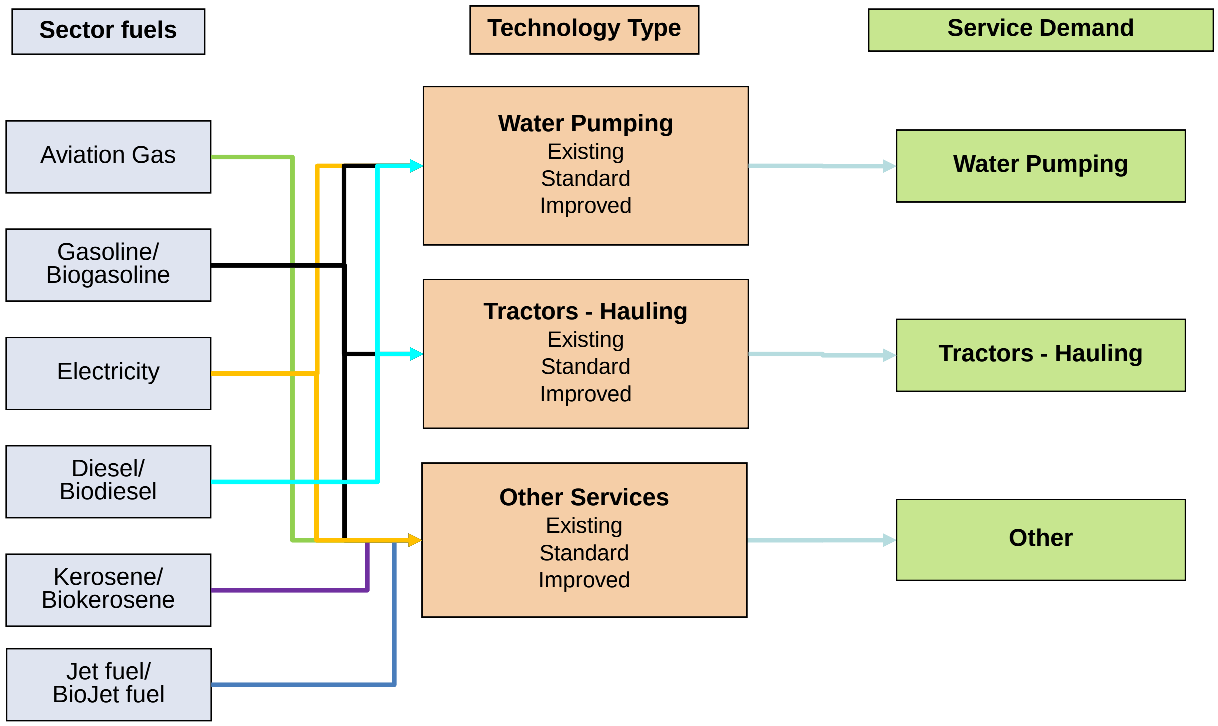


Figure 13: Agriculture Sector RES

4.2.5.2 Commercial

The Commercial sector consists of eight services demands, as shown in Figure 14. A variety of energy carriers are used in the sector, but electricity is by far the most dominant. As with the other demand sectors, the Existing technology characteristics were derived through the Energy Balance decomposition approach that used data on fuel breakdown shares from surveys provided by the Dirección Sectorial de Energía (DSE by its Spanish acronym)[13].

The Commercial sector contains a large suite of new technology options for each service demand that represent Standard, Improved, Better and Advanced quality options based on USDOE and IEA data. Biodiesel and biogasoline are also available through mixing of these fuels with conventional diesel and gasoline. Distributed PV systems provide electricity directly to the sector (for internal consumption, avoiding loses) as well as feeding any excess electricity to the grid. Finally, building efficiency retrofit options are available that reduce building energy consumption – primarily for cooling, lighting and water heating.

[13] "Encuesta de consumo energético nacional en el sector comercio y servicios privados. Año 2014". Ministerio De Ambiente y Energía, Dirección Sectorial de Energía, 2014.

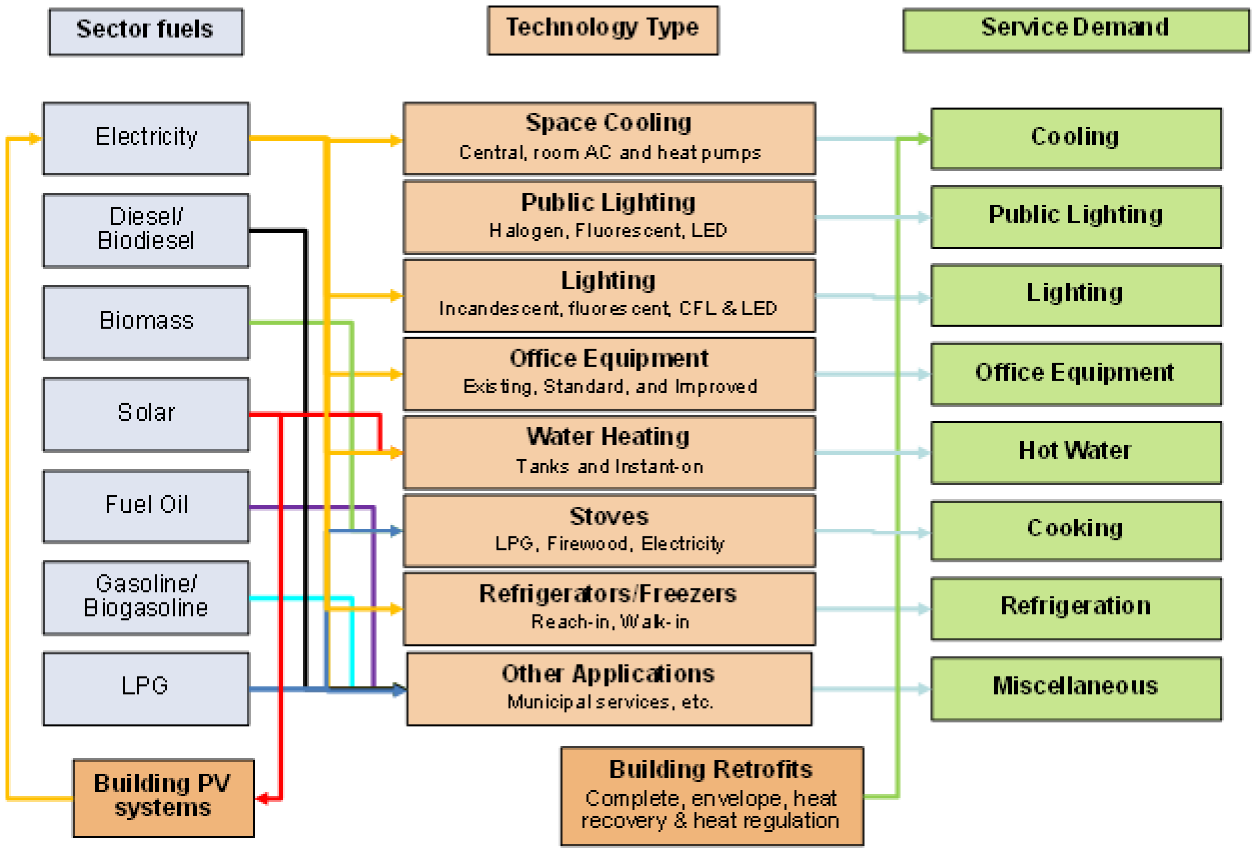


Figure 14: Commercial Sector RES

4.2.5.3 Industry

The Industry sector is comprised of six industrial subsectors as shown in Figure 15, which are the five top energy consumers in the sector, with an Other subsector representing the various smaller industries (including Cement). The industrial sector is not able to be modelled at the process level due to the wide variations in many industrial process line details and due to the lack of data resulting from concerns over proprietary information. Instead, each subsector is served by four (4) main energy services: process heat, machine drive, facilities/other, and steam needed to produce their output products. The initial shares for these components of the subsector energy demand were developed through the Energy Balance decomposition approach, as informed by a recent survey on industrial energy use[14].

The Industry sector is characterized by a wide range of fuel and energy types that can provide the four component energy services. Biomass fuels include bagasse, coffee husk, firewood, and other organic residues. Biogas is also available as an aggregate from several sources. Auto-generation is already occurring in the Pulp and Paper and Food and Tobacco subsectors, and co-generation is a future option in these subsectors. As with the other demand sectors, biodiesel and

[14] "Encuesta de consumo energético nacional en el sector industrial 2014", Ministerio de Ambiente y Energía, Dirección Sectorial de Energía, 2014.

biogasoline are available through mixing of these fuels with conventional diesel and gasoline. For the Industry sector, only Standard and Improved technology quality levels are used.

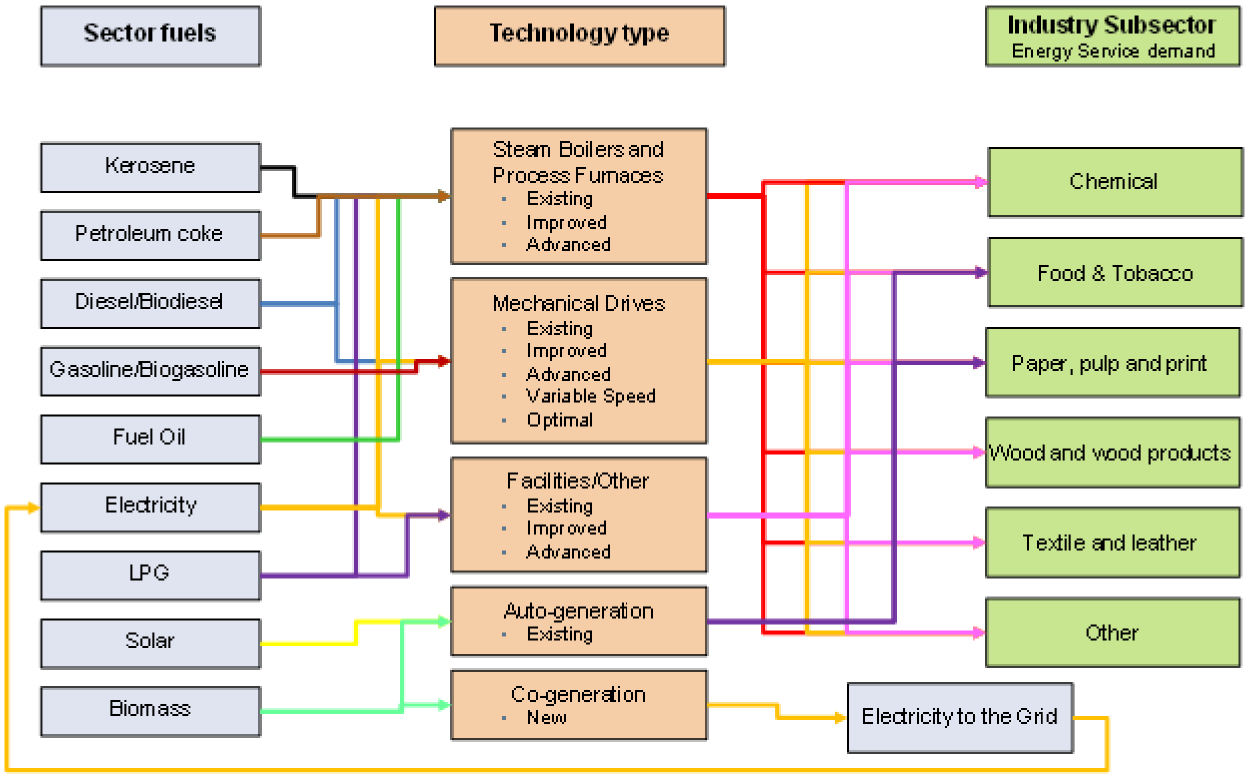


Figure 15: Industry Sector RES

4.2.5.4 Residential

The Residential sector consists of six end-use service demands as shown in Figure 16. Although a variety of energy carriers are used in this sector, electricity is by far the most dominant one, followed by important contributions from firewood and LPG. As with the other demand sectors, the existing technology characteristics were derived through the energy balance decomposition approach that used data on fuel breakdown shares from surveys provided by DSE[15].

TIMES-CR contains a large suite of new technology options for each service demand that represent Standard, Improved, Better and Advanced options based on USDOE and IEA data. Biodiesel and biogasoline are available through mixing of these fuels with conventional diesel and gasoline. Distributed PV systems provide electricity directly to the sector (for internal consumption, avoiding grid losses) as well as feeding any excess electricity to the grid. Finally, building efficiency retrofit options are available that reduce building energy consumption – primarily for cooling, lighting and water heating.

[15] "Encuesta de consumo energético nacional en el sector residencial de Costa Rica, año 2012". Ministerio de Ambiente y Energía, Dirección Sectorial de Energía, 2012.

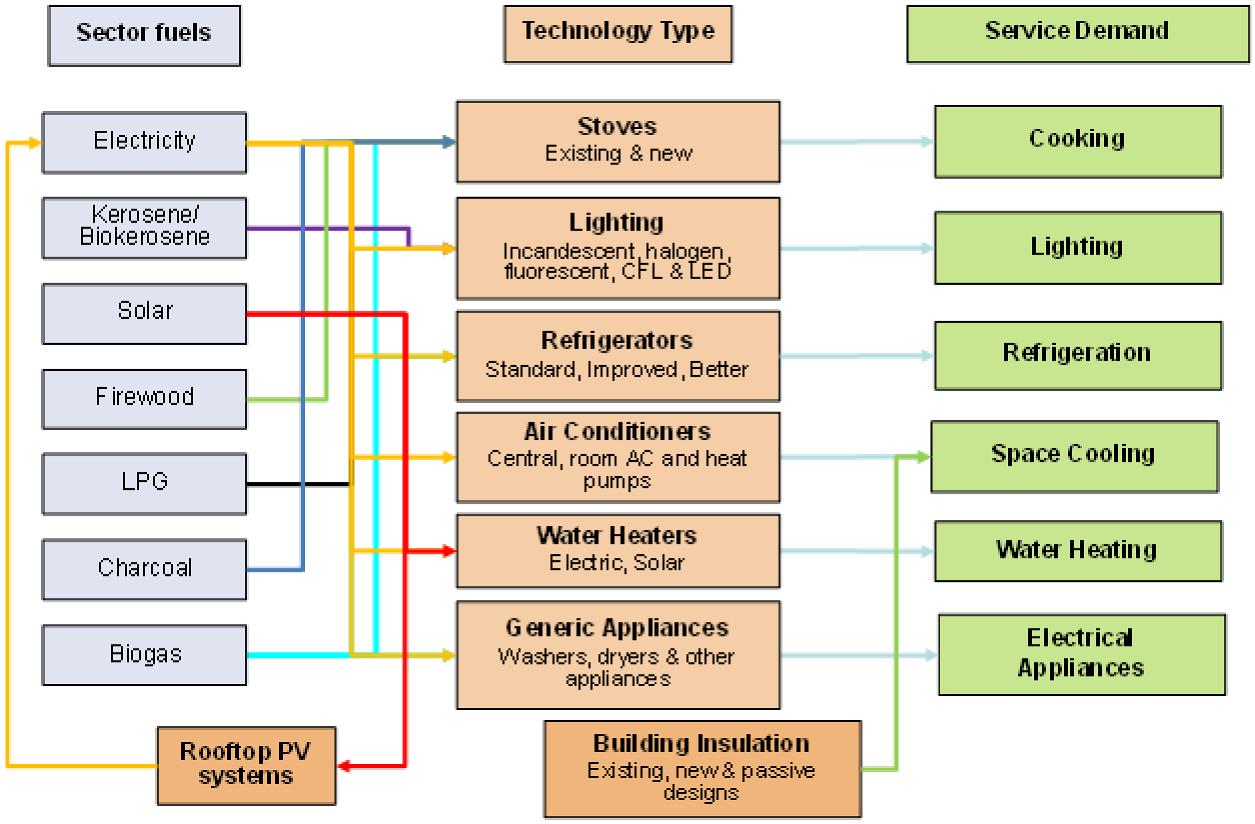


Figure 16: Residential Sector RES

4.2.5.5 Transport

The Transport sector consists of the various transport modes, including road, rail, ship and airplane, as well as covering both passenger and freight transport demands[16]. Figure 17 shows the RES for all forms of passenger transport, which are split into seven mode types, each with a specific service demand. Light Duty Vehicles (LDV, for personal use) and Taxis are disaggregated into seven classes ranging from mini-compacts to large Sport Utility Vehicles (SUV). The alignment of vehicle type found in the Costa Rica data sources[17] with the vehicle categories found in the USEPA data base was determined by the AT using local knowledge of the situation, providing an accurate representation of the vehicle fleet composition today.

In addition to conventional vehicles, the model contains Flex-fuel, Hybrid and Plug-in (all electric and plug-in-hybrid) new technology options for both LDVs and Taxis. Buses and Mini-buses also have Hybrid and Plug-in vehicle options, while Motorcycles have only conventional and electric options. Passenger rail demand is divided into commuter and intercity.

[16] "Encuesta de consumo energético nacional en el Sector Transporte (Julio – Noviembre 2013)". Ministerio de Ambiente y Energía, Dirección Sectorial de Energía, 2013.
[17] "Plan nacional de transportes de Costa Rica 2011-2035". Ministerio de Obras Públicas y Transportes (MOPT), 2011.

Note that while the other sector demands are expressed in energy units (PJ), the passenger transport demands are expressed as million passenger kilometers (mpkm), and the vehicle data includes the average passengers per vehicle[18] so that energy demand is calculated properly within each mode.

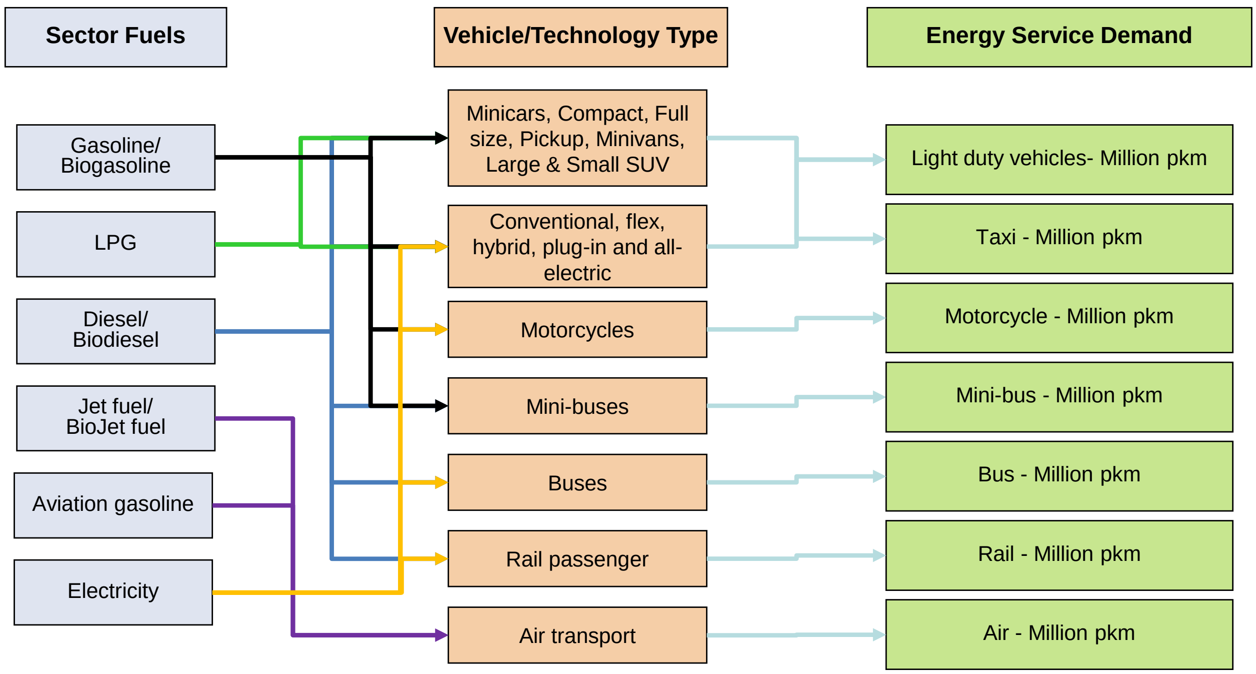


Figure 17: Passenger Transportation Modes

Figure 18 shows the RES for all forms of freight transport, which are divided into five mode types with a specific service demand. The three truck types consist of existing vehicle types and new technology options including Conventional, Hybrid, Improved and Advanced vehicles. Freight transport demands (with the exception of Off-road) are expressed as million metric ton kilometers (mtkm), and the vehicle data includes the average load per vehicle so that energy demand is calculated properly within each mode. Off-road demands are modelled in PJ and no advanced technology options are included for this small demand category.

Vehicle registration data was used to determine the initial splits of LDVs and Taxis into the different size classes, and this data was also used to determine the base year fuel splits between diesel, gasoline, LPG, etc. for the various road vehicles, including motorcycles, LDVs, buses and the three truck types.

[18]"Línea base de GEI para el sector de transporte de la GAM de San José, Costa Rica". Grutter Consulting, 2016.

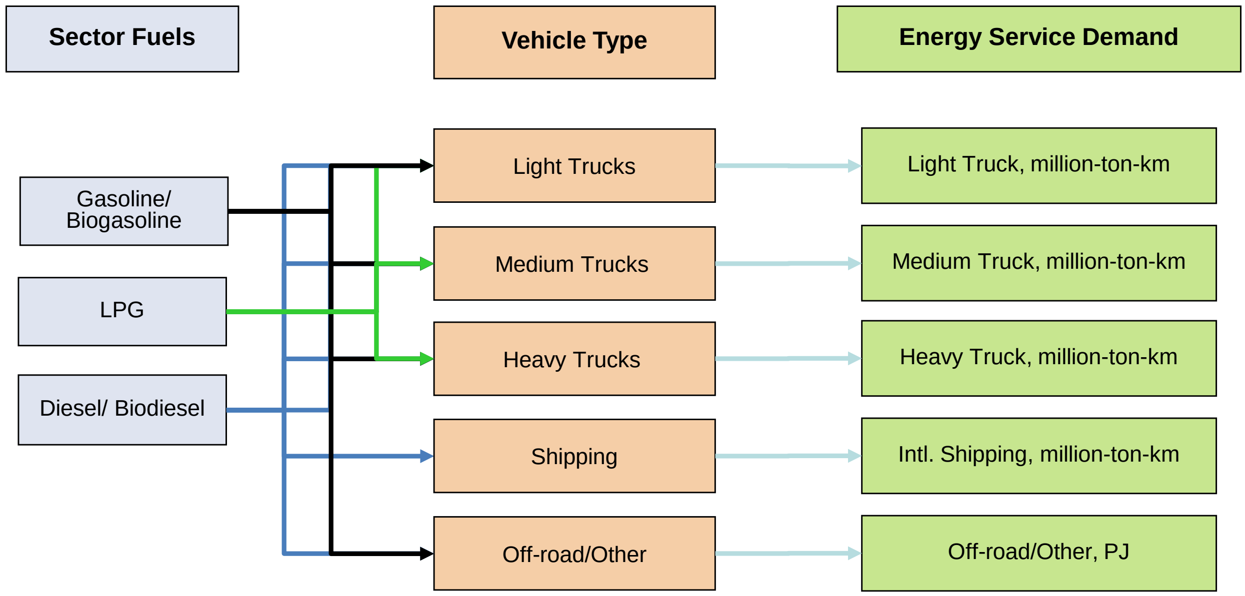


Figure 18: RES for Freight Transport Modes

Note that the model has no existing rail freight option, as none currently exists in Costa Rica. However, a large shipping port complex is under development, and a rail freight line is a possible follow-on to this development project[19] [20]. Following review of the data from MOPT regarding future expansion plans at all the major shipping ports, all the other proposed infrastructure projects necessary to accommodate the projected shipping demand increases over time were included, and the associated increases in demand were incorporated in the transport demand projections, which are tied to the projected future GDP per capita increases.

4.2.6 End-use Service Demand Projections

As noted at the beginning of this chapter, the TIMES-CR model solves for the mix of resources and technologies (on both the supply and demand sides) that satisfy the projected demands for useful energy services at the least-cost, considering any additional technical and policy constraints placed on the model. The projected demands for the five main demand sectors: Agriculture, Commercial, Industry, Residential and Transportation are calculated for each end-use service demand using the base year value, determined by the energy balance decomposition and calibration process, and appropriate drivers of service demand growth. The primary demand drivers, which are shown in Table 15, include GDP growth[21], population growth[22], GDP per capita growth, and the number of persons per household. There are secondary drivers for each demand sector, such as the elasticity of energy use to GDP growth, and industrial production

[19] "Plan de acción de la Estrategia Nacional de Cambio Climático (ENCC). Hacia un modelo de desarrollo bajo en emisiones carbono y resiliente al CC". Ministerio de Ambiente y Energía, Dirección Sectorial de Energía y EPYPSA, Sin año .
[20] "Plan Nacional en Logística de Cargas – PNLog Costa Rica 2014 – 2024". BID, 2014.
[21] Data received directly from the Banco Central de Costa Rica (BCCR).
[22] "Costa Rica: Población total por años quinquenales, según sexo, grupos especiales de edades y edades simples Proyecciones nacional.". Instituto Nacional de Estadística y Censos – INEC.

projections, along with market penetration rates for space cooling, refrigeration and electric appliances.

Table 15: Primary Demand Drivers

Demand Drivers	2015	2018	2021	2024	2027	2030	2035	2040	2045	2050
GDP (Million 2012 $US)	47,932	54,087	60,656	68,033	76,307	85,588	103,631	125,478	151,931	183,960
Population (1000 persons)	4832	5003	5163	5309	5443	5564	5742	5893	6010	6093
Number of persons per household	3.30	3.24	3.18	3.12	3.06	3.00	2.91	2.82	2.73	2.65
GDP growth	4.72%	4.11%	3.89%	3.90%	3.90%	3.90%	3.90%	3.90%	3.90%	3.90%
Population growth		1.17%	1.05%	0.94%	0.83%	0.73%	0.63%	0.52%	0.39%	0.28%
GDP/pop growth		2.91%	2.81%	2.93%	3.04%	3.14%	3.25%	3.36%	3.49%	3.61%
Persons per household growth	-0.62%	-0.62%	-0.62%	-0.62%	-0.62%	-0.62%	-0.62%	-0.62%	-0.62%	-0.62%

Table 16 provides the elasticity values by sector along with other sector-specific drivers. For the Agricultural and Commercial sectors, the elasticity of energy use to GDP growth was based on local expert judgment and data from modeling efforts in other countries. The share of buildings with space cooling is assumed to increase from 53.4% in 2015 to almost 96% by 2050. For the Industry sector, because it is much more country-specific than the other sectors, and because data was available from BCCR, elasticity values were derived from Industrial subsector GDP contributions for the period from 1991 to 2014. The Residential and Transport sectors use the elasticity of energy use to GDP per capita growth, and the elasticity values were also based on local expert judgment and data from modeling efforts in other countries. Based on the 2012 survey data[23], households with space cooling are assumed to increase from 2% in 2015 to 38% in 2050, refrigerators grow from 98% in 2015 to 100% by 2021, and electric appliances, such as washers and dryers, are assumed to increase from 34% in 2015 to 56% in 2050.

Table 16: Elasticities of Energy Demand to GDP or GDP/capita

AGRICULTURE	2018	2021	2024	2027	2030	2035	2040	2045	2050
Water Pumping	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Tractors - Hauling	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Other Use	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5

[23]"Encuesta de consumo energético nacional en el sector residencial de Costa Rica, año 2012". Ministerio de Ambiente y Energía, Dirección Sectorial de Energía, 2012.

COMMERCIAL	2018	2021	2024	2027	2030	2035	2040	2045	2050
Water Heating	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Space Cooling	1	1	0.8	0.7	0.6	0.5	0.5	0.5	0.5
Increase in buildings with Space Cooling	4.0%	3.0%	2.0%	2.0%	2.0%	1.0%	1.0%	1.0%	1.0%
Share of Buildings with Cooling (53.4% in 2015)	60.1%	65.6%	69.7%	73.9%	78.4%	82.4%	86.6%	91.1%	95.7%
Cooking	1.0	1.0	0.9	0.7	0.4	0.4	0.3	0.3	0.3
Lighting	1.0	1.0	0.9	0.7	0.4	0.4	0.3	0.3	0.3
Refrigeration	1	1	0.8	0.7	0.6	0.5	0.5	0.5	0.5
Office Equipment	1	1	0.8	0.7	0.6	0.5	0.5	0.5	0.5
Public Lighting	1	1	0.8	0.7	0.6	0.5	0.5	0.5	0.5
Misc. Electricity	1	1	0.8	0.7	0.6	0.5	0.5	0.5	0.5
Misc. Energy	1	1	0.8	0.7	0.6	0.5	0.5	0.5	0.5

INDUSTRY	2018	2021	2024	2027	2030	2035	2040	2045	2050
Chemical and petrochemical	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
Food and tobacco	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Paper, pulp and print	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Wood and wood products	1.50	1.50	1.50	1.25	1.25	1.00	1.00	1.00	1.00
Textile and leather	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Other	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80

RESIDENTIAL	2018	2021	2024	2027	2030	2035	2040	2045	2050
Water heating	1	1	1	0.8	0.6	0.4	0.2	0.2	0.2
Space Cooling	0.40	0.40	0.40	0.40	0.35	0.35	0.35	0.30	0.30
Increase in households with Space Cooling	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%
Share of dwellings with Cooling (30% in 2015)	34%	38%	42%	46%	50%	54%	58%	62%	66%
Cooking	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Refrigeration	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Lighting	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
ELC Appliances	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Refrigeration increase rate	2.04%	2.07%	2.09%	2.09%	2.09%	2.09%	2.09%	2.09%	2.09%
Households with Refrigeration (50% in 2015)	52%	54%	56%	58%	60%	62%	64%	66%	68%
Lighting increase rate	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Households with Lighting (100% in 2015)	100%	100%	100%	100%	100%	100%	100%	100%	100%
ELC Appliances increase rate	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%
Households with ELC Appliances (50% in 2015)	52.5%	55%	57.5%	60%	62.5%	65%	67.5%	70%	72.5%

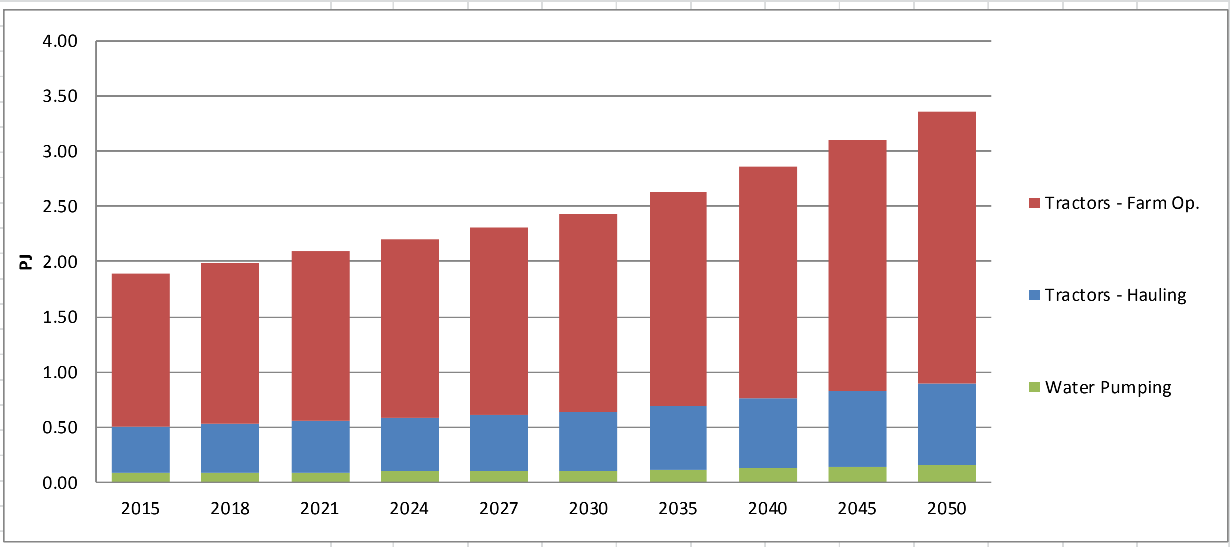
PASSENGER TRANSPORT	2018	2021	2024	2027	2030	2035	2040	2045	2050
Light Duty Vehicles	1	1	0.9	0.8	0.7	0.6	0.5	0.5	0.5

Buses	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Air	0.8	0.8	0.7	0.7	0.6	0.6	0.5	0.5	0.5
Passenger rail	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Mini Buses	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Taxis	1	1	0.9	0.8	0.7	0.6	0.5	0.5	0.5
Motorcycles	1	1	0.9	0.8	0.7	0.6	0.5	0.5	0.5

FREIGHT TRANSPORT	**2018**	**2021**	**2024**	**2027**	**2030**	**2035**	**2040**	**2045**	**2050**
Light Weight Trucks	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6
Medium and Heavy Weight Trucks	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5
Rail - Freight	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64
Ship	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Off-road	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5

NON-ENERGY/OTHER	**2018**	**2021**	**2024**	**2027**	**2030**	**2035**	**2040**	**2045**	**2050**
Non-specified (other)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Non-energy use	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5

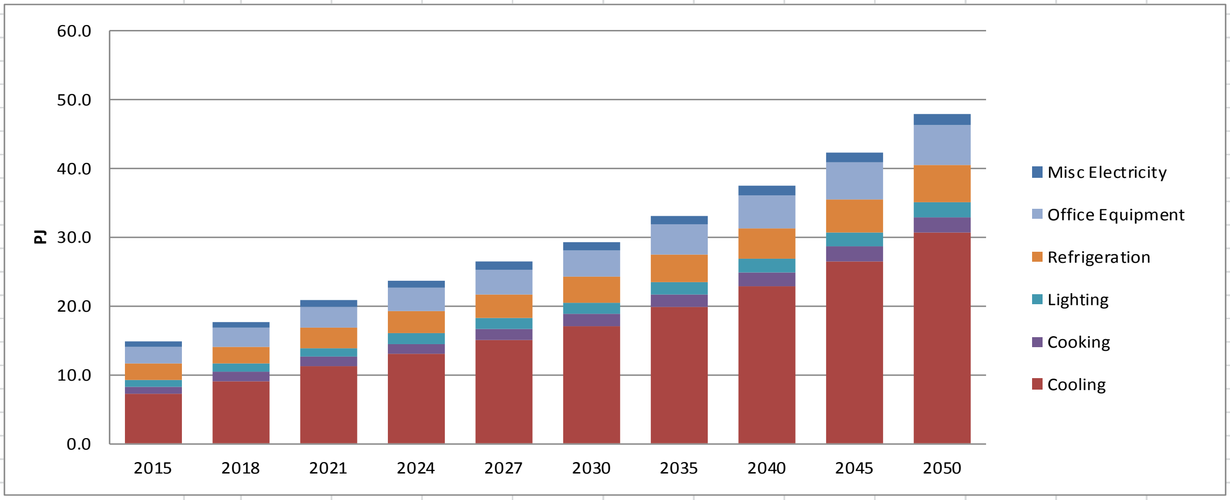
For the Agriculture and Industry sectors, an autonomous efficiency improvement factor was used to account for the general process improvements that happen over time. The current values, based on international experience, are 0.3% per year for Agriculture and 0.1% per year for Industry. The resulting useful energy demands are shown by sector in Figure 19 through Figure 25.



Agriculture Useful Energy Demand

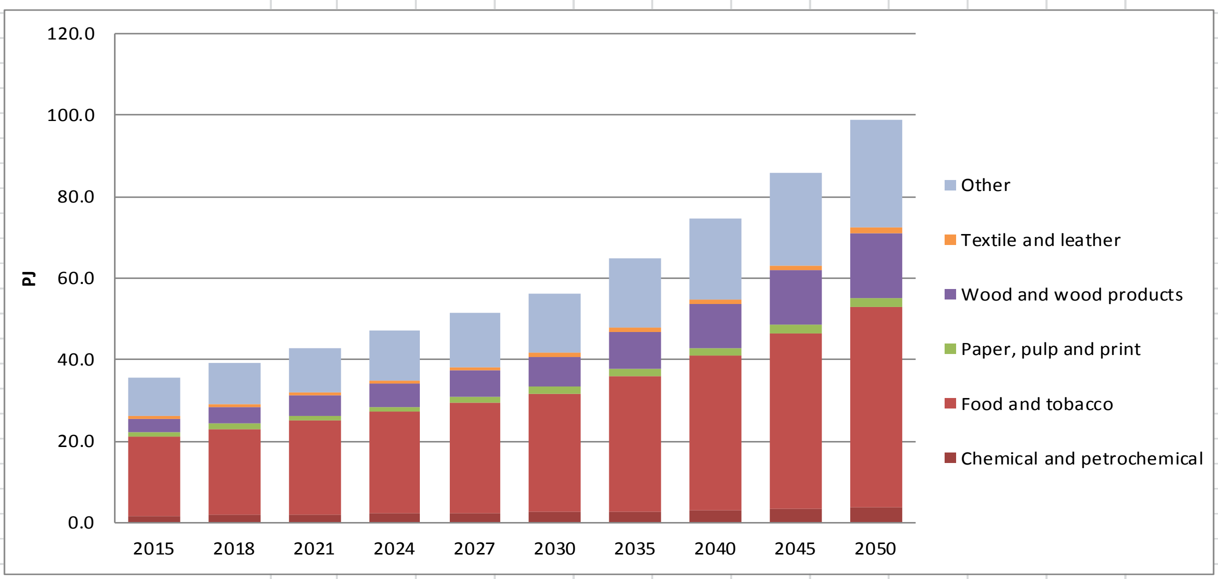
	Unit	2015	2018	2021	2024	2027	2030	2035	2040	2045	2050	Growth
Water Pumping	PJ	0.08	0.09	0.09	0.10	0.10	0.11	0.12	0.13	0.14	0.15	78%
Tractors - Hauling	PJ	0.42	0.44	0.46	0.49	0.51	0.54	0.58	0.63	0.69	0.74	78%
Tractors - Farm Op.	PJ	1.39	1.46	1.53	1.61	1.69	1.78	1.93	2.09	2.27	2.47	78%
Total		**1.89**	**1.99**	**2.09**	**2.20**	**2.31**	**2.42**	**2.63**	**2.85**	**3.10**	**3.36**	78%

Figure 19: Agricultural Sector Useful Energy Demand



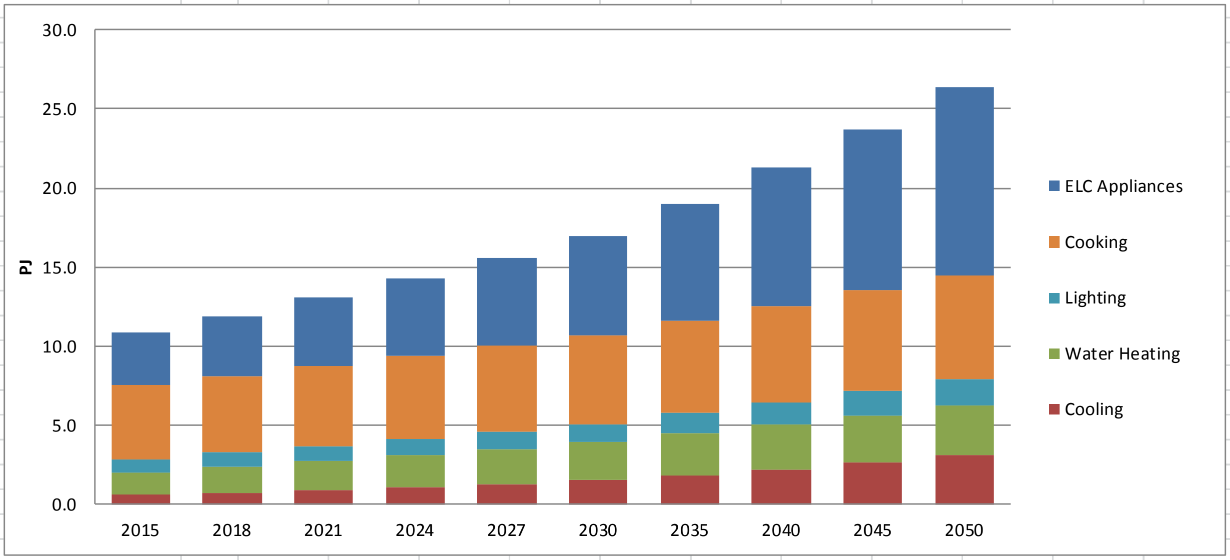
Commercial Useful Energy Demand												
	Unit	**2015**	**2018**	**2021**	**2024**	**2027**	**2030**	**2035**	**2040**	**2045**	**2050**	**Growth**
Heating	PJ	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	n/a
Cooling	PJ	7.22	9.17	11.23	13.07	15.04	17.11	19.80	22.92	26.53	30.71	325%
Water Heating	PJ	0.17	0.18	0.19	0.20	0.21	0.23	0.25	0.27	0.30	0.33	97%
Cooking	PJ	1.07	1.21	1.36	1.50	1.63	1.71	1.85	1.96	2.07	2.20	105%
Lighting	PJ	1.07	1.21	1.36	1.50	1.63	1.71	1.85	1.96	2.07	2.20	105%
Refrigeration	PJ	2.28	2.57	2.89	3.17	3.43	3.68	4.05	4.46	4.91	5.41	137%
Office Equipment	PJ	2.42	2.73	3.06	3.36	3.64	3.91	4.30	4.74	5.22	5.75	137%
Public Lighting	PJ	1.41	1.59	1.78	1.95	2.12	2.27	2.50	2.75	3.03	3.34	137%
Misc Electricity	PJ	0.73	0.83	0.93	1.02	1.10	1.18	1.30	1.44	1.58	1.74	137%
Total		**16.38**	**19.49**	**22.79**	**25.78**	**28.81**	**31.78**	**35.89**	**40.49**	**45.72**	**51.68**	**216%**

Figure 20: Commercial Sector Useful Energy Demand



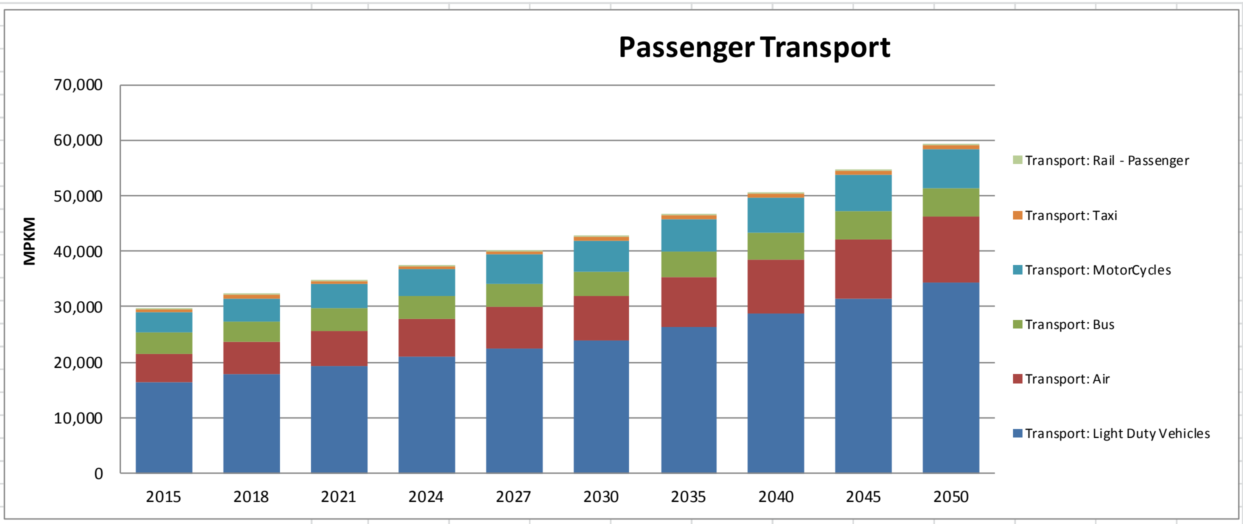
Industrial Useful Energy Demand												
	Unit	**2015**	**2018**	**2021**	**2024**	**2027**	**2030**	**2035**	**2040**	**2045**	**2050**	**Growth**
Chemical and petrochemical	PJ	1.78	1.91	2.06	2.21	2.36	2.52	2.82	3.15	3.52	3.93	121%
Food and tobacco	PJ	19.36	21.10	22.95	24.91	26.99	29.17	33.22	37.82	43.06	49.03	153%
Paper, pulp and print	PJ	1.17	1.24	1.32	1.40	1.48	1.56	1.71	1.88	2.06	2.26	93%
Wood and wood products	PJ	3.31	3.98	4.76	5.68	6.56	7.54	9.09	10.95	13.20	15.90	381%
Textile and leather	PJ	0.65	0.69	0.73	0.77	0.82	0.86	0.95	1.04	1.14	1.25	93%
Other	PJ	9.18	10.13	11.15	12.25	13.42	14.68	17.03	19.76	22.93	26.61	190%
Total		**35.44**	**39.05**	**42.97**	**47.22**	**51.63**	**56.34**	**64.82**	**74.60**	**85.91**	**98.98**	**179%**

Figure 21: Industry Sector Useful Energy Demand



Residential Useful Energy Demand												
	Unit	**2015**	**2018**	**2021**	**2024**	**2027**	**2030**	**2035**	**2040**	**2045**	**2050**	**Growth**
Cooling	PJ	0.61	0.75	0.91	1.10	1.30	1.52	1.85	2.23	2.65	3.11	412%
Water Heating	PJ	1.42	1.61	1.80	2.02	2.23	2.41	2.65	2.81	2.97	3.12	119%
Lighting	PJ	0.85	0.91	0.97	1.03	1.10	1.16	1.28	1.40	1.53	1.67	98%
Cooking	PJ	4.65	4.86	5.06	5.25	5.43	5.60	5.88	6.13	6.36	6.57	41%
ELC Appliances	PJ	3.33	3.81	4.33	4.91	5.54	6.24	7.38	8.69	10.19	11.91	258%
Total		**12.70**	**14.03**	**15.44**	**16.96**	**18.58**	**20.28**	**22.96**	**25.87**	**29.09**	**32.65**	**157%**

Figure 22: Residential Sector Useful Energy Demand

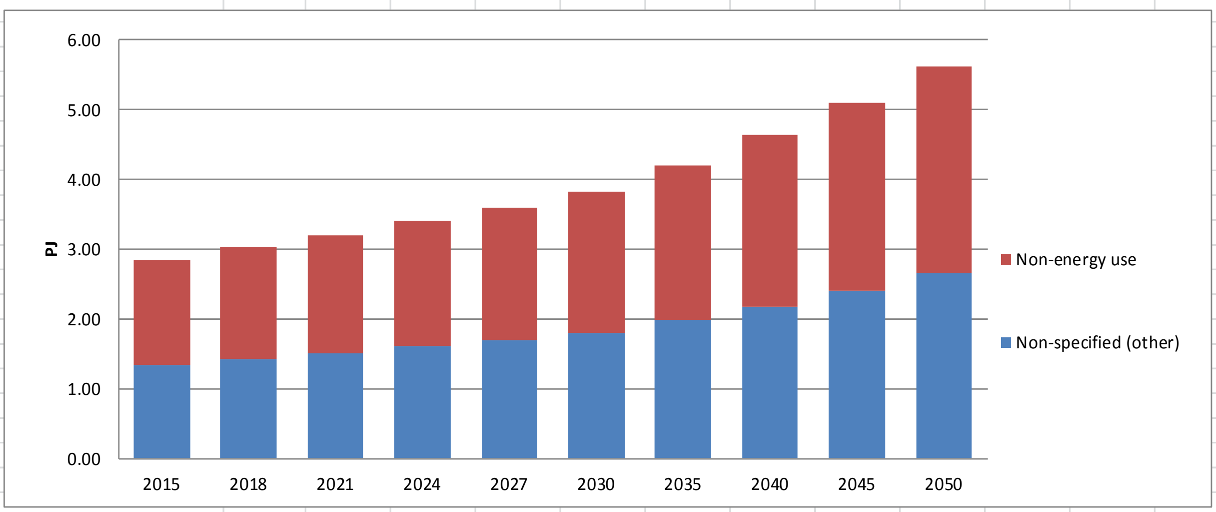


Passenger Transport Useful Energy Demand												
	Unit	**2015**	**2018**	**2021**	**2024**	**2027**	**2030**	**2035**	**2040**	**2045**	**2050**	**Growth**
Transport: Light Duty Vehicles	Mpkm	16,354	17,823	19,370	20,946	22,513	24,032	26,466	28,768	31,369	34,306	110%
Transport: Air	Mpkm	5,209	5,739	6,293	6,822	7,397	7,928	8,900	9,802	10,796	11,890	128%
Transport: Bus	Mpkm	3,742	3,859	3,973	4,090	4,211	4,335	4,551	4,777	5,014	5,264	41%
Transport: MotorCycles	Mpkm	3,799	4,140	4,499	4,865	5,229	5,582	5,915	6,218	6,550	6,911	82%
Transport: Taxi	Mpkm	467	509	553	598	642	686	727	764	805	849	82%
Transport: Rail - Passenger	Mpkm	40	43	45	48	51	54	59	65	72	79	97%
Total		**29,611**	**32,112**	**34,732**	**37,369**	**40,043**	**42,617**	**46,617**	**50,394**	**54,605**	**59,300**	**152%**

Figure 23: Passenger Transport Useful Energy Demand

Freight Transport Useful Energy Demand												
		2015	**2018**	**2021**	**2024**	**2027**	**2030**	**2035**	**2040**	**2045**	**2050**	**Growth**
Transport: Light Weight Trucks	Mtkm	4,011	4,420	4,846	5,314	5,761	6,246	7,147	8,023	9,007	10,111	152%
Transport: Medium and Heavy Weight Trucks	Mtkm	13,356	14,542	15,764	17,091	18,319	19,635	22,043	24,277	26,738	29,449	120%
Transport: Ship	Mtkm	280	298	316	335	355	376	414	456	502	553	97%
Transport: Off-road	PJ	2	2	3	3	3	3	3	4	4	4	97%
Total		**17,650**	**19,262**	**20,929**	**22,742**	**24,438**	**26,260**	**29,606**	**32,759**	**36,251**	**40,117**	**110%**

Figure 24: Freight Transport Useful Energy Demand



Non-Energy Demand												
	Unit	**2015**	**2018**	**2021**	**2024**	**2027**	**2030**	**2035**	**2040**	**2045**	**2050**	**Growth**
Non-specified (other)	PJ	1.35	1.43	1.52	1.61	1.70	1.80	1.99	2.19	2.41	2.65	97%
Non-energy use	PJ	1.51	1.60	1.70	1.80	1.90	2.02	2.22	2.45	2.70	2.97	97%
Total		**2.85**	**3.03**	**3.21**	**3.40**	**3.61**	**3.82**	**4.21**	**4.64**	**5.10**	**5.62**	**97%**

Figure 25: Non Energy/Other Energy Demand

4.3 TIMES-CR Database

The TIMES-CR model database consists of a set of Excel workbooks that comprise the source input files that are read into the ANSWER-TIMES model management software. ANSWER assembles the data templates as scenarios into a single Microsoft Access database (MDB). The organization of the workbooks and components of the database are described in detail in Appendix A.

5 Baseline Scenario

5.1 Base Year Calibration

The calibration tables found in each of the sector base year workbooks and the *CalibrationCheck_REF* workbook (see Appendix A.8.1) are used to ensure that the 1^{st} year of the model properly aligns with the 2015 Energy Balance. The calibration sheet in each base year workbook sets up the 1^{st} year energy and technology details as summarized in Section 3, and determines the 1^{st} year demand for energy services by applying the efficiency and utilization factor of each demand device to the final energy leveled assigned to it as part of the decomposition process. The Calibration Check workbook compares the final energy consumption values generated by the model against the Energy Balance input data and identifies any values that do not match. The Calibration workbook also checks that the base year primary energy supplies and electricity generation match with the Energy Balance and ICE data. This process ensures that model reproduces the base year energy supply data based upon the final energy values determined from the useful energy demand, process efficiencies, and initial capacity values.

5.2 Baseline Scenario

The Baseline scenario is intended to represent a business-as-usual projection of the Costa Rica energy system based on the continuation of current practices and no new policy implementation. The input data and resulting configuration of the energy system has been through several rounds of review with the AT. The main sources for the model data and assumption were mentioned in Section 3, and the full set of data sources can be found in the individual model input templates.

The Baseline scenario serves as the point of comparison for how the various policy and mitigation measures scenarios impact the energy system cost, technology make-up, fuel use, etc. This section summarizes the Baseline scenario.

5.2.1 Baseline Scenario Guidance

Because the Baseline scenario is intended to represent a business-as-usual projection of the energy system some constraints on the rates of change allowed are needed. Historical experience in many countries indicates that without new policies, no major changes or shifts are expected in fuel use, technology types and the adoption rate of high-efficiency technology. Therefore, the TIMES-CR Baseline scenario constrains some resource supplies; imposes the ICE expansion plan until 2027, so that the large regulated dam planned in that year (Diquis) is always built; limits the build rates for solar and wind power plants; and uses multiple user constraints that help guide the Baseline scenario by limiting the allowed rate of fuel switching, and technology change. These Baseline scenario constraints include:

- Fuel share constraints limit the allowed rate of fuel switching in each sector and end-use application, where the base year fuels shares are allowed to relax by 10% by 2050;
- Technology type share constraints limit the allowed rate of technology change within each end-use application, where the base year technology type shares are allowed to relax by 10% by 2050, and
- Technology quality share constraints limit the allowed rate of update of Improved, Better and Advanced technologies within each sector, where the Baseline scenario allows new technologies to consist of up to 30% Improved, 20% Better and 10% Advanced devices.

In many of the policy scenarios, these share constraints are relaxed to allow for more fuel switching, more realigning of the technology types, and more rapid uptake of higher quality technologies.

5.2.2 Primary Energy Supply

As shown in Figure 26, there are three key categories of primary energy used in Costa Rica:

- Oil products – mainly fuel oil, diesel, gasoline, jet fuel, kerosene, aviation gas and petroleum coke;
- Biofuels – mainly bagasse, coffee husk, fuelwood, biogases and other organic residues, and
- Renewables – mainly hydropower, geothermal, solar and wind.

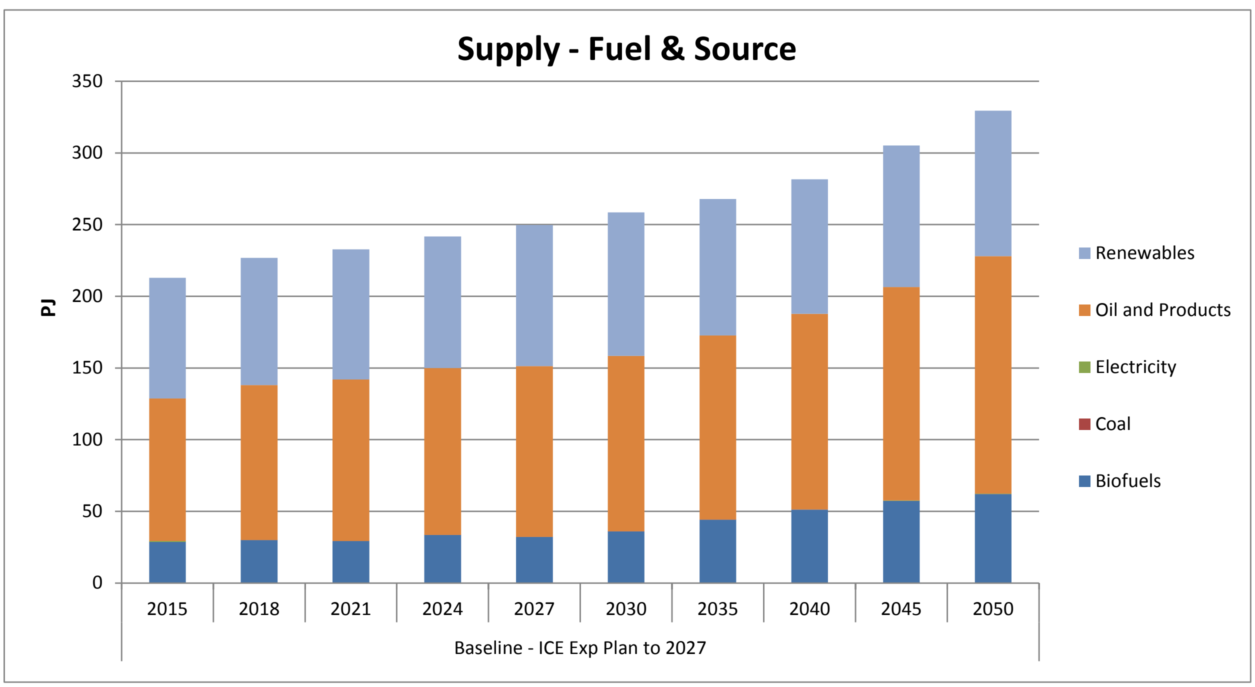


Figure 26: Baseline Primary Energy Supply

Table 17 provides a detailed breakdown of primary energy supply by energy type for the Baseline scenario.

Table 17: Baseline Primary Energy Detail (PJ)

Energy Type	2015	2018	2021	2024	2027	2030	2035	2040	2045	2050
Electricity Imports	0.58							0.04	0.24	0.31
Aviation Gasoline	0.05	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.13	0.14
Bagasse	11.27	11.94	12.66	14.17	13.93	14.87	16.82	18.67	20.93	22.54
Biogases	0.01	0.00	0.00	0.50	0.00	0.11	1.14	2.10	2.10	2.42
Coal	0.01	0.02	0.02	0.03	0.02	0.04	0.05	0.07	0.09	0.12
Coffee Husk	0.37	0.38	0.39	0.42	0.40	0.41	0.43	0.45	0.53	0.56
Crude Oil		0.06	0.07	0.07	0.08	0.08	0.09	0.10	0.11	0.12
Diesel	42.22	43.54	45.04	46.71	48.14	49.75	52.71	56.39	60.94	66.59
Firewood	11.05	11.29	9.43	10.58	9.98	12.06	16.06	18.95	20.53	22.11
Fuel Oil	5.25	5.47	5.69	5.94	6.20	6.44	7.02	7.68	8.41	9.28
Gasoline	37.07	39.25	40.49	40.62	40.75	40.63	39.90	40.23	41.45	43.44
Geothermal	62.10	45.41	46.61	47.81	44.57	45.77	40.37	34.96	34.00	26.06
Hydro	36.04	38.24	39.32	39.32	49.34	50.24	50.99	51.73	56.48	57.96
Jet Fuel	7.97	8.50	9.16	9.79	10.47	11.10	12.35	13.60	14.97	16.49
LPG	6.31	7.69	8.25	9.09	9.06	9.48	10.93	11.89	14.76	19.66
Other organic residues	5.96	6.39	6.88	7.93	7.88	8.62	9.79	11.08	13.16	14.36
Petroleum Coke	3.21	3.48	3.77	4.07	4.40	4.74	5.37	6.50	8.05	9.91
Solar	0.01	0.03	0.03	0.07	0.06	0.10	0.14	1.20	2.70	3.52
Wind	3.89	5.08	4.82	4.56	4.30	4.03	3.60	5.81	5.73	13.96
Total	**233.4**	**226.8**	**232.7**	**241.8**	**249.7**	**258.6**	**267.9**	**281.6**	**305.3**	**329.5**

5.2.3 Power Sector

Figure 27 shows the growth in electricity generation under the Baseline scenario, which as discussed earlier assumes that the ICE expansion plan is fixed to 2027. Most of the growth in generation comes from regulated hydropower plants, with growth in biofuel fired plants starting in 2035. Run-of-rive hydro plants increase by 24%, and there is important growth in wind and solar generation, increasing 40% and 1000% respectively in 2050, although solar starts from small 2015 value.

Figure 28 shows the timing of new power plant builds under the Baseline scenario. A total of 3.92GW of new capacity need to be built over the planning horizon, which as noted above includes the 650 MW regulated hydropower plant planned for 2027 in the ICE expansion plan. If this plant is not included in the Baseline, the model choses instead to invest in run-of-river hydropower plants in 2030 and 2035 because they are significantly less expensive than the regulated hydropower plants, but the model does not fully consider the local environmental concerns of these projects. So the current expansion plan, which includes Diquis, is assumed for the Baseline, and sensitivity runs were made to determine the impact of not including this plant in the Baseline.

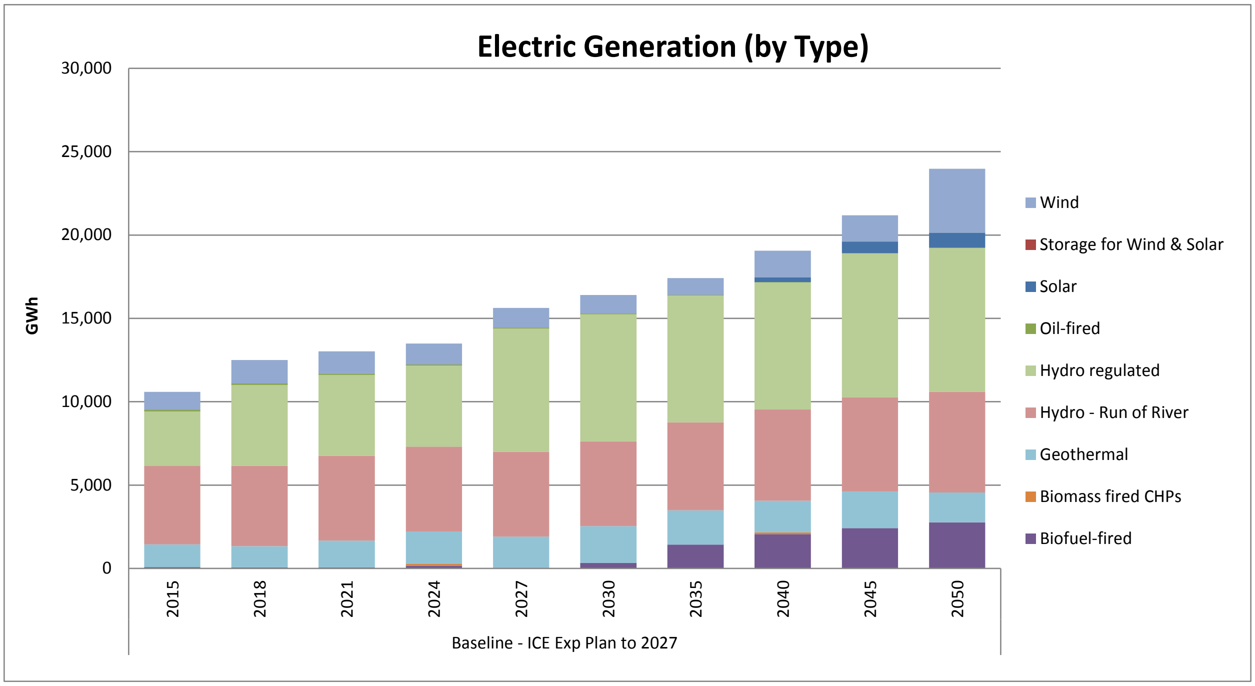


Figure 27: Baseline Electricity Generation

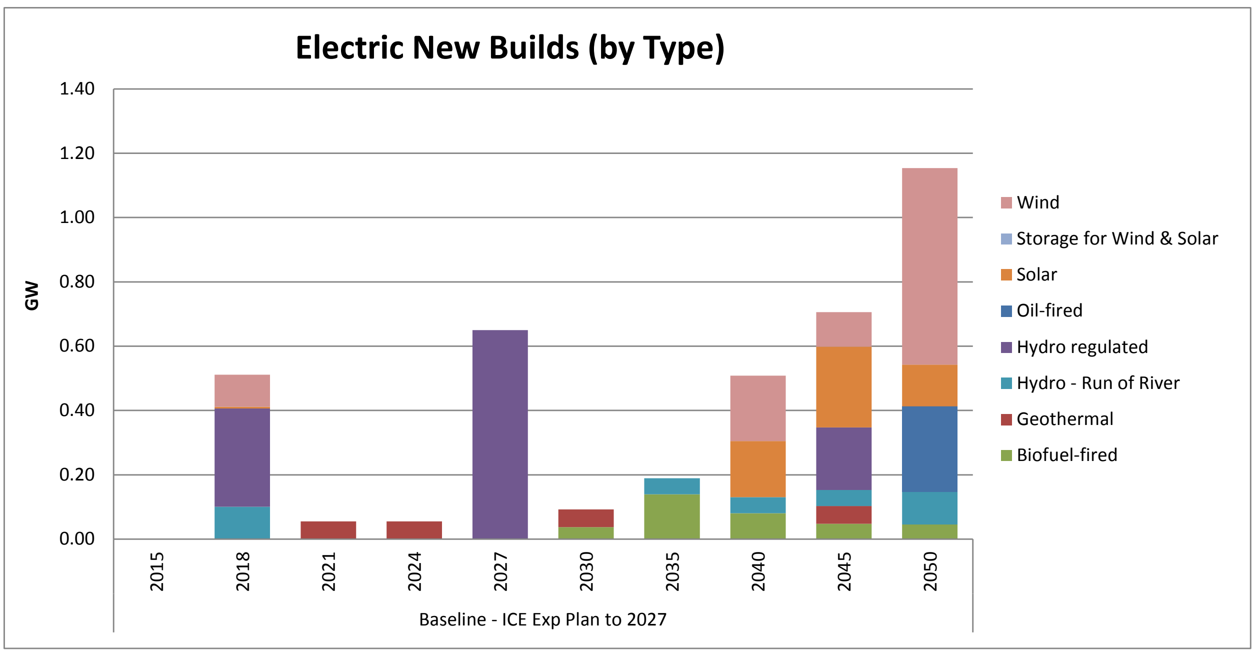


Figure 28: Baseline New Power Plant Builds

5.2.4 Final Energy to the Demand Sectors

Figure 29 shows the Final Energy Consumption (FEC) by sector for the Baseline scenario. Transport and Industry are the two sectors with the largest levels of energy consumption, and the greatest growth in consumption occurs for the Industry sector. Total FEC increases by 82% by 2050 compared to 2015, with the Industry sector leading the growth at 165%.

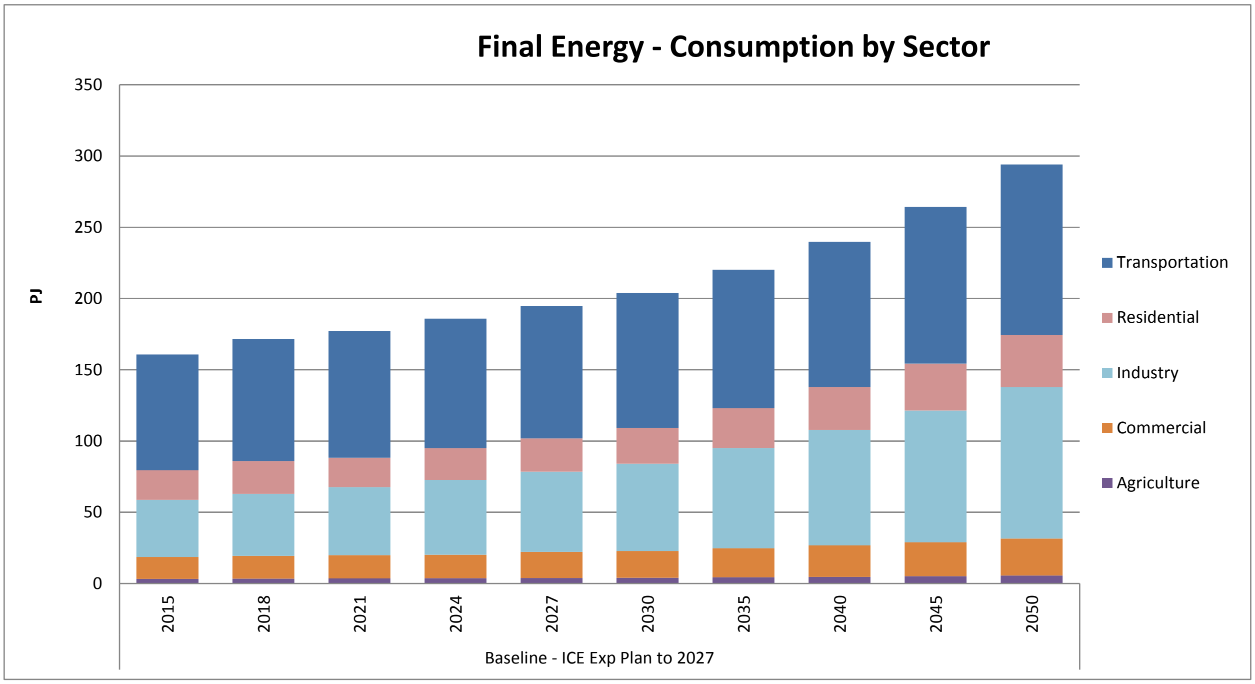


Figure 29: Final Energy Demand by Sector

Figure 30 shows the FEC by fuel type. Oil products continue to be the dominant energy carriers, comprising 58% of all final energy use, and growing 48% by 2050, but the relative shares of oil products decrease, because electricity grows by 115% and biofuels use increases by 127%. Diesel and gasoline are the leading oil products followed by LPG and Jet fuel. Bagasse is the dominant form of biomass.

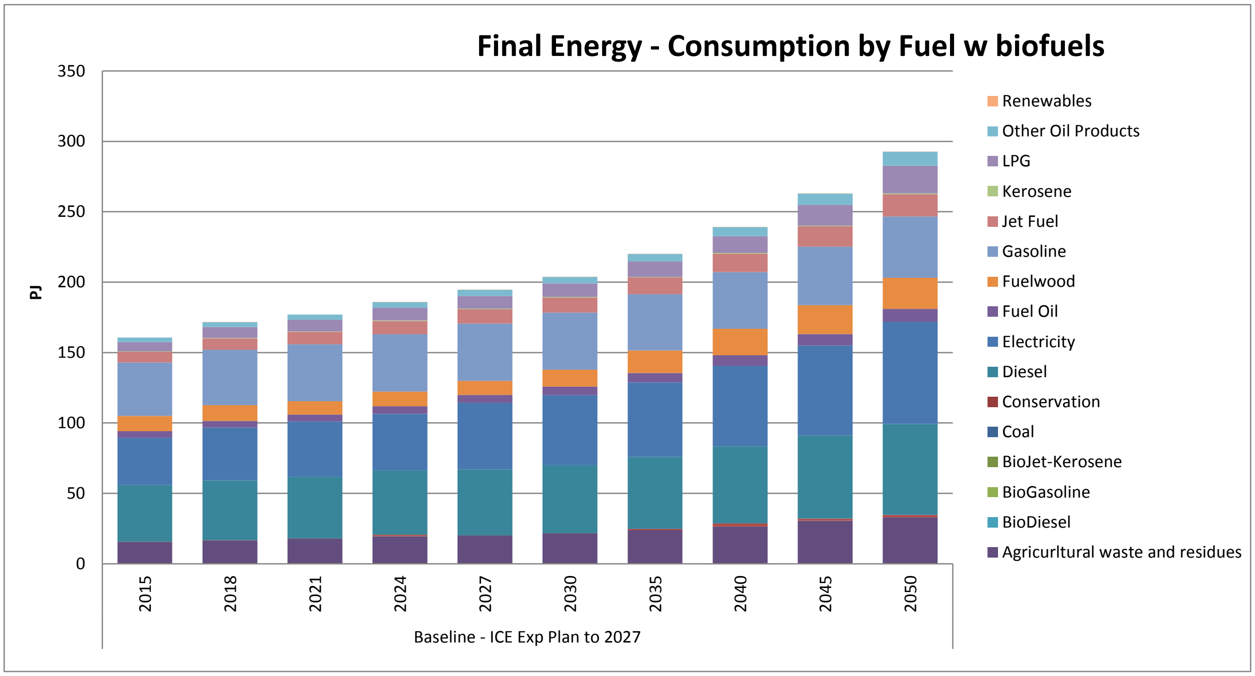


Figure 30: Final Energy Demand by Fuel

5.2.5 Emissions

Figure 31 shows the energy system GHG emissions from the Baseline scenario by sector and gas. Hydropower and geothermal power plants were given CO2 eq. emission factors based on ICE data. The methane and nitrous oxide emissions from the energy system come from incomplete combustion of fuels in the different energy sectors, and their CO_2 equivalent emissions are shown from all energy sectors. Overall energy sector related GHG emissions growth is 58% between 2015 and 2050, with Transport and Industry sectors accounting for over 93% of the total growth. Therefore, the Costa Rica NDC target of reducing GHG emissions by some 60% is quite aggressive, and innovative policies and measures along with a strong national commitment will be needed to achieve this goal.

Table 18 provides a detailed breakdown of the GHG emissions from the Baseline scenario. Overall GHG emissions increase by 44%, with the greatest growth for Industry (165%) and Transport (37%). The methane and nitrous oxide emissions are all a result of incomplete combustion, and are generally in proportion to the sector energy use.

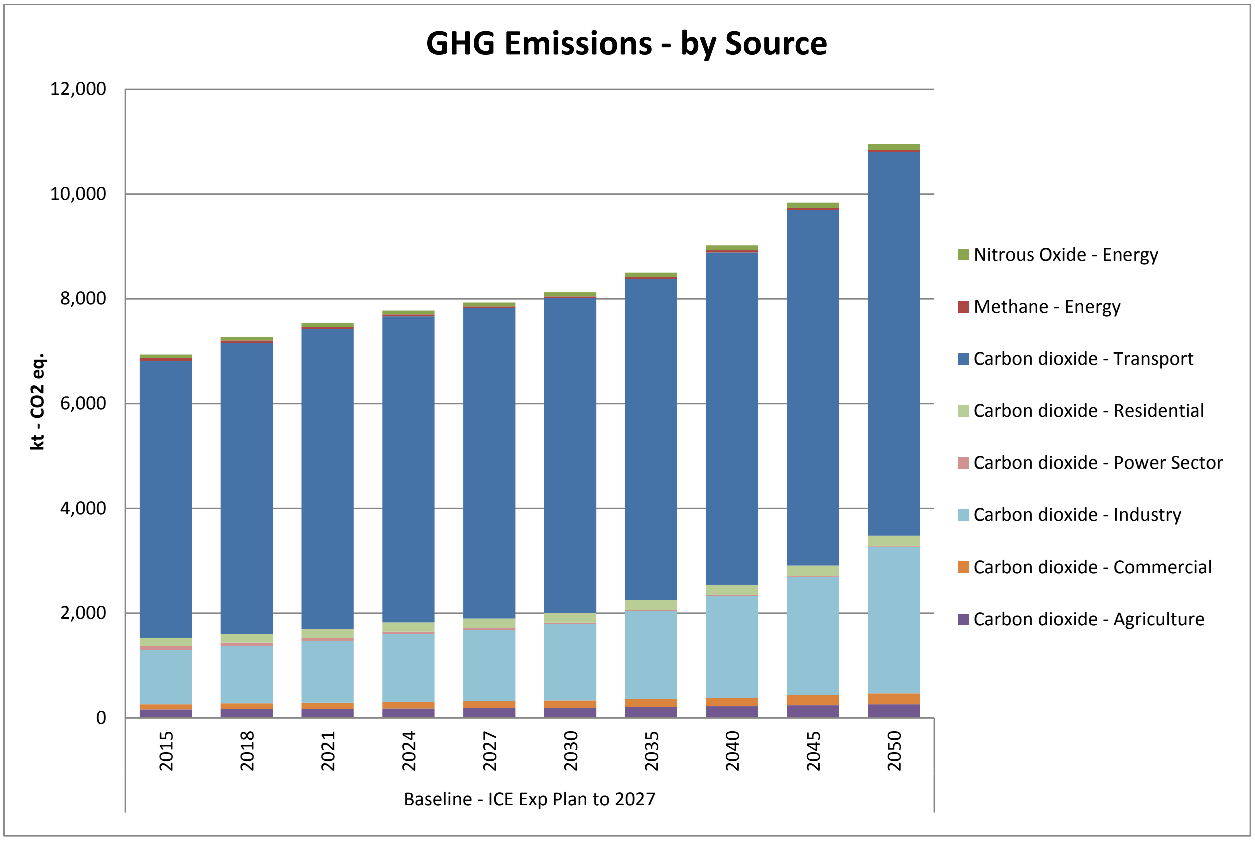


Figure 31: Baseline GHG Emissions

Table 18: Baseline GHG Emissions from Energy Sector (kt CO2eq.)

Emission / Sector	2015	2018	2021	2024	2027	2030	2035	2040	2045	2050
CO2 - Agriculture	160	166	172	178	184	192	207	223	241	260
CO2 - Commercial	99	109	120	129	137	143	152	160	194	209
CO2 - Industry	1,035	1,097	1,179	1,295	1,358	1,453	1,676	1,942	2,259	2,797
CO2 - Power Sector	73	62	54	46	39	32	27	21	16	11
CO2 - Residential	164	168	172	176	180	184	190	195	200	203
CO2 - Transport	5,284	5,550	5,732	5,839	5,926	6,007	6,121	6,343	6,783	7,322
Methane - Energy	54	53	34	37	30	33	37	39	39	39
Nitrous Oxide - Energy	66	69	70	75	74	78	87	95	106	114
Total	**7,016**	**7,360**	**7,620**	**7,863**	**8,017**	**8214**	**8,591**	**9,118**	**9,940**	**11,066**

6 GHG Mitigation Measures Analyzed

A comprehensive set of GHG mitigation measures for Costa Rica was identified from existing policy documents by the PMR, in consultation with the Directorate of Climate Change (DCC) for consideration as possible options to help realize the NDC goals of the country. These measures were derived from a large number of documents, including Costa Rica's NDC[24], National Climate Change Strategy[25], National Development Plan[26], National Energy Plan[27], Reducing Emissions from Deforestation and Forest Degradation (REDD+) national strategy[28], and several Nationally Appropriate Mitigation Actions (NAMAs) from the United Nations Framework Convention on Climate Change (UNFCCC) National Communication regarding Coffee, Livestock, Urban transport, and others. This initial list included 320 measures directed at reducing both energy and non-energy GHG emissions.

As this analysis focuses on the energy sector, a review of the initial list of mitigation measures identified over 75 energy-related measures that were candidates for evaluation using TIMES-CR. Because several of the measures were enabling activities (not mitigation measures) and some measures were duplicated from different source documents, approximately 60 specific mitigation measures were identified that could be modelled with TIMES-CR. The set of Planned policy measures, that is those identified by the PMR, were first examined on their own, then combined by sector, and finally included with all other Planned measures to determine their combined impact. The energy sector portion of the NDC GHG target was then imposed on the Planned policy measures indicating a shortfall in terms of meeting the reduction target, so additional measures were added and the results examined to identify the Enhanced measures and critical policies needed to achieve the country's NDC goals.

Costa Rica's **NDC** ambitions were translated into the stated 2030 target (capped linearly from 2018) and a calculated 2050 target based on the 2050 per capita emission goal of 1.19 tons. This was done with the assumption that the energy sector share of total GHG emissions would remain the same as 2015 (approximately 77%) throughout the planning horizon. The result was approximately a 60% reduction in energy sector emissions from the Baseline in 2050. However, the ratio of energy to non-energy emissions could change depending on emission reduction activities in the non-energy sectors which were not covered here for lack of data. Therefore, the NDC target set for the energy sector in this analysis may be overly aggressive.

Table 19 lists the suite of mitigation measures, and combinations thereof, along with their short name and definition. The measures are organized into several policy areas: Baseline, Supply &

[24] Costa Rica's Intended Nationally Determined Contribution. Goverment of Costa Rica, Ministry of Environment and Energy. 2015. Available in: http://www4.unfccc.int/Submissions/INDC/Published%20Documents/Costa%20Rica/1/INDC%20Costa%20Rica%20Version%202%200%20final%20ENG.pdf

[25] Costa Rica. Ministerio de Ambiente, Energía y Telecomunicaciones. 2009. Estrategia Nacional de Cambio Climático. San José, Costa Rica: Editor Calderón y Alvarado S. A. 2009.

[26] Costa Rica. Ministerio de Planificación Nacional y Política Económica. "Plan Nacional de Desarrollo 2015-2018 "Alberto Cañas Escalante". Ministerio de Planificación Nacional y Política Económica. San José, CR. MIDEPLAN, 2014

[27] Plan Nacional de Energía 2015-2030. VII. Ministerio de Ambiente y Energía, San José,. Costa Rica. 2015.

[28] "Estrategia Nacional REDD+ Costa Rica. Una iniciativa del programa de bosques y desarrollo rural". ". Ministerio De Ambiente y Energía. 2015.

Power, Efficiency (in Buildings and Industry), Transportation, GHG levy, NDC target and Combinations as discussed next. The PMR Mitigation Number column provides the mapping from the original list of measures provided by the PMR to the various model runs done.

A **Baseline** scenario represents a business-as-usual evolution of the Costa Rica energy system, and will be the point of reference for comparing the impacts of different policy scenarios. The core Baseline scenario (BL-ICE), forces new power plants to be built according to the ICE expansion plan thru 2027, which includes the Diquis hydropower dam project. Two other Baseline scenarios were examined as sensitivity runs to understand the significance of this assumption. The BL-ICE-24 scenario only forces the ICE plan through 2024, and thus does not force the inclusion of the Diquis plant. A strict least-cost baseline (BL-NO-ICE) was also run and was used to examine the implications of following the ICE expansion plan on some of the scenarios (e.g., more efficient public lighting).

In the Baseline scenario, the adoption of new high efficiency (Improved, Better and Advanced) demand technologies (such as hybrid and electric vehicles, high efficiency air conditioners, LED lights, etc.) is limited to meeting at most 30%, 20% and 10% respectively of their associated demand by 2050. This constraint on the “quality” or allowed penetration of high efficiency technologies is used because experience shows that a slow uptake of advanced technologies (usually more costly to purchase though more efficient to operate) can be expected in the absence of specific policies to promote them. A number of scenarios were examined that allow either 50% or 90% uptake of these more advanced technologies by 2050 based on mitigation measures that incentivize the adoption of these more efficient demand devices. The design of these advanced technology (AdvTech) quality constraints allows cost-effective Improved, Better, and Advanced devices to be purchased up to their adoption rate limit, but does not force their uptake. Note that these scenarios result in lower overall energy system costs due to their life-cycle costs being less than that of conventional (Standard) devices owing mainly to the reduced amount of fuel consumed.

The **Supply and Power** sector measures include those to promote electricity generation from renewable energy (RE) sources, increase the share of renewables in Gross Final Energy[29] (GFE) consumption, increase efficiency in power generation along with transmission and distribution (T&D) of electricity, promote use of distributed generation resources, and to either allow liquid biofuels to enter all sectors or to force system-wide biofuel targets. A scenario looking at life extension at existing geothermal plants was also developed, and included in the Baseline scenario based on ICE’s policy to maintain (and not deplete) these renewable energy resources.

There are more than a dozen core energy **Efficiency** mitigation measures covering energy use in the agriculture, buildings and industry sectors. These include improved appliance standards, incentives for more efficient demand devices, integrated PV systems for Commercial and Residential buildings, public lighting, public building shell retrofits, fuel switching in the cement industry, coffee process improvements, and the promotion of biomass residues in the agriculture and industry sectors.

Transport sector measures include incentives for hybrid and electric vehicles, improved technologies for public transport, early retirement of older Light Duty Vehicles (LDVs), a

[29] The total energy consumed for end-use applications, including the gross energy inputs to electricity production. It differs from primary energy use only in that it does not include/exclude imports and exports.

number of mode-shift measures that move transport demand from LDVs to buses, rail or walking/cycling. There are also several scenarios looking at a GHG cap for the Transport sector.

Two levels of **GHG** emissions levy were examined, and scenarios were run for stationary sources, transportation sources, and all sources, with and without the 90% allowance for the share of advanced technologies, and also with and without liquid biofuels being available.

In the final set of individual scenarios, the energy sector share of Costa Rica's 2050 **NDC** ambitions were modelled in three stages to be able to see what incremental activities might be needed to reach the final target.

Following analysis of the individual measures, the Planned policy measures were combined by sector and then all sectors were combined to determine their aggregate result. Next, a 60% GHG reduction scenario was run as an approximation of the NDC target requirements on the energy sector. The Planned policies results were short of the NDC emission reduction target, and Enhanced policy measures were identified by examining the additional changes needed to meet the NDC target.

The scenario descriptions in Table 19 specify the mitigation measures in terms of changes in capacity, number, percentage or share of capacity or activity being addresses. Appendix B provides information on all identified mitigation measures from which the Planned measures were developed, and identifies the source documents from which the measures were derived. Appendix C provides the scenario run matrices, Appendix D links all the mitigation measure scenario files with their specification template, and Appendix E provides details on the results for each measure.

Table 19: List of Preliminary Mitigation Measures & Scenario Definitions

Policy Area	Scenario Code	Scenario Name	Description	PMR Mitigation Measure Number
Baseline	BL-ICE	Baseline - ICE Expansion Plan - 2027	BAU scenario (Allows 30%, 20% and 10% for improved, better and advanced tech classes) with ICE Expansion Plan to 2027	NA
	BL-ICE-24	Baseline - ICE Expansion Plan - 2024	BAU scenario with ICE expansion plan to 2024 (no Diquis HPP)	NA
	BL-NO-ICE	Baseline - No ICE Exp Plan	BAU scenario with least-cost expansion plan	NA
Supply & Power	SP-RES-ELC	RE Electricity Share	Maintain RE electricity share at 98% until 2030 and transition to 100% by 2050	82
	SP-DIST-EFF	Improve Distribution Efficiency	Reduce T&D losses from 12.2% in 2015 to 8% by 2050	150
	SP-GEN-EFF	Improve Generating Efficiency	Increase efficiency of all hydropower plants from 91% in 2015 to 94% in 2050	153
	SP-PV-DG	Promote PV Distributed Generation	Install 100 MW of distributed PV systems by 2050	95, 107
	SP-PV-LARGE	Promote Large-Scale Solar	Install 500 MW of centralized PV systems by 2050	206
	SP-ELC-STRG	Electric Energy Storage	Implement Li-Ion battery storage systems starting in 2024 to improve the utilization of variable wind and solar energy	Enhanced
	SP-BIOF-LIMT	Biofuels Allowed in Petroleum Products - All Sectors	Allow biofuels up to the following limits by 2050 across all sectors: Biodiesel-50%, biogasoline-30%, biojetfuel-20%	96, 260, 262
	SP-BIOF-TRGT	Biofuels Target in Petroleum Products - All Sectors	Force biofuels to the following levels by 2050 across all sectors: Biodiesel-50%, biogasoline-30%, biojetfuel-20%	96, 205, 260, 262
	SP-RESF-TRGT	RE Share of Gross Final Energy	Increase RE share of gross final energy use from 56% in 2015 to 70% in 2050	81
	SP-GEO-LIFE	Geothermal Power Plant Life Extension	Retrofit retiring geothermal capacity to extend life by 30 years	Enhanced
	SP-ALL-90	All Supply & Power Measures - 90% AT	All Supply & Power Measures - 90% AT	81, 82, 95, 96, 107, 205, 206, 260, 262

Buildings & Industry Efficiency	EE-APL-COM	COM Appliance Standards	Transition Commercial devices to 100% improved, better and advanced techs by 2030	135
	EE-APL-RSD	RSD Appliance Standards	Transition Residential devices to 100% improved, better and advanced techs by 2030	135
	EE-APL-STD	COM & RSD Appliance Standards	Transition Commercial & Residential devices to 100% improved, better and advanced techs by 2030	135
	EE-TAX-INC10	EE Incentive (10%) for COM & RSD with 90% sector AdvTech	Reduce the cost of improved, better and advanced techs in Commercial & Residential sectors by 10% starting in 2021	134
	EE-TAX-INC20	EE Incentive (20%) for COM & RSD with 90% sector AdvTech	Reduce the cost of improved, better and advanced techs in Commercial & Residential sectors by 20% starting in 2021	134
	EE-AT-50	Baseline - ICE w 50% AdvTech	BAU scenario with ICE expansion plan and 50% allowable penetration of improved, better and advanced techs by 2050	160, 231
	EE-AT-90	Baseline - ICE w 90% AdvTech	BAU scenario with ICE expansion plan and 90% allowable penetration of improved, better and advanced techs by 2050	160, 231
	EE-PUBLDG-R	Public Building Efficiency Improvement	Reduce Public Build energy use by 15% and all public buildings are retrofitted by 2050 [assumes public buildings represent 10% of Commercial sector demand]	100
	EE-PUBLTG	LED Public Lighting	Transition to 100% LED Public Lighting by 2024	151
	EE-PUBLTG-NX	LED Public Lighting - No ICE Exp Plan	Transition to 100% LED Public Lighting by 2024 - using No ICE Expansion Plan scenario	151
	EE-IND-FOSR	IND Fossil Fuel Reduction	Reduce fossil fuel share in Industry sectors to 25% by 2050	Enhanced
	EE-AGIND-BIO	Bioenergy Utilization by AGR & IND	Increase use of organic residues by Agriculture and Industry sectors	106, 269
	EE-CEMENT-P	Cement Industry Fuel switching	Increase bio-energy demand in Cement sector to 75% of all process heat demand to the Other sector by 2050	277
	EE-COFFEE-P	Coffee NAMA	Improve process efficiency in Coffee sector by forcing new Improved boilers and furnaces using coffee and other biomass residues	10, 11
	EE-BLDGS-90	All Building Efficiency Measures - 90% AdvTech	All building and appliance efficiency measures with 90% allowed improved, better and advanced techs by 2050	100, 107, 135, 151, 160

	EE-INDALL-90	All Industry Efficiency Measures - 90% AdvTech	All industry efficiency and fuel switching measures with 90% allowed improved, better and advanced techs by 2050	10 , 106, 160, 269, 277
	EE-ALL-90	All Efficiency Measures - 90% AdvTech	All Buildings and Industry efficiency measures with 90% allowed improved, better and advanced techs by 2050	100, 107, 135, 151, 10 , 106, 160, 269, 277
	EE-GHG-TAX-L	Low GHG Levy ($10-150) on Stationary Sources	Apply a Low GHG Levy ($10 To 150/t CO2 eq.) to stationary (Buildings, Industry and Power sector) emission sources	135
	EE-GHG-TAX-H	High GHG Levy ($10-300) on Stationary Sources	Apply a High GHG Levy ($10 to 300/t CO2 eq.) to stationary (Buildings, Industry and Power sector) emission sources	135
	EE-GHGT-L90	Low GHG Levy ($10-150/t) on Stationary Sources - 90% NT	Apply a Low GHG Levy ($10 To 150/t CO2 eq.) to stationary (Buildings, Industry and Power sector) emission sources with 90% allowed improved, better and advanced techs by 2050	160, 229
	EE-GHGT-H90	High GHG Levy ($10-300) on Stationary Sources - 90% NT	Apply a High GHG Levy ($10 to 300/t CO2 eq.) to stationary (Buildings, Industry and Power sector) emission sources with 90% allowed improved, better and advanced techs by 2050	160, 229
	EE-GHGT-L90B	Low GHG Levy ($10-150) on Stationary Sources - 90% NT & Biofuels	Apply a Low GHG Levy ($10 To 150/t CO2 eq.) to stationary (Buildings, Industry and Power sector) emission sources with 90% allowed improved, better and advanced techs by 2050 and with Biofuels allowed	160, 229, 260, 262
	EE-GHGT-H90B	High GHG Levy ($10-300) on Stationary Sources - 90% NT & Biofuels	Apply a High GHG Levy ($10 to 300/t CO2 eq.) to stationary (Buildings, Industry and Power sector) emission sources with 90% allowed improved, better and advanced techs by 2050 and with Biofuels allowed	160, 229, 260, 262
Transportation	TR-LDV-CLUN	LDV clunkers	Force earlier retirement of about 20% of the existing LDVs	232
	TR-LDV-AD-N	25% share of electric and hybrid in LDV New stock	By 2030 achieve 25% (50% by 2050) of **New** cars are hybrids or electric	241, 288, 289
	TR-PUB-AD-N	100% share of advanced techs in Public Transport New stock	Improve share of Advanced Taxis, Buses and Mini-buses to 100% of new stock by 2050	286
	TR-MSH-FRE	Rail Freight	Improve rail freight capacity to shift 25% of heavy truck demand to rail by 2050.	74-114

	TR-MSH-IC	Intercity Rail	Intercity train connecting the four main cities shifts 57 mpkm from LDV to passenger rail in 2030.	112
	TR-MSH-PUBTR	Integrated Public Transport System	15% shift to Bus, improvement of load factor by 8%, reduction of distances by 33% and decrease of vehicle efficiency by 17%. Share of large busses 34%. Costs are unchanged.	72, 73, 282
	TR-MSH-NMT	5% shift of passenger transport to Non-motorized modes (cycling, walking)	Assumes 5% shift to NMT by 2030. 60% is shifted from bus demand, 40% is shifted from LDV demand.	245, 246
	TR-MSH-DEM	Demand Controlling measures	10% of LDVs are affected. LDV demand reduces by 3% by 2020 and 4% by 2030. 80% of reduced demand is shifted to buses.	113, 284
	TR-MSH-TRAM	5.4% shift from LDV to tram	To improve urban mass transit plans to shift 5.4% of LDV demand to urban trains by 2030	Enhanced
	TR-GREEN	Green driving	Measure affects 50% of vehicles. LDV and taxi efficiency is increased by 5%, bus, mini-bus and (Light Commercial Vehicles) LCV by 2%	Enhanced
	TR-EFF-ALL	50% share of AdvTechs in all transport modes	Improve efficiency of all Road vehicles by allowing up to 50% penetration of improved and advanced techs by 2050.	241, 286, 288
	TR-UC90	Reference with TRN 90% AdvTech	Allow 90% Advanced technologies and 50% fuel shift in Transport sector	231
	TR-CO2-CAP	25%-50% cap of CO2 from Transport	Reduce GHG emissions from the transport sector by 25%/50% by 2030/2050	278-280
	TR-GHG-TAX	High emissions levy on all Transport GHGs	Gradually increasing levy on emissions from entire transport sector - $10/ton levy in 2018 increasing to $300/ton in 2050	228
	TR-GHG-TAX50	Moderate emissions levy on all Transport GHGs with 90% AdvTech	Gradually increasing levy on emissions from entire transport sector - $10/ton levy in 2018 increasing to $150/ton in 2050 with 90% allowed penetration of improved and advanced techs	228, 231
	TR-GHG-TAX90	High emissions levy on all Transport GHGs with 90% AdvTech	Gradually increasing levy on emissions from entire transport sector - $10/ton levy in 2018 increasing to $300/ton in 2050 with 90% allowed penetration of improved and advanced techs	228, 231
	TR-MSH-TI	Combines LDV to passenger rail measures (tram and intercity)	Combines the TRN-MSH-I and TRN-MSH-T measures	112, Enhanced

	TR-COMB-M	Combines all TRN technology and mode-shift measures	Combines the TR-LDV-AD-T, TR-PUB-AD-T, TR-LDV-CLUN, TR-WLK-CYC,TR-MSH-PUBTR, TR-MSH-TRAM and TR-EFF-ALL measures	72, 73, 231, 232, 241, 245, 246, 282, 286, 278-280, 288. 289
	TR-COMB-MB	Combines TRN-COMB-M with the Biofuels scenario	Combines TRN-COMB-M measures with SP-BIOF-SECT measure	72, 73, 96, 231, 232, 241, 245, 246, 282, 286, 278-280, 288. 289
	TR-COMB-MBT	Combines TRN-COMB-MB with High TRN emissions levy	Combines TRN-COMB-MB measures with SP-BIOF-SECT and TR-GHG-TAX50 measures	72, 73, 96, 228, 231, 232, 241, 245, 246, 282, 286, 278-280, 288. 289
GHG Levy	GHG-TAX-LO	Low GHG Levy ($10-150/t) on All Sectors	Apply a Low GHG Levy ($10 To 150/t CO2 eq.) to All sectors	135
	GHG-TAX-HI	High GHG Levy ($10-300/t) on All Sectors	Apply a High GHG Levy ($10 to 300/t CO2 eq.) to All sectors	135
	GHG-TX-LO-90	Low GHG Levy ($10-150/t) on All Sectors - 90% AT	Apply a Low GHG Levy ($10 To 150/t CO2 eq.) to All sectors with 90% allowed improved, better and advanced techs by 2050	160, 229
	GHG-TX-HI-90	High GHG Levy ($10-300/t) on All Sectors - 90% AT	Apply a High GHG Levy ($10 To 300/t CO2 eq.) to All sectors with 90% allowed improved, better and advanced techs by 2050	160, 229
	GHG-TX-L90B	Low GHG Levy ($10-150/t) on All Sectors - 90% AT & Biofuels	Apply a Low GHG Levy ($10 To 150/t CO2 eq.) to All sectors with 90% allowed improved, better and advanced techs by 2050 with biofuels allowed	160, 229, 260, 262
	GHG-TX-H90B	High GHG Levy ($10-300/t) on All Sectors - 90% AT & Biofuels	Apply a High GHG Levy ($10 To 300/t CO2 eq.) to All sectors with 90% allowed improved, better and advanced techs by 2050 with biofuels allowed	160, 229, 260, 262
NDC Target	ND-GHGLIM-40	40% GHG Emission Reduction - 90% AT	25% reduction in GHG emissions from Baseline in 2030 and 40% reduction in 2050 with 90% allowed improved, better and advanced techs by 2050	1, 2A, 2B, 80
	ND-GHGLIM-4B	40% GHG Emission Reduction - 90% AT w Biofuels	25% reduction in GHG emissions from Baseline in 2030 and 40% reduction in 2050 with 90% allowed improved, better and advanced techs by 2050	1, 2A, 2B, 80,96

	ND-GHGLIM-50	50% GHG Emission Reduction - 90% AT	30% reduction in GHG emissions from Baseline in 2030 and 50% reduction in 2050 with 90% allowed improved, better and advanced techs	1, 2A, 2B, 80
	ND-GHGLIM-5B	50% GHG Emission Reduction - 90% AT w Biofuels	30% reduction in GHG emissions from Baseline in 2030 and 50% reduction in 2050 with 90% allowed improved, better and advanced techs and biofuels	1, 2A, 2B, 80, 96
	ND-GHGLIM-60	60% GHG Emission Reduction - 90% AT	44% reduction in GHG emissions from Baseline in 2030 and 60% reduction in 2050 with 90% allowed improved, better and advanced techs	1, 2A, 2B, 80
	ND-GHGLIM-6B	60% GHG Emission Reduction - 90% AT w Biofuels	44% reduction in GHG emissions from Baseline in 2030 and 60% reduction in 2050 with 90% allowed improved, better and advanced techs and biofuels	1, 2A, 2B, 80, 96
Combinations	XALL-PLANNED	All EE, SP and TRN Measures	Combines EE, SP and TRN Measures with 90% allowed improved, better and advanced techs and biofuels	All measures except GHG cap
	XALL-ENHANCE	All EE, SP and TRN Measures	Combines EE, SP and TRN Measures with 90% allowed improved, better and advanced techs and biofuels	All measures except GHG cap
	XALL-GHG-60	All Measures with Biofuels allowed & 60% GHG Cap	Combines All EE, SP and TRN Measures with 60% GHG Cap Biofuels allowed and 90% allowed improved, better and advanced techs	All measures including GHG cap
	XALL-GHG-60B	All Measures with Biofuels target & 60% GHG Cap	Combines All EE, SP and TRN Measures with 60% GHG Cap Biofuels target and 90% allowed improved, better and advanced techs	All measures including GHG cap
	XALL-GHG-6LT	All Measures with Biofuels target & 60% GHG Cap	Combines All EE, SP and TRN Measures with 60% GHG Cap Biofuels target and 90% allowed improved, better and advanced techs	All measures including GHG cap
	XALL-GHG-6HT	All Measures with Biofuels target & 60% GHG Cap	Combines All EE, SP and TRN Measures with 60% GHG Cap Biofuels target and 90% allowed improved, better and advanced techs	All measures including GHG cap

7 Baseline Scenario Sensitivity Runs

The Baseline scenario assumes that the ICE Expansion Plan is followed until 2027, which includes the Diquis hydropower dam planned for 2027. However, including the ICE expansion plan in the Baseline scenario does not result is a least-cost development of the energy sector because the ICE plan prioritizes regulating hydropower plants rather than run-of-river plants, despite the total investment cost of new regulated hydropower plants (including interest during construction) being $8,200/kW, compared to run-of-river hydropower plants at $2,400/kW.

Given the possibility that the Diquis plant might not be built, an alternate Baseline was developed that fixed the ICE Expansion plan to 2024 only, and a few sensitivity runs were made to gauge the impact of this assumption. In addition, the ICE expansion plan is based on a slightly higher electricity demand projection and overbuilds generating capacity, compared to the demand projection in the model, by about 8% compared with a No ICE Expansion plan Baseline run, and this masks some potential savings. For example, the measure to switch to LED pubic lighting happens before 2024 results in no reduction in electricity capacity because new power plants builds are forced until 2027.

The top portion of Figure 32 shows electricity generation by plant type for the three Baseline scenario variations: the core Baseline with ICE expansion plan to 2027, the Baseline with ICE expansion plan to 2024, and the Baseline with No ICE expansion plan. The bottom portion of the figure shows the change in generation mix compared to the core Baseline scenario. The figure shows that if the ICE expansion plan is limited to 2024, the model replaces about 650 MW of regulating hydropower with biomass (bagasse), wind, solar and run-of river hydropower. In the No ICE expansion plan, the model further replaces geothermal power plants with run-of-river hydropower plants. These results are driven by the inherent investment cost differences between the regulated hydropower and geothermal verses the run-of-river hydropower.

Figure 33 shows the total discounted system cost for the three Baseline runs. This cost includes all investment, fuel and operating costs for all supply and demand requirements in the model. The core Baseline scenario has a slightly higher total discounted system cost compared to either the Baseline-2024 scenario (0.5%) or the No ICE scenario (0.7%). However, it should be noted that there are additional considerations not captured in the model such as environmental aspects of building a number of run-of-river plants and the need for sufficient dispatchable power that may factor into ICE’s decision-making process.

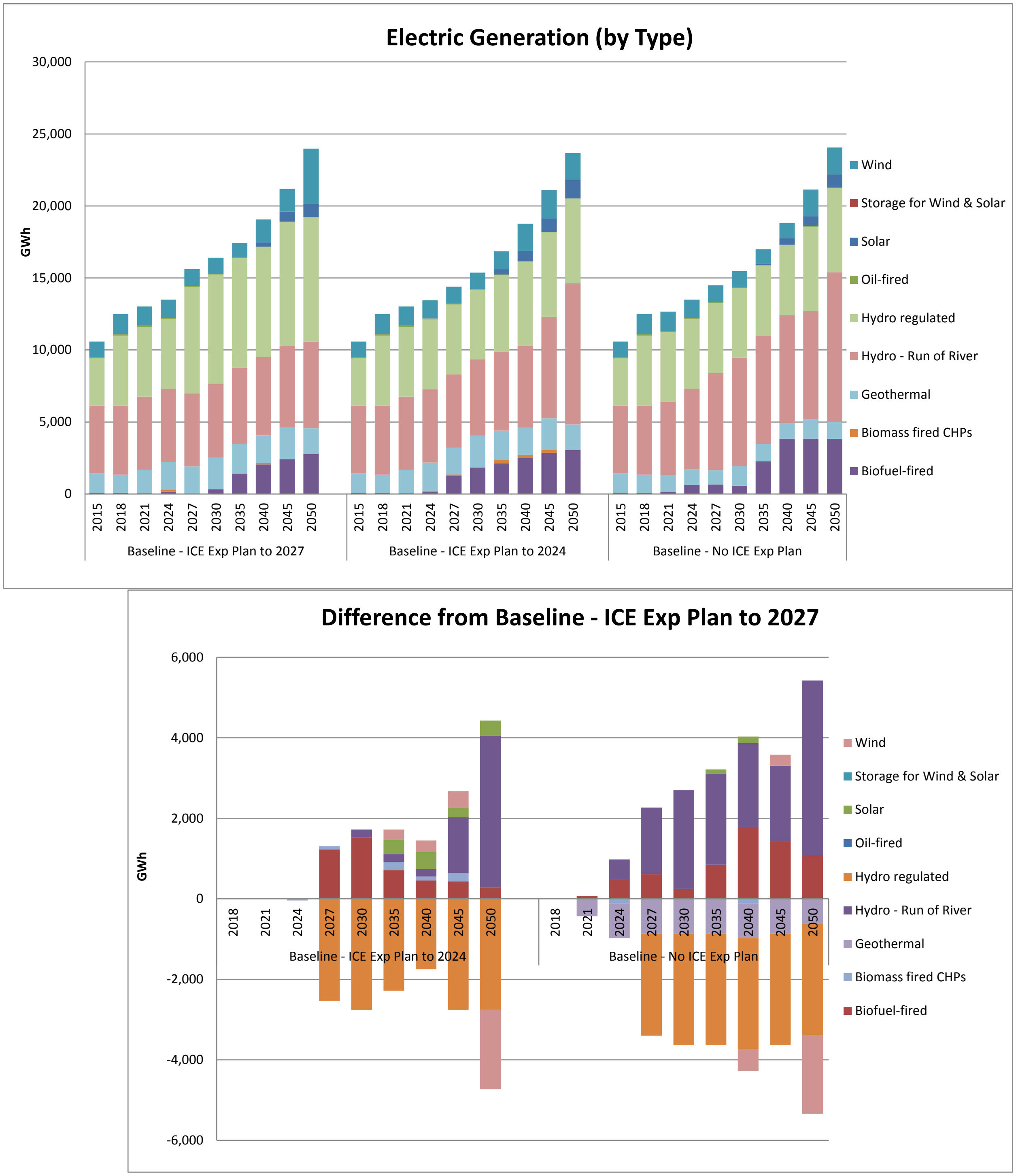


Figure 32: Electricity Generation and Change in Electricity Generation from Baseline

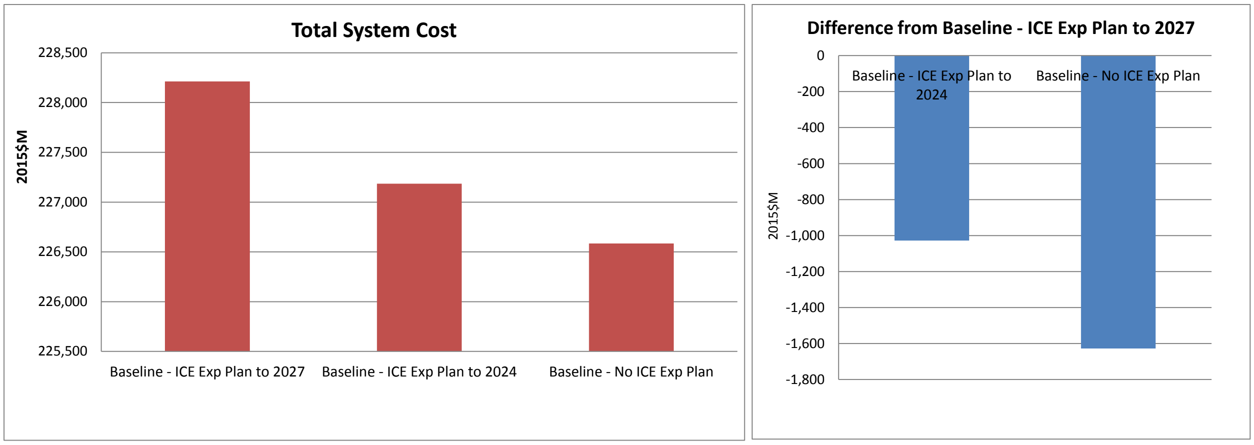


Figure 33: Total Discounted System Cost and Change from Baseline

8 Summary of Planned Policy Measures

8.1 Overview

The impacts of the mitigation measures and policies were quantified using specific metrics that characterize the technical, economic and environmental changes each policy produces. These metrics are the total or cumulative amount over the entire planning horizon (2015-2050), and their definitions are shown in Table 20. These cumulative metrics are used because they integrate the changes occurring over the entire model horizon, which experience shows better represents the impact compared to the results from any particular model period.

The measures were analyzed first individually by sectors as described above, and the sections that follow summarize the key results for each measure and characterize the overall impact for the set of measures. Detailed analysis of each individual measure is contained in Appendix E.

Table 20: Cumulative Analysis Metrics and Definitions

Metric	Definition
System Cost (2015$M)	Net present value of all costs for energy system investments, operating costs and fuel expenditures
Primary Energy (PJ)	Primary energy used
Electricity Generation (GWh)	Electricity generation
Final Energy Consumption (PJ)	Energy consumed in all demand sectors
PP Builds (GW)	New power plants built
Electricity Investment (2015$M)	Lump sum investment in new power plants
Demand Device Purchases (2015$M)	Purchases of demand devices
Fuel Expenditures (2015$M)	Fuel expenditures
GHG Emissions (kt CO2 eq.)	GHG emissions
Mitigation Effectiveness Indicator (2015$/t)	Change in energy system cost divided by cumulative emission reduction

8.2 Supply and Power Sectors

A summary of the key impacts of the set of Supply and Power sector measures is provided in Table 21. Two measures produce the bulk of the impact for this sector: the RE Share of GFE and the Biofuels Target measure. Increasing the share of RE in GFE produces about 14% reduction in cumulative GHG emissions, but increases new power plant builds by 38% and new power plant investment by almost 60%. The Biofuels Target measure produces a 15% reduction in GHG emissions by displacing diesel, gasoline, jet fuel and kerosene with their biofuel equivalents, while increasing fuel expenditures by over 11%, because of the assumed higher cost of the biofuels. The other measures have relatively smaller impacts, and the combination of All Planned Supply and Power sector measures produces a 17% reduction in cumulative GHG emissions, but increases power plant investments by $US 7.1 billion while increasing fuel expenditures by over $US18 billion and demand device purchases by almost $US3 billion. The Supply and Power sector measures are expensive when considered on their own, but will become more cost-effective when combined with demand-side efficiency measures, as discussed later. Geothermal Power Plant Life Extension was incorporated into the Baseline scenario, and the one known Enhanced measure: Electric Energy Storage, increases wind capacity factor, defers regulated hydropower, and displaces new oil-fired capacity. In general though, owing to the high share of RE electricity generation the Power sector measures are not able to deliver substantive GHG reductions.

Table 21: Supply and Power Sector Measures

Planned Measures	Description	Summary Results
RE Electricity Share	Maintain RE electricity share at 98% until 2030 and transition to 100% by 2050.	Has zero impact, as the Baseline case meets this requirement in all periods.
Improve Distribution Efficiency	Reduce T&D losses from 12.2% in 2015 to 8% by 2050.	Results in a 1.8% reduction in electricity generation and reduces cumulative GHG emissions from the Industry sector by 1.2 Mt because reduced T&D losses lower electricity costs and encourage fuel switching to electricity.
Improve Generating Efficiency	Increase efficiency of all hydropower plants from 91% in 2015 to 94% in 2050.	Increases generation from hydropower by 1% and reduces generation from wind. GHG emission reductions are not significant.
Promote PV Distributed Generation	Install 100 MW of distributed PV systems by 2050.	Adds solar in the early periods and increases investment in new power plant by 0.4% but produces minimal GHG emission reductions.
Promote Large-Scale Solar	Install 500 MW of centralized PV systems by 2050.	Displaces almost 300 MW of wind and run-of-river hydropower capacity, and delays 140 MW of regulated hydropower, but produces minimal GHG emission reductions (200 kt).
Promote Larger-Scale Solar	Install 1000 MW of centralized PV systems by 2050.	Displaces over 300 MW of wind and run-of-river hydropower capacity, and delays 160 MW of regulated hydropower, but produces minimal GHG emission reductions (390 kt).
Biofuels Allowed in Petroleum Products - All	Allow biofuels up to the following limits by 2050 across all sectors: Biodiesel-50%,	Simply allowing biofuels to enter the energy system if cost-effective, but with no other driver, produces no impact, because the biofuels are assumed to be 10% more costly

Sectors	biogasoline-30%, biojetfuel-20%.	than conventional fuels.
Biofuels Target in Petroleum Products - All Sectors	Force biofuels to the following levels by 2050 across all sectors: Biodiesel-50%, biogasoline-30%, biojetfuel-20%.	Results in a 15% reduction in GHG emissions while increasing fuel expenditures 11% by displacing diesel, gasoline, jet fuel and kerosene with their biofuel equivalents.
RE Share of Gross Final Energy	Increase RE share of gross final energy use from 56% in 2015 to 70% in 2050.	Realizes over 46 Mt of GHG emission reductions, but increases new power plant builds by 38% (1.5 GW) and new power plant investment by over 60%.
All Supply & Power Measures	All Supply & Power Measures.	Results in a 17% reduction (56 Mt) in cumulative GHG emissions, but fuel expenditures increase due to the higher cost of biofuels, and power plant investment increases because the RE Share measure builds 1.8 GW of additional power plants. Energy system cost increases by $US 7.1 billion (3.1%).
Enhanced Measure	**Description**	**Summary Results**
Electric Energy Storage	Implement Li-Ion battery storage systems starting in 2024 to improve the utilization of variable wind and solar energy.	Increases wind capacity by 480 MW, reduces solar by 360 MW, and defers 190 MW of regulated hydropower. GHG emission reductions are almost 1 Mt due to 270 MW of oil-fired generation displaced in 2050.

Figure 34 shows the cumulative GHG emission reductions for each Supply and Power sector measure and their combination. The Mitigation Effectiveness Indicator (MEI) indicator was calculated for measures generating reductions by dividing the change in system cost by the reduction in emissions, where negative values indicate cost-saving measures and positive values are costly measures. The measures are ordered by the amount of emissions avoided, resulting in a pseudo-MAC (Marginal Abatement Cost) curve. The most cost-effective measures that result in meaningful emission reductions are Improving Distribution Efficiency and Electricity Storage, which collectively reduces emissions 1.1 Mt. However, the two most significant measures (RE Share of Final Energy and Biofuels Target, when not combined with demand reductions measures) have a positive MEI while yielding the biggest reductions, but they do so at a relatively high cost (of $4.8 Billion (2.1%) and $6.6 Billion (2.9%) respectively). This highlights the importance of combining measures as part of a robust cost-effective NDC pathway strategy, which will be discussed later.

8.3 *Efficiency in Buildings and Industry*

This section covers the 24 scenarios that were used to examine the Planned measures regarding efficiency in buildings (Commercial and Residential) and Industry, including the Agriculture sector.

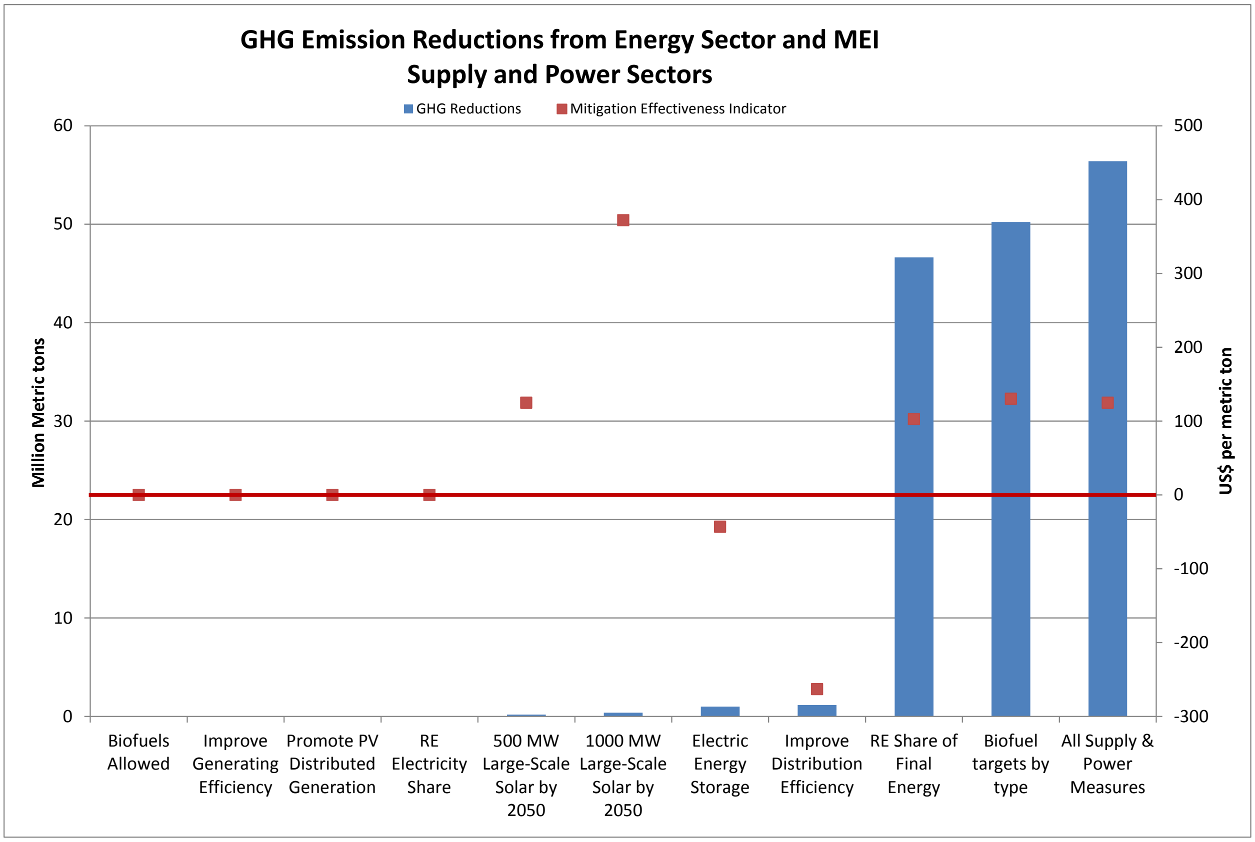


Figure 34: Emission Reductions and MEI for Supply and Power Sector Measures

Appliance standard measures and incentives for the purchase of more efficient devices reduce primary and final energy consumption and electricity demand, as well as power plant investment requirements and fuel costs. However, the GHG emission reductions are small because most of the energy savings are in the form of electricity, which is largely decarbonized in Costa Rica. Although the emission reductions from lowering electricity consumption are small, they are mostly cost-effective and are necessary to facilitate more switching from conventional fuels to electricity without overly increasing the generation requirement.

As discussed in Section 2, the Baseline scenario limits the adoption of new high efficiency (Improved, Better and Advanced) demand technologies (sometimes referred to in general as advanced technologies) to meeting at most 30%, 20% and 10% respectively of their associated demand by 2050. This constraint is used because experience shows that a slow uptake of advanced technologies (usually more costly to purchase though more efficient to operate) can be expected in the absence of specific policies to promote them. Two measures were examined that allow either 50% or 90% uptake of new high efficiency advanced technologies by 2050 based on policies and mitigation measures that incentivize the adoption of these more efficient demand devices (including banning the sale of less efficient devices). The design of these advanced technology (AdvTech) quality constraints allows cost-effective Improved, Better, and Advanced devices to be purchased up to their adoption rate limit, which increases linearly over time to their permitted 2050 level, but does not force their uptake. For the AdvTech measures, most of the reductions come from the Commercial and Industry sectors, with early reductions in the Residential sector resulting in some later final energy increases relative to the Baseline.

Public Building retrofits and Public Lighting measures generate only small GHG emission reductions, as most of the energy saved is hydropower-based electricity. The Industry measures also yield relatively small emission reductions. The Combined buildings measures produce a cumulative GHG emission reduction of 2.8 Mt, as many of the individual measures produce mostly electricity savings, and because some of the measures, such as retrofitting public buildings, have a relatively small footprint (e.g., public buildings represent only 10% of all commercial buildings).

The combination of Industrial Efficiency measures show a more significant reduction of 13.2 Mt, and the combination of All Buildings and Industry efficiency measures generates a 4.9% reduction in cumulative GHG emissions (17.2 Mt). In an attempt to generate more emission reductions from Industry an Enhanced measure requiring a 25% drop in fossil fuel consumption only produces modest reductions (3 Mt) as it results in more switching from fuels to electricity.

Table 22: Efficiency Measures for Buildings and Industry

Planned Measures	Description	Summary Results
COM Appliance Standards	Transition Commercial devices to 100% improved, better and advanced techs by 2030.	Increases system cost by 0.14%, due to the higher cost of the more efficient devices while decreasing power plant investment and fuel expenditures.
RSD Appliance Standards	Transition Residential devices to 100% improved, better and advanced techs by 2030.	Reduces new power plant investments and fuel expenditures, which offset the increased cost of the more efficient residential appliances leading to a 0.15% decrease in system cost.
COM & RSD Appliance Standards	Transition Commercial & Residential devices to 100% improved, better and advanced techs by 2030.	Produces a 0.3% (1 Mt) reduction in GHG emissions, reduces power plant investment and fuel expenditures to offset increased demand device costs resulting in no system cost increase.
EE Incentive (10%) for COM & RSD, with 90% sector AdvTech	Reduce the cost of improved, better and advanced techs in Commercial & Residential sectors by 10% starting in 2021.	Generates almost 8% reduction in power plant investment and a 0.55% reduction in GHG emissions. System cost is reduced by 0.47%, partly due to the reduced device cost. The lost revenue to the government of the tax credit is not included in the system cost.
EE Incentive (20%) for COM & RSD, with 90% sector AdvTech	Reduce the cost of improved, better and advanced techs in Commercial & Residential sectors by 20% starting in 2021.	Produces almost 11% reduction in power plant investment and 0.7% reduction in GHG emissions (2.2 Mt). System cost is reduced by almost 0.7%, partly due to the reduced device cost.
Baseline - ICE w 50% AdvTech	BAU scenario with ICE expansion plan and 50% allowable penetration of improved, better and advanced techs by 2050.	Reduces final energy consumption by 0.9%, fuel expenditures by over 0.5% and GHG emissions by almost 0.7%. Energy system cost is reduced almost 0.4%.
Baseline - ICE w 90% AdvTech	BAU scenario with ICE expansion plan and 90% allowable penetration of improved, better and advanced techs by 2050.	Reduces final energy consumption by 1.7%, fuel expenditures by almost 2.4% and GHG emissions by almost 7.7 Mt. Energy system cost is reduced 1%.
Public Building Efficiency Improvement	Reduce Public Build energy use by 15% and all public buildings are retrofitted by 2050 [assumes	Decreases electricity consumption 0.6% and reduces new power plant builds by 70 MW. Produces only 27 kt of GHG reductions as most of the energy saved is

	public buildings represent 10% of Commercial sector demand].	hydropower-based electricity.
LED Public Lighting	Transition to 100% LED Public Lighting by 2024.	Reduces electricity consumption by 1.2% and new power plant builds by 160 MW. Cumulative GHG emissions reductions are 68 kt.
LED Public Lighting - No ICE Exp Plan	Transition to 100% LED Public Lighting by 2024 - using No ICE Expansion Plan scenario.	Produces reductions in power plant new builds in 2021 and 2024 that are not allowed when the measure is run with the core Baseline scenario. Reduces electricity consumption by 3.2% due to the early savings achieved. Cumulative GHG emissions reductions are 650 kt.
Bioenergy Utilization by AGR & IND	Increase use of organic residues by Agriculture and Industry sectors.	Increases use of fuelwood, agricultural residues and biogases to displace diesel fuel, other oil products and some electricity. Biofuels are diverted from the power sector, resulting in an increased investment in wind power. Cumulative GHG emissions are reduced by 1.2% (3.9 Mt).
Cement Industry Fuel switching	Increase bio-energy demand in Cement sector to 75% of all process heat demand to the Other sector by 2050.	Produces almost a 2.2% reduction in GHG emissions due to fuel switching away from other oil products (largely petroleum coke) to fuelwood and agriculture residues.
Coffee NAMA	Improve process efficiency in Coffee sector by forcing new Improved boilers and furnaces.	Reduce only a very small amount of final energy consumption and produce very little GHG emissions reductions, as mostly biomass fuels are currently used.
All Building Efficiency Measures - 90% AdvTech	All building and appliance efficiency measures with 90% allowed improved, better and advanced techs by 2050.	The combined buildings measures produce a GHG emission reduction of 2.8 Mt, as many of the individual measures produce mostly electricity savings, and because some of the measures, such as retrofitting public buildings, have a relatively small footprint (e.g., public buildings represent only 10% of all commercial buildings).
All Industry Efficiency Measures - 90% AdvTech	All industry efficiency and fuel switching measures with 90% allowed improved, better and advanced techs by 2050.	The combination of industrial efficiency measures shows a more significant reduction of 13.2 Mt and saves $US4.5 B in fuel expenditures while increasing power plant investment $US1.0 B.
All Efficiency Measures - 90% AdvTech	All Buildings and Industry efficiency measures with 90% allowed improved, better and advanced techs by 2050.	The combination of all planned efficiency measures generate a 5.2% reduction in cumulative GHG emissions (16.9 Mt) while decreasing energy system cost by 1% ($2.3 B).
Low GHG Levy ($10-150) on Stationary Sources	Apply a Low GHG Levy ($10 To 150/t CO2 eq.) to stationary (Buildings, Industry and Power sector) emission sources.	Produces only 1.3% (4.1 Mt) reduction in cumulative GHG emissions, and increases energy system costs by $US2.3 B, but raises government revenue by US$2.2 B that could be applied to mitigation measures and improved infrastructure. However, the potential impact of re-investing funds from the levy was not included.
Low GHG Levy ($10-150/t) on Stationary Sources - 90% NT	Apply a Low GHG Levy ($10 To 150/t CO2 eq.) to stationary (Buildings, Industry and Power sector) emission sources with 90% allowed improved, better and advanced techs by 2050.	Produces a 7.6% reduction in emissions (24.7 Mt). Most of the emission reductions occur in the Industry sector. Raises government revenue by US$1.6 B that could be applied to mitigation measures and improved infrastructure. However, the potential impact of re-investing funds from the levy was not included.

Low GHG Levy ($10-150) on Stationary Sources - 90% NT & Biofuels	Apply a Low GHG Levy ($10 To 150/t CO2 eq.) to stationary (Buildings, Industry and Power sector) emission sources with 90% allowed improved, better and advanced techs by 2050 and with Biofuels allowed.	Adding the option to use biofuels has no additional impact on stationary emissions.
High GHG Levy ($10-300) on Stationary Sources	Apply a High GHG Levy ($10 to 300/t CO2 eq.) to stationary (Buildings, Industry and Power sector) emission sources.	Produces only slightly more reduction in cumulative GHG emissions (4.8 Mt) compared to the Low levy level, but more than doubles the increase in energy system costs to $US4.8 B, but raises government revenue by US$4.7 B that could be applied to mitigation measures and improved infrastructure. However, the potential impact of re-investing funds from the levy was not included.
High GHG Levy ($10-300) on Stationary Sources - 90% NT	Apply a High GHG Levy ($10 to 300/t CO2 eq.) to stationary (Buildings, Industry and Power sector) emission sources with 90% allowed improved, better and advanced techs by 2050.	Produces an 8.2% reduction in emissions (26.8 Mt) that occurs mostly in the Industry sector. Final energy use shifts from LPG, fuel oil and other petroleum products to electricity, fuelwood and agricultural residues. Raises government revenue by US$3.4 B that could be applied to mitigation measures and improved infrastructure. However, the potential impact of re-investing funds from the levy was not included.
High GHG Levy ($10-300) on Stationary Sources - 90% NT & Biofuels	Apply a High GHG Levy ($10 to 300/t CO2 eq.) to stationary (Buildings, Industry and Power sector) emission sources with 90% allowed improved, better and advanced techs by 2050 and with Biofuels allowed.	Adding the option to use biofuels has no additional impact on stationary emissions.
Enhanced Measures	**Description**	**Summary Results**
IND Fossil Fuel Reduction	Reduce fossil fuel share in Industry sectors to 25% by 2050.	Increases electricity generation by 4.6% and power plant investment by $US1.7 B. Reduces GHG emissions by 3.0 Mt.

Figure 35 shows the cumulative GHG emission reductions and MEI indicators for each of the Buildings and Industry efficiency measures and their combination. Most of the individual Building sector measures yield relatively small GHG reductions, and the combination of all Building efficiency measures yields about 2.8 Mt of emission reductions, compared to 10.3 Mt for the combination of Industry measures. Buildings sector reductions are small because most measures reduce electricity consumption, which is already mostly decarbonized. The combination of all measures in this sector, except the GHG levy, produces 11.6 Mt of emission reductions. Note that most measures have negative ARCs, and therefore are cost-effective.

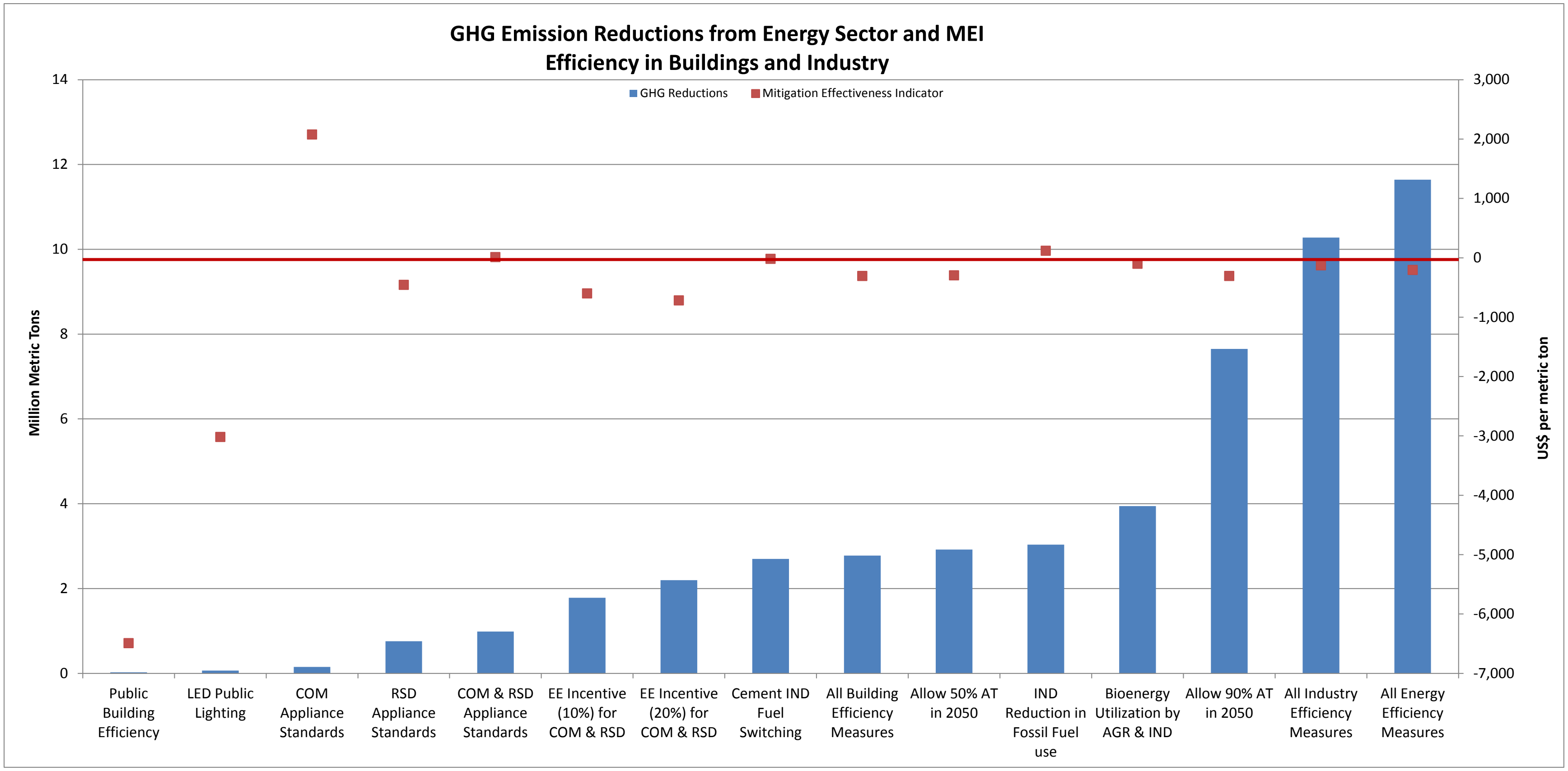


Figure 35: Emission Reductions and MEI for Efficiency in Buildings and Industry Measures

Figure 36 shows the cumulative GHG emission reductions and MEI indicators for each of the stationary source (that is non-transport) GHG emissions levy scenarios. Without access to advanced technologies, both GHG levy measures produce only 4.2 to 4.8 Mt of emission reductions, which indicates that price-only signals are not very effective unless high-efficiency technologies are also incentivized. When combined with the 90% AdvTechs measure, both stationary sources levies produce 24 to 26 Mt in emission reductions, which indicates that the High levy does not produce significantly more reductions compared to the Low levy. Also, in both case, adding the option to use biofuels has no impact on stationary emissions.

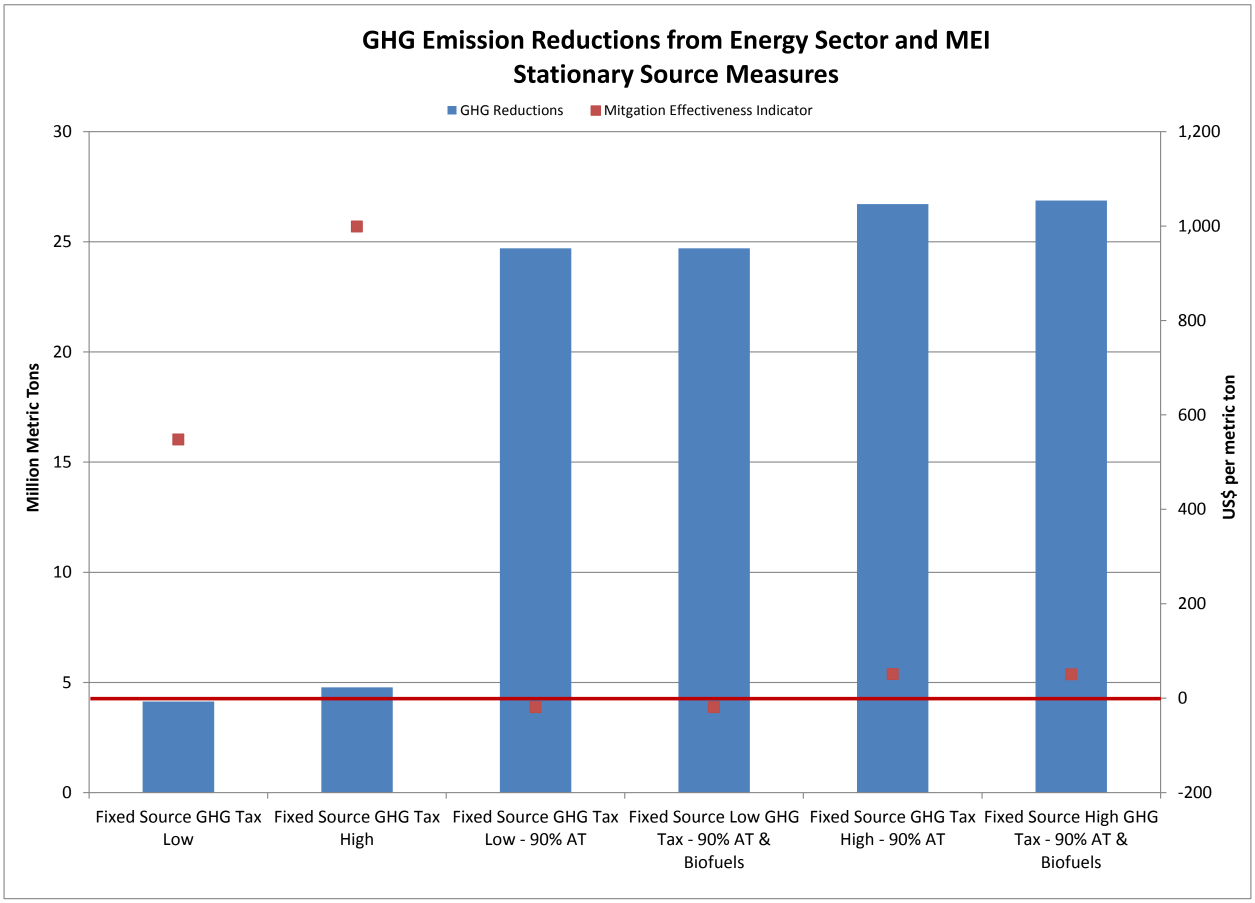


Figure 36: Emission Reductions and MEI for Fixed Source GHG Levy Measures

8.4 Transport Sector Measures

The Transport sector consists of 22 measures that cover vehicle technology improvement, mode-shifting for both passenger and freight transport, as well as cap and levy measures, as shown in Table 23. Most of the individual measures achieve less than 10 Mt in GHG emission reductions. Measures that exceed that level are the ones that allow 50% and 90% of all new vehicles using advanced technologies by 2050. The combination of non-levy Transport measures produces more GHG reductions (42 Mt) than the low GHG levy measures, but less than the high GHG transport levy (64 Mt). The 25-50% GHG Cap in 2030/2050 is feasible and produces almost 66

Mt of emission reductions, while resulting in a minimal (0.04%) change in the energy system cost thanks to the higher permitted uptake of advanced vehicles. The Enhanced measures, which include bigger infrastructure projects and behavioural changes, can produce up to 2.7% reduction in emissions.

Table 23: Transport Sector Measures

Planned Measures	Description	Summary Results
LDV clunkers	Force earlier retirement of about 20% of the existing LDVs.	Achieves a small reduction in GHG (820 kt) due to the fact that the measure affects only 20% of the existing vehicles, while increasing system cost through the added cost of buying new vehicles sooner than in the Baseline.
25% share of electric and hybrid in LDV New stock	By 2030 achieve 25% (50% by 2050) of New cars are hybrids or electric.	Reduces the energy system cost by 0.4% because over the long run, the savings in fuel expenditures outweighs the increased cost of the hybrid and electric vehicles and the cost of increasing electricity generation and investments in new power plants. The cumulative GHG emission reductions are 4% (13 Mt).
25% share of hybrid in LDV New stock	By 2030 achieve 25% (50% by 2050) of New cars are hybrids.	Reduces cumulative GHG emission by less than 0.1% (286 kt) as hybrids are not forced and the model does not find them cost-effective over the long run.
25% share of electric in LDV New stock	By 2030 achieve 25% (50% by 2050) of New cars are electric.	Increases cumulative GHG emission reductions (13.7 Mt) because of increased reduction in final energy use. Confirms that electric vehicles are cost-effective, especially after 2030.
100% share of advanced techs in Public Transport New stock	Improve share of New Advanced Taxis, Buses and Mini-buses to 100% by 2030.	Reduces 5.4 Mt in cumulative GHG emissions. The change in energy system cost is minimal because the savings in fuel expenditures balance out the increased investment in demand devices and added power plants.
Integrated Public Transport System – 8%	Move to larger buses with increased load factor and decreased vehicle efficiency (20% improvement in mpkm/PJ per bus), reduced driving distances and 8% increase in bus demand.	Reduces the energy system cost by 0.7% due to lower fuel expenditures and vehicle costs. GHG emission reductions are 0.6% (2 Mt).
Integrated Public Transport System – 35%	Move to larger buses with increased load factor and decreased vehicle efficiency (20% improvement in mpkm/PJ per bus), reduced driving distances and 35% increase in bus demand.	Reduces the energy system cost 1.1%, but GHG reductions are increased only to 2.5 Mt because the measure reduced gasoline use by LDVs is offset by increased diesel use (relative to the 8% case) to accommodate the greater bus transport demand.
5% shift of passenger transport to Non-motorized modes (cycling, walking)	Assumes 5% shift to NMT by 2030. 60% is shifted from bus demand, 40% is shifted from LDV demand.	Achieves a 6.1 Mt reduction in GHG emissions, reduces fuel expenditures by $US2.5 B and reduces energy system cost by over 2.7%.
Demand Control Measures	Administrative measures to reduce urban LDV demand, affecting 10% of LDV demand.	Reduces fuel expenditures slightly and produces only 55 kt of GHG emission reductions.

50% share of AdvTechs in all transport modes	Improve efficiency of all Road vehicles by allowing up to 50% penetration of improved and advanced techs by 2050.	Reduces fuel expenditures by $US11 B, increases investment in power plants by $US410 M due to the greater share of electric vehicles, and produces 18.4 Mt of reductions.
Reference with TRN 90% AdvTech	Allow 90% Advanced technologies and 50% fuel shift in Transport sector.	Reduces fuel expenditures by almost $US20 B, increases investment in power plants by $US1.2 B, and produces 32.9 Mt of emission reductions.
25%-50% cap of CO2 from Transport	Reduce GHG emissions from the transport sector by 25%/50% by 2030/2050.	Achieves the target GHG emission reduction (66 Mt) because of strong access to advanced vehicle technologies and access to biofuels and electricity. Change in system cost is minimal as fuel cost savings offset increased vehicle and power plant costs.
High emissions levy on all Transport GHGs	Gradually increasing levy on emissions from entire transport sector - $10/ton levy in 2018 increasing to $300/ton in 2050.	Without advanced technology access achieves relatively little GHG emission reductions (1.5 Mt) compared to the following two cases where 90% advanced technology penetration is allowed.
Moderate emissions levy on all Transport GHGs with 90% AdvTech vehicles	Gradually increasing levy on emissions from entire transport sector - $10/ton levy in 2018 increasing to $150/ton in 2050 with 90% allowed penetration of improved and advanced techs.	Achieves over 10% reduction in cumulative emissions (33.7 Mt), but increases system cost by 1.2% as the fuel cost savings does not fully offset the increased vehicle and power plant costs plus the levy.
High emissions levy on all Transport GHGs with 90% AdvTech vehicles	Gradually increasing levy on emissions from entire transport sector - $10/ton levy in 2018 increasing to $300/ton in 2050 with 90% allowed penetration of improved and advanced techs.	Achieves over 11.6% (37.8 Mt) reduction in cumulative GHG emissions which indicates that there are diminishing returns for going much beyond a levy of $150/t.
Combines all TRN technology and mode-shift measures	Combines individual planned measures.	Achieves a 13% reduction in GHG emissions (42 Mt) through the implementation of advanced technology, such as hybrid and electric vehicles, and promotion of public transport measures. System cost is reduced by 6% ($US13.8 B) due to fuel and device cost savings.
Combines planned individual measures with the Biofuels scenario	Combines individual planned measures with biofuel access.	The addition of biofuels to the allowed fuel mix does not impact the results, primarily due to the assumed 10% higher cost of biofuels over traditional fuels.
Combines planned individual measures with the Biofuels and High TRN emissions levy scenarios	Combines individual planned measures with biofuel access and high transport emission levy.	Even when the GHG levy is added, the addition of biofuels to the allowed fuel mix increases cumulative GHG emission reductions to over 14% (46.2 Mt).
Enhanced Measures	**Description**	**Summary Results**
5.4% shift from LDV to tram	To improve urban mass transit plans to shift 5.4% of LDV demand to urban trains by 2030.	Achieves a 3.5 Mt reduction in GHG emissions, and reduces energy system cost by over $US3.0 B as the increase in electricity demand does not offset the savings in vehicle costs and fuel expenditures. However, infrastructure costs are not included.

Intercity Rail (Enhanced)	Intercity train connecting the four main cities shifting 57 Mpkm of passenger demand from cars to intercity rail by 2050.	Achieves only 134 kt of GHG emission reductions because the demand shift (57 mpkm) is quite small. Infrastructure costs estimated at $US1.6 B are not included.
Rail Freight (Enhanced)	Improve rail freight capacity to shift 25% of heavy truck demand to rail by 2050.	Produces 7.8 Mt of GHG emission reductions and reduces the energy system cost by US$4.2 B as the savings in fuel expenditures outweigh the cost of increased electricity generation. Infrastructure costs of US$1.6 B were not included.
Green driving	Measure affects 50% of vehicles. LDV and taxi efficiency is increased by 5%, bus, mini-bus and LCV by 2%.	Achieves almost 2.1 Mt reduction in GHG emissions, reduces fuel expenditures by $US1.0 B and reduces energy system cost by over 0.2%.

Figure 37 shows the cumulative GHG emission reductions and MEI indicators for each of the Transport sector measures. Note that about two-thirds of the Transport sector measures have a negative MEI indicator, and therefore are cost-effective even without internalizing co-benefits like health and efficiency gains from reduced pollutants and congestion. However, some costs are not considered, mainly costs of “soft” measures” such as costs for behavior change programs for mode shifts, information campaigns, green driving training programs etc., as well as some infrastructure costs such as bike lines, pedestrian lines.

Figure 38 shows the cumulative GHG emission reductions and MEI indicators for each of the Transport sector measures involving a GHG levy, Cap or combination of measures. Note that the combination scenarios all have negative ARCs, which indicates they are cost-effective, while delivering substantial emission reductions.

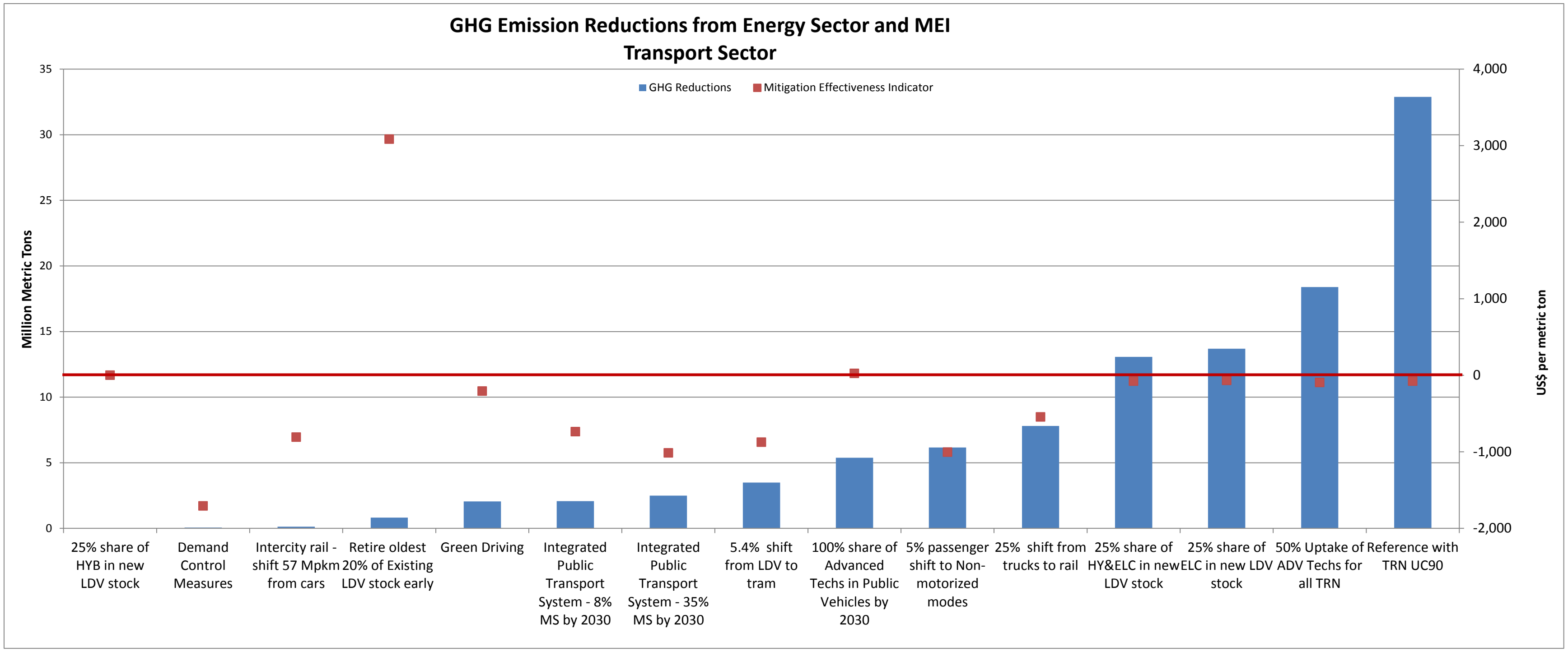


Figure 37: Emission Reductions and MEI for Transport Sector Measures

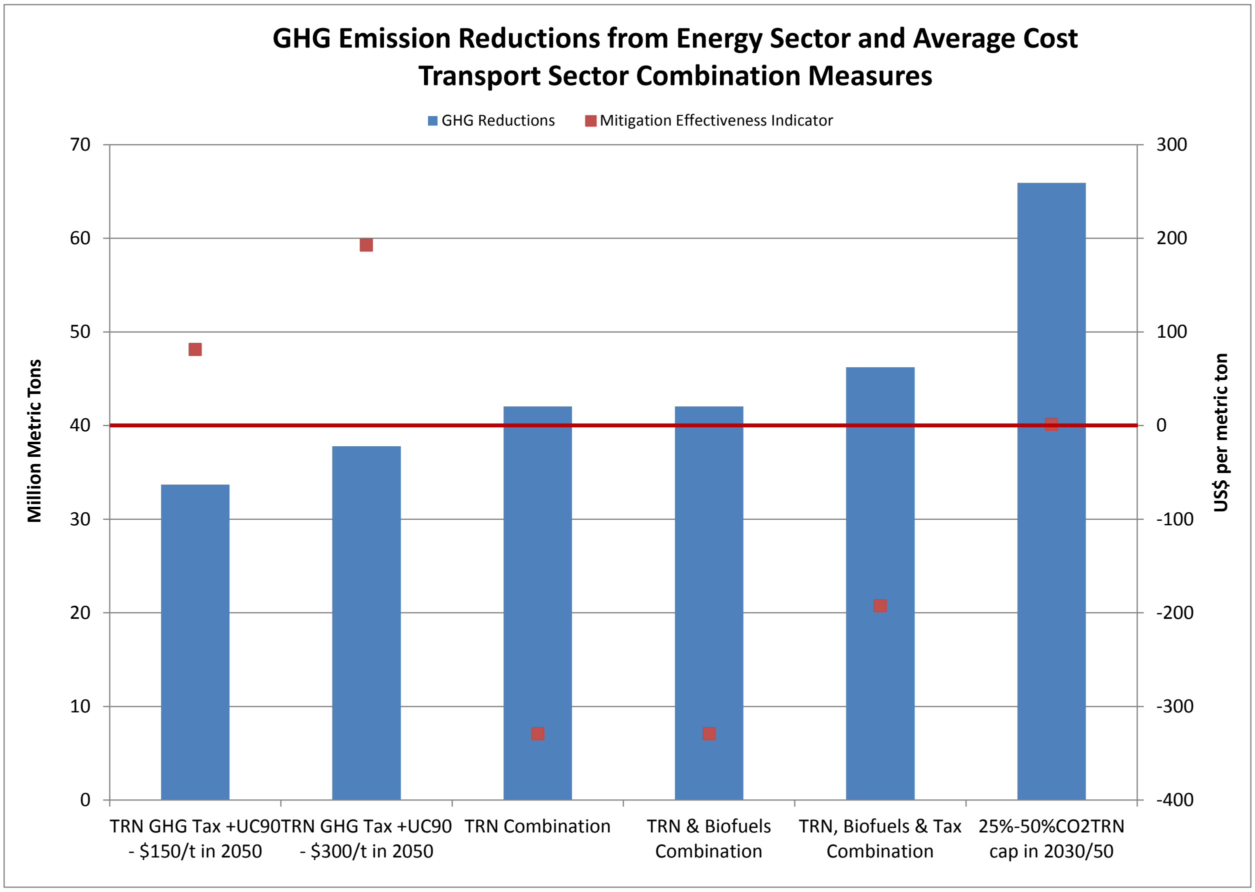


Figure 38: Emission Reductions and MEI for Transport Levy, Cap and Combination Measures

8.5 GHG Levy Measures

This section examines measures that apply a GHG levy to the entire energy system. Two levels of levy were considered: a Low GHG Levy that starts at $10/t in 2021 and increases linearly to $150/t CO2 eq. in 2050, and a High GHG Levy starts $10/t in 2021 and increases linearly to $300/t CO2 eq. in 2050. Neither levy achieves significant emission reductions without incentivizing advanced demand device technologies. However, with incentives the emission reduction increases dramatically, and the energy system cost decreases because of the cost-effectiveness of the advanced demand devices more than covers the cost of the more expensive devices and increased power sector investments needed to achieve the GHG emission reductions.

Table 24: System-wide GHG Levy Measures

Planned Measures	Description	Summary Results
Low GHG Levy ($10-150/t) on All Sectors	Apply a Low GHG Levy ($10 To 150/t CO2 eq.) to All sectors.	Without incentives to promote advanced demand devices, emission reductions are only 4.6 Mt, with a 3.7% increase in the energy system cost.

Low GHG Levy ($10-150/t) on All Sectors - 90% AT	Apply a Low GHG Levy ($10 To 150/t CO2 eq.) to All sectors with 90% allowed improved, better and advanced techs by 2050.	With advanced demand devices emission reduction increases to 59 Mt, and the energy system cost increases by 1%.
Low GHG Levy ($10-150/t) on All Sectors - 90% AT & Biofuels	Apply a Low GHG Levy ($10 To 150/t CO2 eq.) to All sectors with 90% allowed improved, better and advanced techs by 2050 with biofuels allowed.	Does not significantly increase the use of biofuels.
High GHG Levy ($10-300/t) on All Sectors	Apply a High GHG Levy ($10 to 300/t CO2 eq.) to All sectors.	Without advanced technology incentives produces only 6.2 Mt of emission reductions, and the energy system cost increases by 8.1%.
High GHG Levy ($10-300/t) on All Sectors - 90% AT	Apply a High GHG Levy ($10 To 300/t CO2 eq.) to All sectors with 90% allowed improved, better and advanced techs by 2050.	With advanced technology incentives emission reduction increases to 65 Mt, but the energy system cost increases by 4.5%.
High GHG Levy ($10-300/t) on All Sectors - 90% AT & Biofuels	Apply a High GHG Levy ($10 To 300/t CO2 eq.) to All sectors with 90% allowed improved, better and advanced techs by 2050 with biofuels allowed.	Allowing biofuels increases the GHG emission reductions to almost 78 Mt.

Note that for all these measures, the cost of the levy is charged against the energy system, but that revenue could be used to subsidize lower income households, incentivize energy efficiency, fund infrastructure for mode shifting, or support other measures that benefit the energy system. Looking for example, at the High GHG Levy with 90% AdvTech case, while the energy system cost increases by $US6.4 Billion, the total levy collected exceeds that at $US15.9 Billion, meaning that the overall actual costs for the energy system have come down (due to the move to more efficient technologies and such).

8.6 GHG Target Measures

Three system-wide GHG emission target measures were examined – 40%, 50% and 60% below the Baseline in 2050. The 60% case represents the energy systems share of the NDC target for 2050, and the 40% and 50% cases are sensitivity analyses to understand how the energy system responds to the GHG cap. Each target was examined with and without biofuels.

The two 40% target cases both generate over 88 Mt in cumulative emission reductions between 2015 and 2050, and the 50% target case with biofuels achieves 107 Mt of emission reductions. However, the 50% case without biofuels and both 60% reduction scenarios are not feasible, unless supplemented by Enhanced measures as discussed in the next section.

Although the two 40% target cases generate similar emission reductions, without biofuels the energy system cost increases about 12.5% compared to a 3.2% increase for the case with biofuels. This is because without biofuels the model needs to use more expensive electric vehicles and generate more electricity from renewables to get emission reductions in the transport sector. The 50% target case with biofuels increases the energy system cost 5.4%.

Table 25: GHG Target Measures

Planned Measures	Description	Summary Results
40% GHG Emission Reduction - 90% AT	25% reduction in GHG emissions from Baseline in 2030 and 40% reduction in 2050 with 90% allowed improved, better and advanced techs by 2050.	Generates over 88 Mt in cumulative emission reductions, but the energy system cost increases about 12.5%.
40% GHG Emission Reduction - 90% AT w Biofuels	25% reduction in GHG emissions from Baseline in 2030 and 40% reduction in 2050 with 90% allowed improved, better and advanced techs by 2050.	Generates over 88.5 Mt in cumulative emission reductions, and the energy system cost increases 3.2%.
50% GHG Emission Reduction - 90% AT	30% reduction in GHG emissions from Baseline in 2030 and 50% reduction in 2050 with 90% allowed improved, better and advanced technologies.	Not Feasible. Cannot achieve enough reductions for agriculture tractors (diesel), as well as coal and petroleum coke in industry.
50% GHG Emission Reduction - 90% AT w Biofuels	30% reduction in GHG emissions from Baseline in 2030 and 50% reduction in 2050 with 90% allowed improved, better and advanced techs and biofuels.	Achieves over 107 Mt in emission reductions, and increases the energy system cost by 5.4%.
60% GHG Emission Reduction - 90% AT	44% reduction in GHG emissions from Baseline in 2030 and 60% reduction in 2050 with 90% allowed improved, better and advanced techs.	Not Feasible. Cannot achieve enough reductions for all transport fuels, as well as coal and petroleum coke in industry.
60% GHG Emission Reduction - 90% AT w Biofuels	44% reduction in GHG emissions from Baseline in 2030 and 60% reduction in 2050 with 90% allowed improved, better and advanced techs and biofuels.	Not Feasible. Cannot achieve enough reductions for agriculture tractors (diesel), as well as coal and petroleum coke in industry in 2030 only.

9 Combined Policy Runs

While it is important to analyze how individual measures affect the energy system, the individual measures interact with each other so they cannot necessarily be added up to determine the aggregate reduction that might be achieved. The TIMES-CR model properly accounts for these interactions, and in this section we examine the combined impact of the Planned measures in the three policy areas discussed above, and then the NDC target, biofuels option and GHG taxes are added to this Combined scenario to begin the process of examining what insights the TIMES-CR model provides regarding areas where Enhanced policies may be needed to achieve the NDC goals, as discussed in Section 9. A more detailed discussion of the Combined scenarios is also included in Appendix E.

9.1 Planned Policy Combination

The All Planned policies scenario integrates the planned Supply and Power, Building and Industry Efficiency and Transport sector measures with 90% allowed Improved, Better and Advanced technologies and biofuels. As shown in Figure 39, the Planned policies combination achieves over 103 Mt of cumulative GHG emission reductions, compared to 2.8 Mt for All Building Efficiency Measures, 10.3 Mt for All Industry Efficiency Measures, 42 Mt for the

Transport & Biofuels Combination, and 56.4 Mt for All Supply & Power Measures. Biofuels are a common measure between the latter two scenarios, and these overlapping measures are primarily why the All Planned policies scenario is much less than the sum of the components.

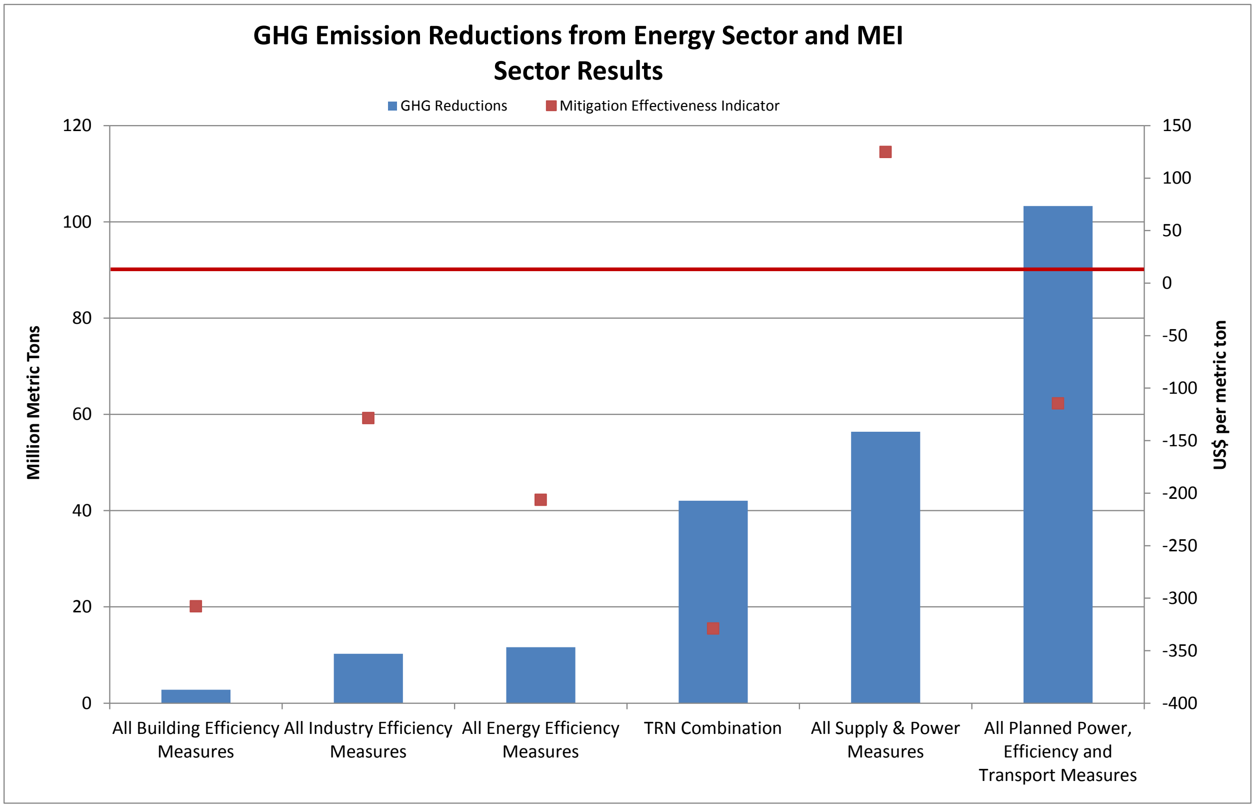


Figure 39: GHG Emissions and MEI for Sectoral and All Planned Policies Scenarios

Table 26 shows the sectoral breakdown of GHG emission reductions achieved by the Planned policies. The Transport and Industry sectors account for 97% of all reductions (78% and 19% respectively).

Table 26: 2015-2050 Cumulative GHG Emissions by Sector (kt CO2 eq.)

Emissions	Source	Baseline - ICE Exp Plan to 2027	All Planned Measures	Reductions Achieved by Planned Measures
Carbon dioxide	Agriculture	7,655	5,910	1,745
	Commercial	5,682	5,474	208
	Industry	64,589	45,515	19,074
	Power	1,219	1,217	3
	Residential	6,910	5,616	1,294
	Transport	230,581	149,632	80,949
Methane	Entire Energy sector	1,440	1,417	23
Nitrous Oxide	Entire Energy sector	3,238	2,932	306
Total	**Entire Energy sector**	**321,314**	**217,713**	**103,601**

Figure 40 shows the breakdown of GHG emissions by gas and sector for the Baseline and All Planned policies scenarios. The 2050 GHG emission level from the energy sector is 5,207 kt CO2eg, compared to 11,066 kt in the Baseline, which is a 53% reduction. However, the GHG emissions reduction NDC target for the energy sector has been estimated to be 60% below the Baseline in 2050. Therefore, Enhanced policies need to be identified that can cost-effectively fill the gap.

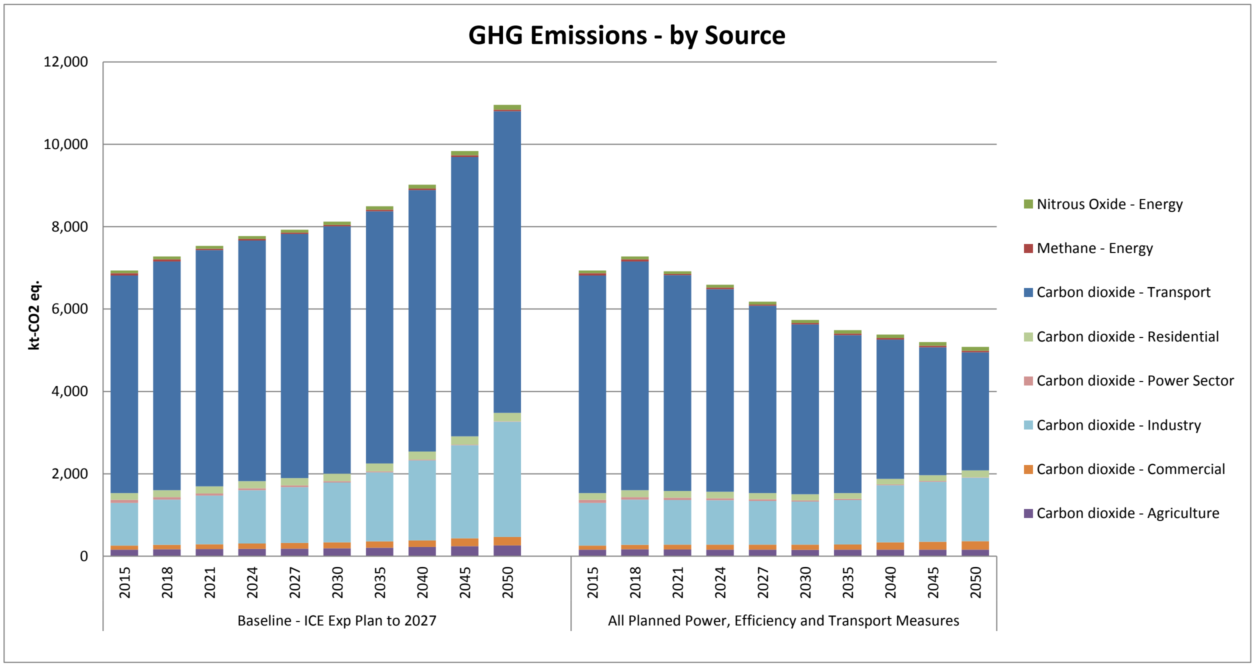


Figure 40: GHG Emissions for Baseline and All Planned Policies Scenarios

9.2 Enhanced Policy Combinations

As noted in the previous section, the Planned policy measures fall short of achieving the reductions goals of the NDC, estimated as a 60% reduction from the baseline in 2050, and so additional Enhanced measures need to be considered. First, the Enhanced policy measures identified during the study were added to the All Planned policies scenario as the Planned and Enhanced run. Although this scenario increases the emission reduction in 2050 to 56%, a gap in GHG emission reductions remains to reach the NDC reduction target. To help identify the additional Enhanced measures needed, the Planned & Enhanced policies were run with the 60% GHG emission reduction target, which forces the level of emission reduction needed to meet the NDC goal. Examination of how the GHG gap between the Planned & Enhanced policies and the NDC target run is eliminated provides an initial indication of what additional Enhanced measure are needed.

The rest of this section provides a sense of what the Planned and Enhanced measures are able to achieve, and examines the gap remaining to reach the NDC target by identifying the sectors where the additional GHG emission reductions are achieved and the changes in power generation and FEC. Then Section 9 examines the technology shifts that facilitate achieving the additional GHG reductions to determine exactly what measures need to happen (e.g., how many more of what kind of vehicles need to be purchased). Together these sections provide a picture of what a least-cost NDC roadmap for Costa Rica might look like and entail.

9.2.1 GHG Emissions

The 60% GHG target cannot be achieved without polices and measures that effectuate change. However, the contributions from all the Planned and Enhanced measures make achieving the 60% GHG target possible. As shown in Figure 41, the Planned & Enhanced Measures with 60% target run makes additional emission reductions starting in 2021 mostly from the Transport sector early, and the Industry sector later. This scenario achieves over 139 Mt in GHG emission reductions, while increasing energy system cost by 6.9% (almost $US16 B).

Table 27 provides a breakdown of the additional emission and shows that 93% of the additional GHG emissions reductions needed to achieve the NDC target are found in the Transport and Industry sectors.

The additional measures needed to move from the Planned & Enhanced policies scenario to the NDC target are examined in the next few charts, which highlight the changes between the NDC target scenario and the Planned Policy scenario (not the Baseline scenario.)

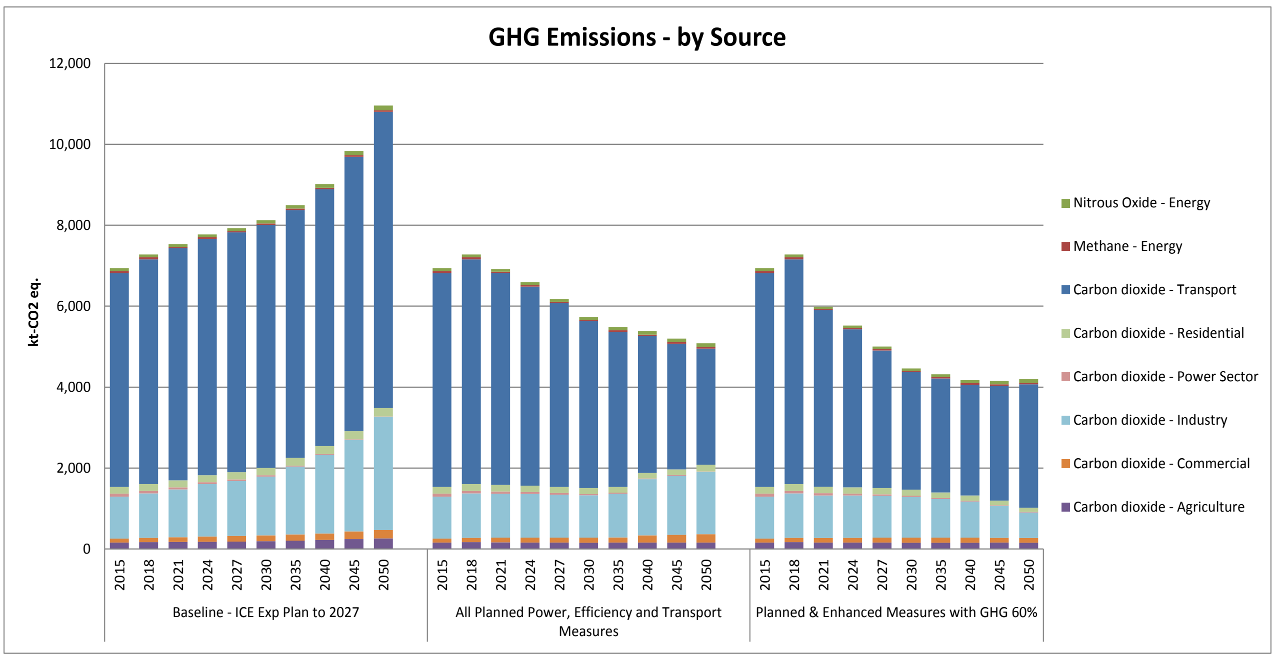


Figure 41: GHG Emissions for Planned Policy Measures without and with 60% GHG Target

Table 27: 2015-2050 Cumulative GHG Emissions from Enhamced Policy Runs (kt CO2 eq.)

Emissions	Source	Planned & Enhanced Measures	Planned & Enhanced Measures with GHG 60%	Additional Reductions Needed

Carbon dioxide	Agriculture	5,910	5,834	76
	Commercial	5,474	4,376	1,098
	Industry	45,165	34,076	11,089
	Power	1,217	1,217	0
	Residential	5,592	5,143	450
	Transport	144,462	127,844	16,618
Methane	Entire Energy Sector	1,404	1,357	46
Nitrous Oxide	Entire Energy Sector	2,879	2,682	198
Total	**Entire Energy Sector**	**212,103**	**182,528**	**29,575**

9.2.2 Final Energy Use

Figure 42 compares total FEC showing and shows that the known Enhanced measures make small decreases in gasoline use and increases in electricity use, but that the NDC goal requires much greater reductions in gasoline and diesel use initially through more efficient vehicles, and later through greater use of electricity to substitute for LPG, other petroleum products and some biofuels, especially after 2030.

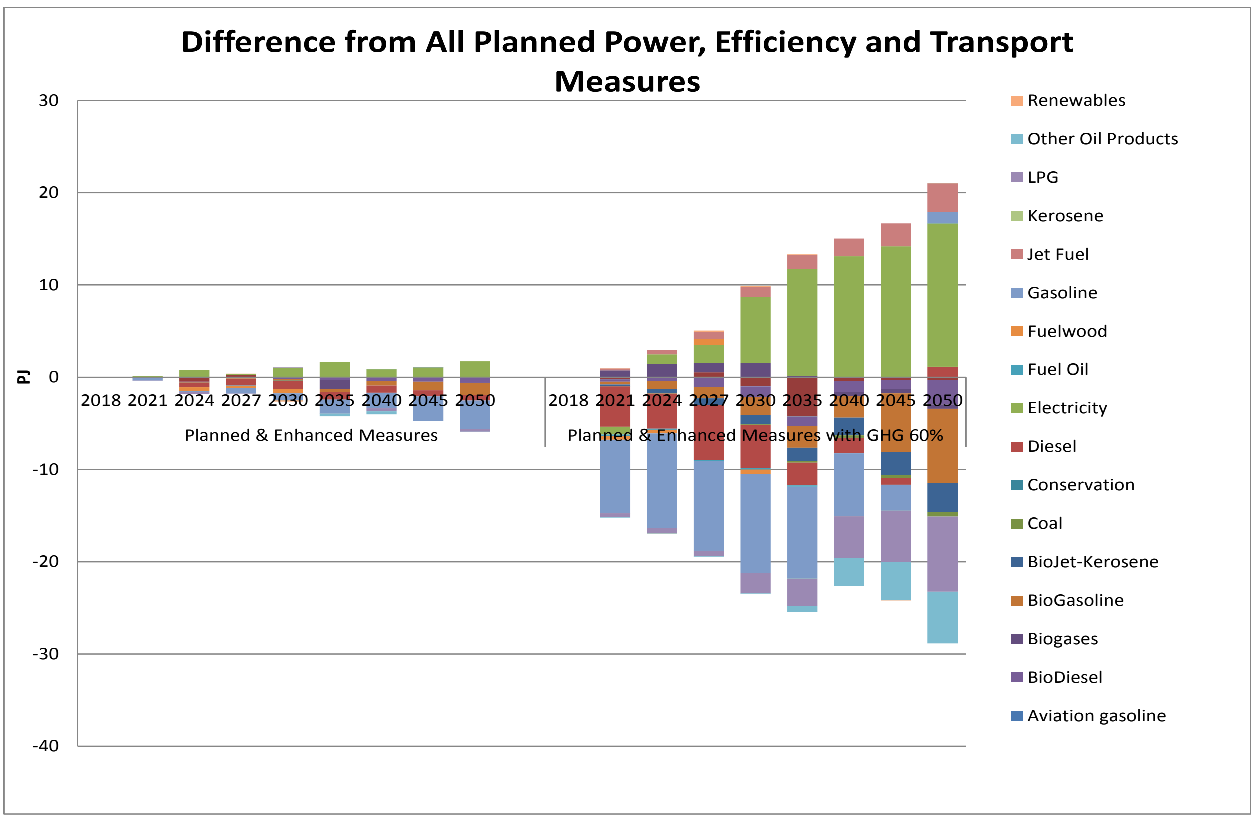


Figure 42: Change in FEC by Fuel compared to Planned Policy Scenario

Table 28 shows the cumulative changes in FEC between the Baseline, Planned, Enhanced and NDC scenarios, with positive changes in green, while negative changes are red, which provides a quick visual indication of how fuel choice changes over the entire planning horizon between the scenarios. The Planned measures reduce over 700 PJ, mostly from diesel and gasoline, while increasing use of biofuels and electricity. The Enhanced measures make small additional reductions in diesel and gasoline use, while continuing the increased use of electricity. However, to achieve the NDC goal, other fuels, particularly LPG and Other petroleum products (largely petroleum coke) need to be reduced, while electricity use increases significantly. Interestingly, some of the biofuel use in the Planned policy run is reduced in the NDC target run in favor of electricity, as higher efficiency Electric vehicles are favored over Hybrid vehicles, as will be shown in Section 9.

Table 28: 2015-2050 Changes in Cumulative Final Energy Consumption (PJ)

Fuel	Planned - Baseline	Enhanced - Planned	NDC - Enhanced	NDC - Baseline
Agricultural waste and residues	15.78	0.13	-25.71	-9.80
Aviation gasoline	0.00	0.00	-0.25	-0.25
BioDiesel	360.77	-10.22	-31.87	318.68
BioGasoline	183.98	-16.20	-91.79	75.98
BioJet-Kerosene	53.10	0.00	-52.44	0.67
Biogases	20.79	0.64	6.09	27.52
Coal	4.78	0.04	-6.52	-1.70
Diesel	-782.15	-20.70	-50.51	-853.36
Electricity	81.49	12.74	286.62	380.85
Fuel Oil	-61.79	0.01	-2.43	-64.21
Fuelwood	25.74	0.47	-1.25	24.96
Gasoline	-458.74	-49.89	-158.41	-667.04
Jet Fuel	-57.07	0.00	52.57	-4.49
Kerosene	-6.75	0.00	-0.11	-6.87
LPG	-31.58	3.07	-120.68	-149.19
Other Oil Products	-65.64	0.16	-67.78	-133.27
Renewables	13.28	0.65	0.67	14.61
Total	-704.01	-79.08	-263.80	-1,046.89

One of the concerns with liquid biofuels is size of the domestic resource and the likelihood of needing to import biofuels to meet the NDC goals. Based on the current estimates of domestic biofuels production, Figure 43 shows that the share of imported biofuels is highest in the Planned and Planned & Enhanced scenarios, with biodiesel reaching 63% and biojet-kerosene reaching 50% in 2050. Biogasoline is only domestically produced in these scenarios. However, in the NDC target scenario, the biojet-kerosene imports are eliminated, and the biodiesel imports decrease to 52% in 2050.

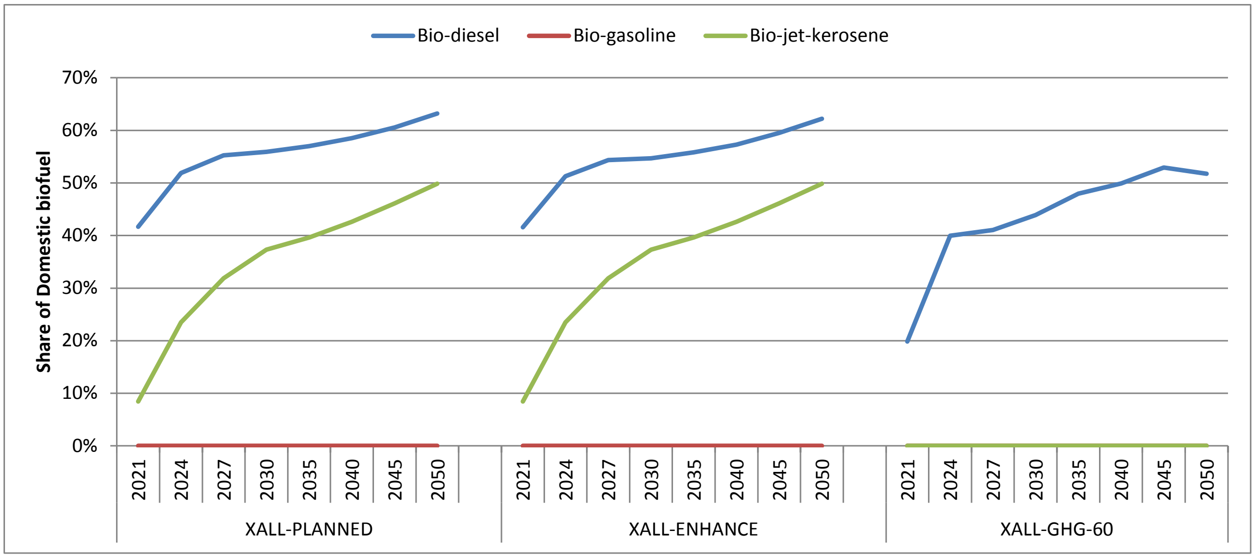


Figure 43: Share of Imported Biofuels

9.2.3 Electricity Generation and Capacity

With the known Enhanced measures total generation in 2050 increases by 2% and the NDC target increases generation by 18%, highlighting the key role that the power sector needs to play by providing green electricity to drive the low carbon economy. Figure 44 shows that identified Enhanced measures increase electricity generation from solar, geothermal and hydropower with some reductions in wind generation. The NDC target requires additional generation from solar, wind, biofuels and run-of-river hydropower to meet the increased demand for electricity.

Figure 45 shows the identified Enhanced measures build new solar plants sooner than with the Planned policies, and there is a 2050 swap of run-of-river hydropower in place of wind, which persists even if its costs are increased to $4,385/kW in 2050. The NDC target scenario builds solar, wind and biomass-fired power plants sooner, and builds run-of-river hydropower in 2045 and 2050 to meet the increased demand for clean electricity.

Table 29 shows the change in power plant investment between 2015 and 2050. The Planned policies require a net added investment of $US933 M for new solar and wind plants with reduced investments for thermal, hydropower and biomass-fired generation. The identified Enhanced measures increase investments by $US2.9 B, primarily in run-of-river hydropower, geothermal and solar. This investment averages $US82 M per year. The NDC target adds an additional $US3.7 B, primarily in run-of-river hydropower, geothermal, wind and biomass-fired plants. The total added investment averages $US217 M per year.

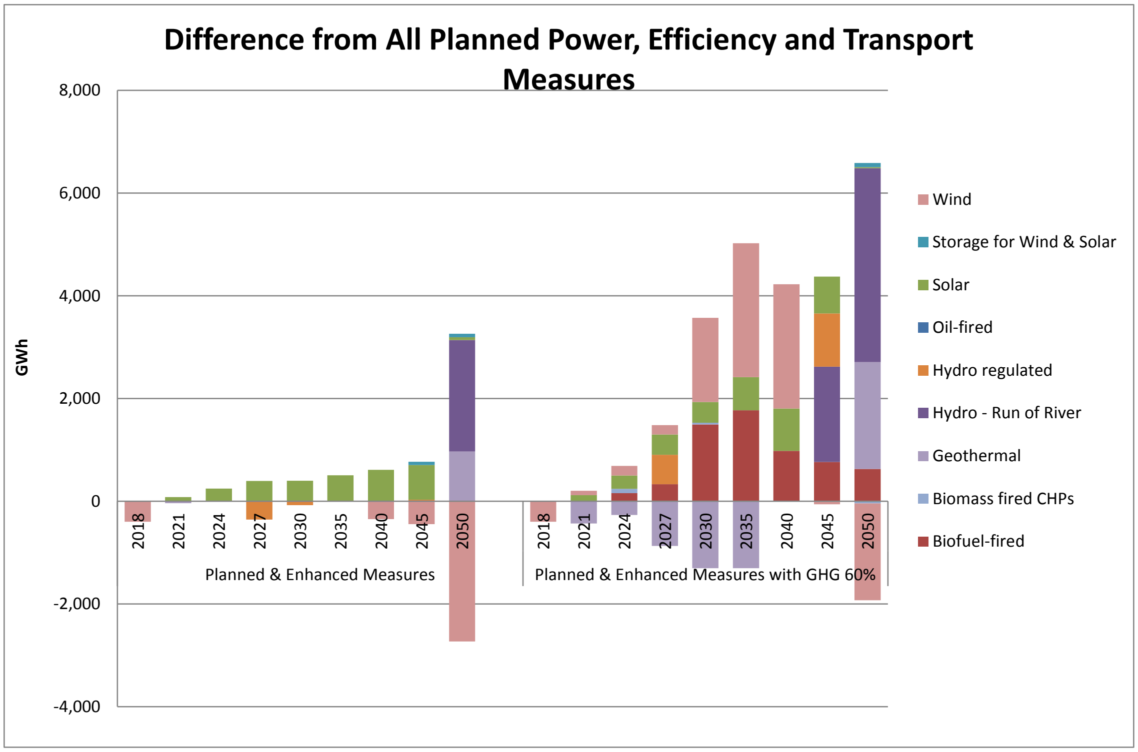


Figure 44: Change in Electricity Generation compared to Planned Policy Scenario

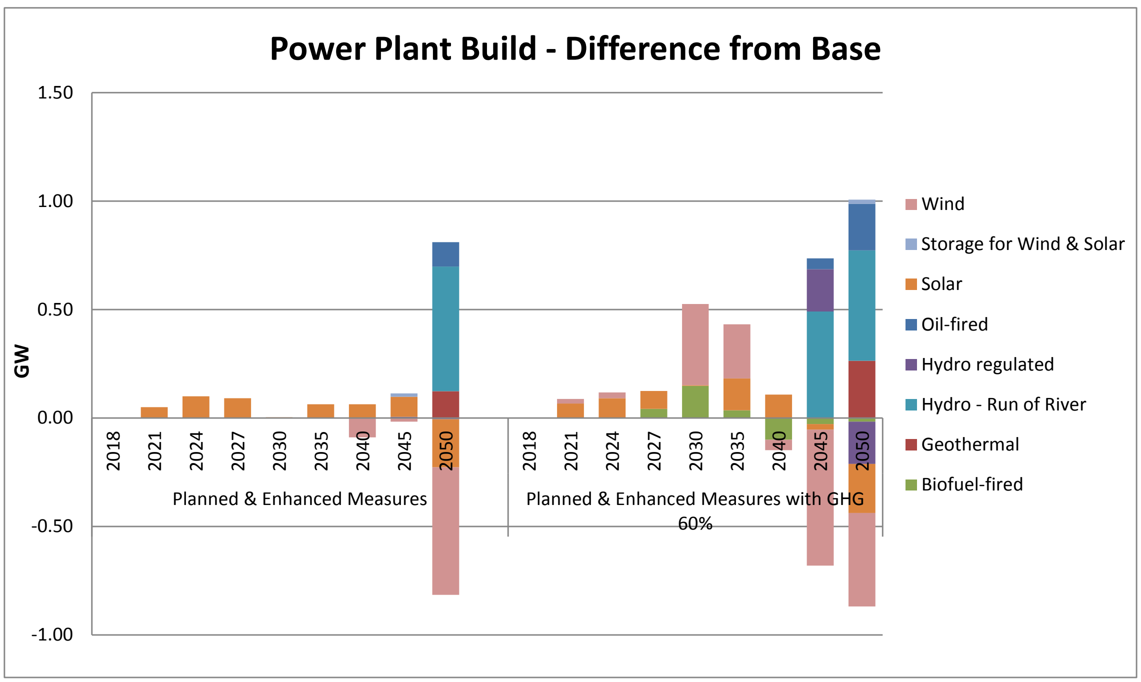


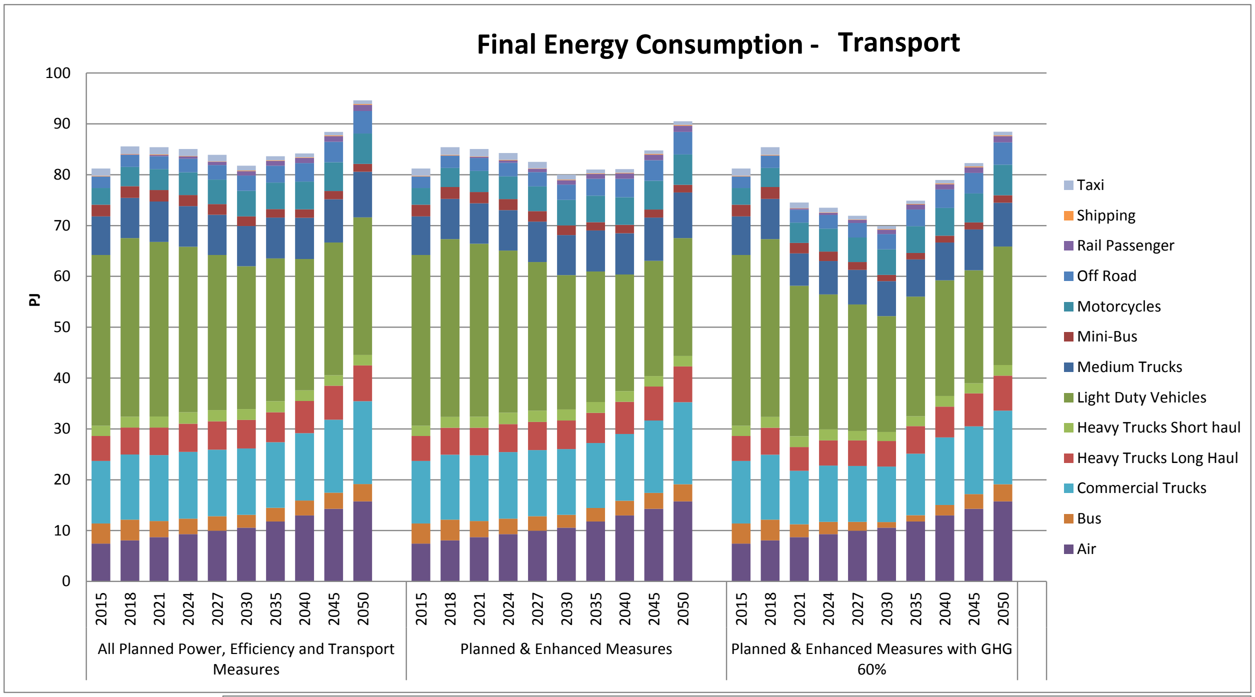
Figure 45: Change in New Power Plant Builds compared to Planned Policy Scenario

Table 29: 2015-2050 Changes in Lumpsum Power Plant Investment ($US M)

Power plant Type	Planned - Baseline	Enhanced - Planned	NDC - Enhanced	NDC - Baseline
Biofuel-fired	-79.93	0.00	151.51	71.58
Geothermal	0.00	964.23	1,101.39	2,065.61
Hydro - Run of River	-216.14	2,520.37	1,864.78	4,169.01
Hydro regulated	0.00	0.00	0.00	0.00
Oil-fired	-337.76	143.43	194.33	0.00
Solar	936.76	387.12	11.35	1,335.24
Storage for Wind & Solar	0.00	5.27	1.31	6.58
Wind	630.33	-1,075.92	408.34	-37.26
Total	933.26	2,944.50	3,733.01	7,610.77

9.2.4 Transport Sector Energy Use

Figure 46 shows the FEC in the Transport sector by mode. The known Enhanced measures primarily make reductions in LDVs energy use, but to meet the NDC target, reductions are also needed from LCVs, medium trucks and heavy trucks. Table 30 shows the change in cumulative FEC for the Transport sector by fuel, which not surprisingly follows the changes to the total FEC, with reductions in diesel and gasoline, and increases in biofuels and electricity. Note that electricity use in Transport increases more than for the total FEC because of efficiency improvements in the other sectors that reduce electricity consumption. Overall, the NDC target requires diesel and gasoline in transport to be reduced 66% and 68%, respectively in 2050. Electricity use increases to 17% of all transport fuels and 47% of all LDV fuel use. Liquid biofuels comprise 30% of the total transport fuels in 2050, and are preferred by trucks of all types, which will be examined in Section 9.



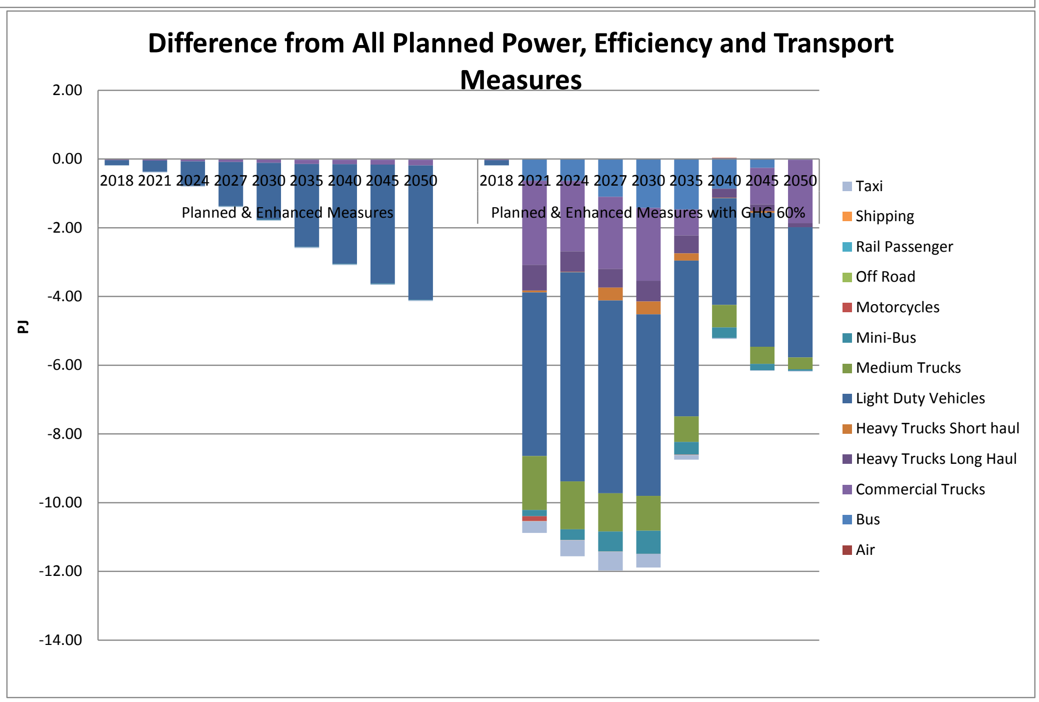


Figure 46: FEC for Transport and Change compared to Planned Policy Scenario

Table 30: 2015-2050 Changes in Transport FEC by Fuel (PJ)

Fuel Category	Planned - Baseline	Enhanced - Planned	NDC - Enhanced	NDC - Baseline
Aviation gasoline	0	0	0	0
BioDiesel	338	-10	-33	309
BioGasoline	177	-16	-86	125
BioJet-Kerosene	52	0	-52	49
Diesel	-664	-21	-75	-761
Electricity	148	19	165	333
Gasoline	-471	-50	-141	-715
Jet Fuel	-52	0	3	-48
LPG	14	-3	-21	-5
Total	**-457**	**-80**	**-190**	**-714**

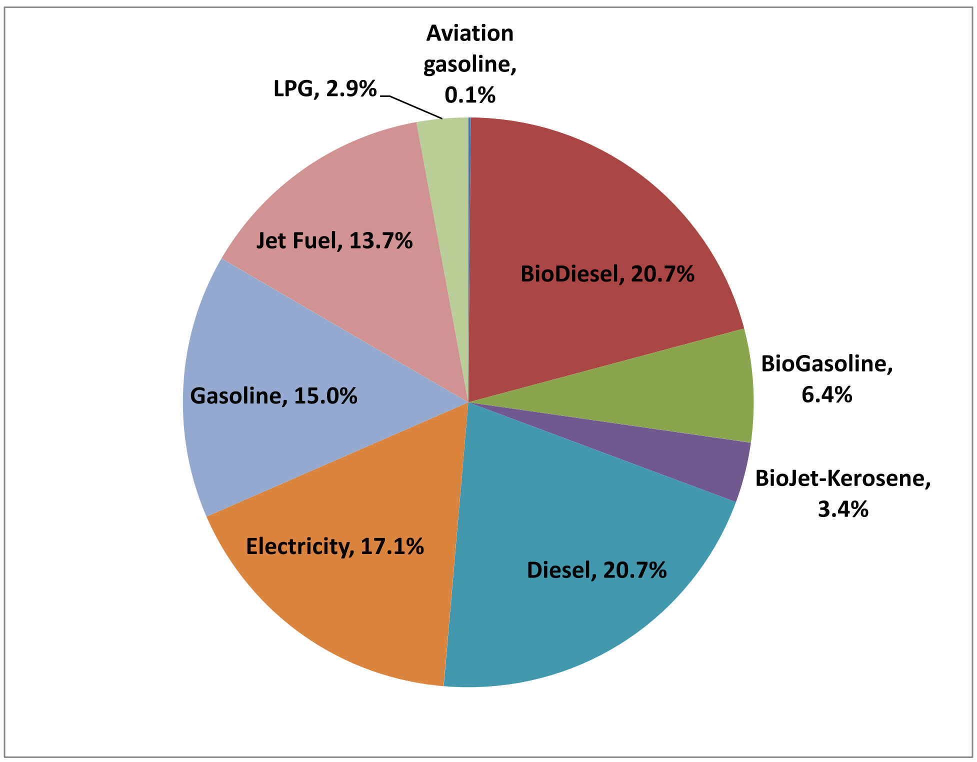


Figure 47: 2050 Shares of All Transport Fuels under the NDC Target Scenario

9.2.5 Industry Sector Energy Use

Figure 48 shows the change in Industry sector energy use by subsector, and clearly indicates the known Enhanced measures decrease energy use in the Wood Products subsector and increase use of biomass in the Food and Tobacco subsector in later periods. The NDC target requires additional reductions primarily from the Food and Tobacco and Other subsectors and Wood

Products subsector. Figure 49 shows the change in Industry FEC, and indicates that the known Enhanced measures increase fuel switching from LPG to electricity. The NDC Target requires additional measures reduce petroleum coke and LPG, both of which are switched to electricity.

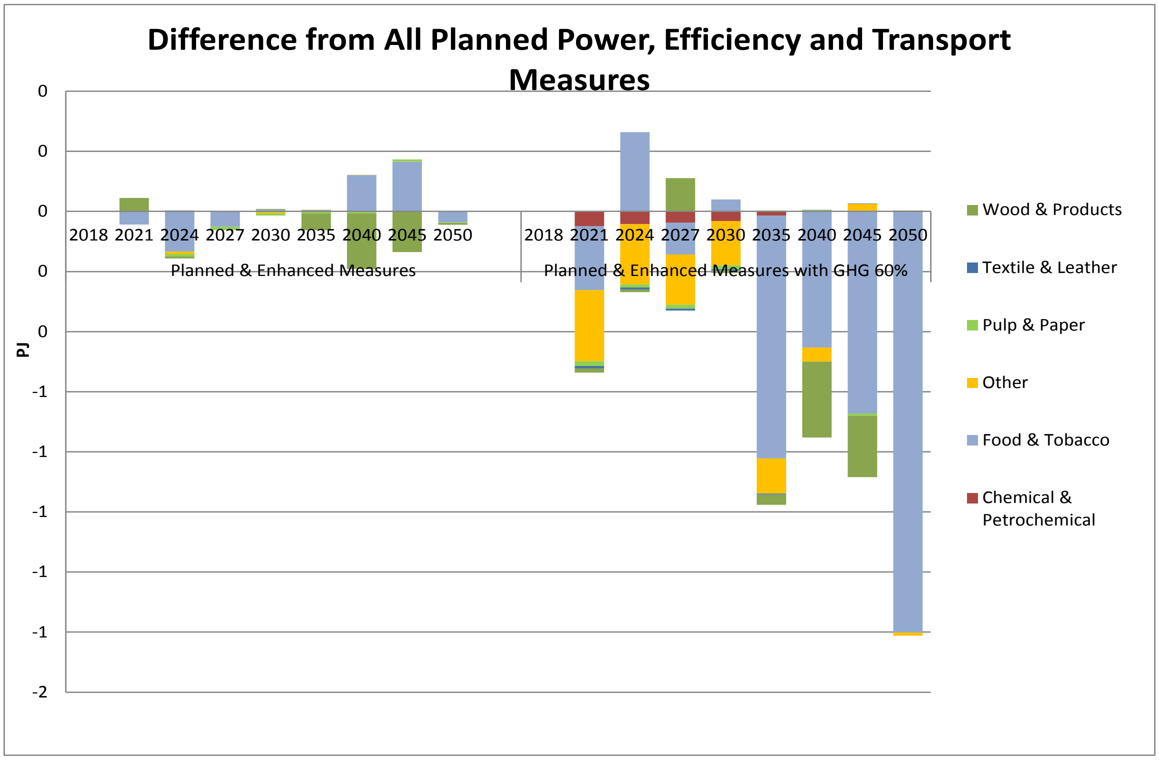


Figure 48: Change in FEC by Industry Sub-Sector compared to Planned Policy

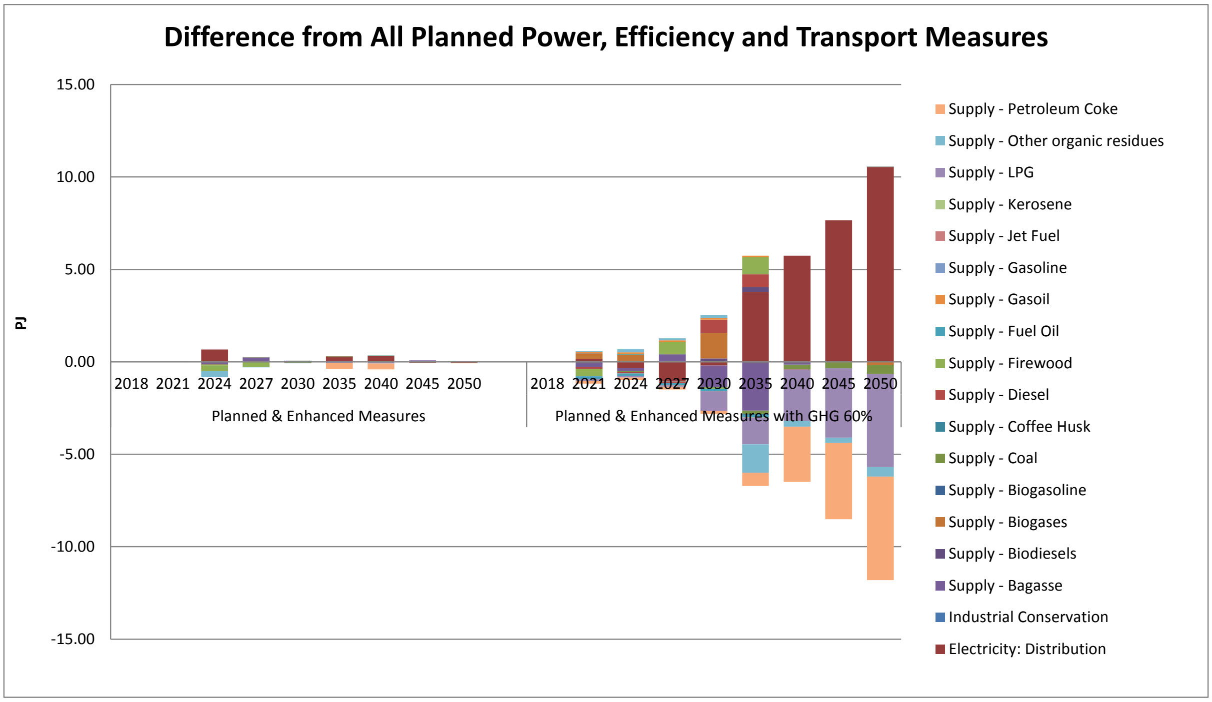


Figure 49: Change in Industry Sector Fuel Consumption compared to Planned Policy

9.2.6 Building Sector Energy Use

There are small but important emission reductions to be found in the Commercial and Residential sectors. In the Commercial sector, the LPG for cooking is replaced with electricity, and in the Residential sector there is increased use of biogas, fuelwood, and solar for water heating and cooking.

9.3 Non-energy Mitigation Measure Example

As the non-energy emission sectors were a secondary priority, and because data from all the sectors was not available, an example showing how they can be factored into the NDC analysis was performed using a REDD+ strategic mitigation measure that reduces deforestation and forest degradation, and fosters conservation, sustainable management of forests, and enhancement of forest carbon stocks. The annual potential reductions were estimated at 2,053,323 tCO_2 per year, with a cost of $15/t, based on the recent REDD+ Strategy, which projected 28.75 million tons of emission reductions up to 2025 based on current policy, with the possibility of additional emission reductions being achieved in the future. As there are currently no estimates after 2025, for this example, the maximum REDD+ reduction was limited to 28.75 million tons.

To illustrate the potential impact of this REDD+ mitigation measure, it was assumed that all the REDD+ emission reductions would offset energy sector emissions. Given that the Forestry and Land Use sector is a net absorber of CO_2, this assumption is seen as reasonable. Table 31 contains the results metrics for the Planned & Enhanced Measures and the NDC target runs with and without the REDD+ measure. Comparing the latter two scenarios, the addition of the REDD+ measure to the NDC target lowers the impact on the energy system cost by over $US20 B between 2015 and 2050, because net energy sector emission reductions are offset by 22.5 Mt (2018 thru 2027) of REDD+ reductions. The increases in electricity generation are similar to the NDC target case without REDD+, but the purchases for advanced end-use technologies (mostly advanced vehicles) is reduced by approximately $US30 B.

If these REDD+ strategic measures are fully implemented, the mitigation requirements of the energy sector are significantly reduced between 2018 and 2027, which delays energy sector reductions that would otherwise occur, especially in the Transport sector. As a result, the REDD+ scenario causes a rather abrupt shift from gasoline to electricity in the 2030 period. This transition happens more gradually in the NDC target run. The transition has a relatively small impact on electricity generation requirements, primarily because power plant builds thru 2027 are fixed to the ICE expansion plan.

Table 31: Example Non-energy (REDD+) Mitigation Measure Impacts

Metrics / Scenario	Baseline - ICE 2027	Planned & Enhanced Measures		Planned & Enhanced Measures with GHG 60% & REDD+		Planned & Enhanced Measures with GHG 60%	
	Value	Difference	% Change	Difference	% Change	Difference	% Change
System Cost (2015$M)	228,212	-12,392	-5.43%	-4,274	-1.87%	15,812	6.93%
Primary Energy (PJ)	9,975	-733	-7.35%	-972	-9.75%	-1,131	-11.34%
Electricity Generation (GWh)	642,439	17,931	2.79%	97,143	15.12%	101,682	15.83%
Final Energy Consumption (PJ)	8,212.05	-783	-9.54%	-917	-11.17%	-1,040	-12.66%
PP Builds (GW)	3.92	1.04	26.41%	2.05	52.36%	2.10	53.64%
Electricity Investment (2015$M)	14,546	3,878	26.66%	7,709	53.00%	7,611	52.32%
Demand Device Purchases (2015$M)	290,920	-12,067	-4.15%	15,441	5.31%	45,938	15.79%
Fuel Expenditures (2015$M)	184,668	-24,113	-13.06%	-42,338	-22.93%	-45,575	-24.68%
GHG Emissions (kt CO2 eq.)	324,823	-109,062	-33.58%	-150,305	-46.27%	-139,344	-42.90%

10 Determining NDC Pathways

As introduced in the previous section, examining possible NDC pathways for Costa Rica starts by assessing the key energy sector changes between the Planned and Enhanced scenario, and the NDC Target scenario. This section provides a closer look, by sector, at the technology changes that need to occur in order to achieve the NDC target cost-effectively, and identify additional Enhanced measures.

10.1 Power Sector Measures

Table 32 shows the changes in new power plant capacity over the planning horizon, and indicates that an additional 2100 MW of new capacity is needed compared to the Baseline to meet the NDC target. About 660 MW comes from Planned policies, while all Enhanced measures need to add over 1420 MW.

Table 32: Change in New Power Plant Capacity, 2015-2050 (MW)

Technology	Planned - Baseline	Enhanced - Planned	NDC - Enhanced	NDC - Baseline
Biomass-fired	-45	0	80	35
Geothermal	0	123	141	264
Hydro - Run-of-river	-49	575	425	951
Hydro regulated	0	0	0	0
Oil-fired	-266	113	0	0
Solar	614	243	5	863
Wind	407	-694	260	-28
Total	661	360	1064	2104

The key Planned measures for this sector include the RE Share of GFE, the Biofuels Target and the measures to expand solar resources beyond the Baseline. The known Enhanced measures increase capacity of geothermal, run-of-river hydro and solar while decreasing wind. The oil-fired capacity that is added in the Enhanced scenario uses a blend of diesel and biodiesel. To meet the NDC target, another 425 MW of run-of-river hydro is needed along with 400 MW of wind and geothermal and 80 MW of biomass-fired plants over what the Enhanced scenario delivers on its own. The blended diesel/biodiesel capacity added in the Enhanced scenario is eliminated.

10.2 Transport Sector Measures

The following tables show how technological improvements are adopted between the Planned, Enhanced and NDC scenarios in the Transport sector. The tables show changes in energy use, with positive changes shaded green, while negative changes are shaded red, which provides a quick visual indication of how technology choice changes over the entire planning horizon between the scenarios.

As shown in Table 33, which looks at passenger transport modes, the Planned measures move Buses to Improved, Advanced and Hybrid options. But the NDC scenario shifts many of the

Hybrid and Advanced buses to electricity and redirects biodiesel use to Trucks. The Planned measures move Minibuses into gasoline Hybrid and Electric vehicles, and to reach the NDC goal all Minibuses shift to Electric vehicles.

The Planned measures move LDVs into Electric and Hybrid vehicles. The known Enhanced measures continue the trend to Electric vehicles, and to meet the NDC target, all LDVs move to Electric (electric-only and plug-in hybrid) vehicles.

The Planned measures move Taxis into Electric vehicles and Hybrids, and to reach the NDC goal almost all Taxis transition to Electric vehicles, although some Hybrids remain. Air transport is not impacted since most flights are international and emissions from international air transport are not included in national inventories.

Table 33: Change in Improved Technology Adoption by Passenger Transport Mode

Change in Energy Use by Technology Type (PJ)					
Quality	**Technology**	**Planned - Baseline**	**Enhanced - Planned**	**NDC - Enhanced**	**NDC - Baseline**
Air	Conventional Vehicles	0	0	0	0
Bus	Advanced Vehicles	7,485	0	-13,446	-5,961
	Conventional Vehicles	-112,545	0	-6,026	-118,571
	Electric Vehicles	0		49,269	49,269
	Hybrid Vehicles	2,051	0	-2,051	0
	Improved Vehicles	60,704	0	-27,745	32,959
Light Duty Vehicles	Conventional Vehicles	-278,899	-108,783	-19,602	-407,284
	Electric Vehicles	175,196	107,317	34,109	316,622
	Hybrid Vehicles	9,311	1,466	-14,507	-3,730
Minibuses	Conventional Vehicles	-182,042	0	-13,887	-195,930
	Electric Vehicles	108,980	0	101,066	210,046
	Hybrid Vehicles	73,063	0	-87,179	-14,116
Taxi	Conventional Vehicles	-18,484	0	-2,089	-20,573
	Electric Vehicles	15,940	0	3,196	19,136
	Hybrid Vehicles	2,544	0	-1,107	1,437
		Positive	Negative		

Table 34 shows the changes in fuel consumption for LDVs. The Planned measures move LDVs into Biofuel and Electric vehicles. The known Enhanced measures continue the trend to Electric vehicles, and to meet the NDC target, all vehicles move to Electric and Biofuel vehicles. LPG use increases a little with Planned measures but is eliminated with the Enhanced and NDC measures.

Table 34: LDV Improved Technology Adoption and Fuel Use Change

LDV Fuel Use Changes (PJ)				
Fuel	**Planned - Baseline**	**Enhanced - Planned**	**NDC - Enhanced**	**NDC - Baseline**
Aviation gasoline	0	0	0	0
BioDiesel	338	-10	-33	295
BioGasoline	177	-16	-86	75
BioJet-Kerosene	52	0	-52	0
Diesel	-664	-21	-75	-760
Electricity	148	19	165	333
Gasoline	-471	-50	-141	-661
Jet Fuel	-52	0	53	0
LPG	14	-3	-21	-10
Total	-457	-80	-190	-727
	Positive	Negative		

Table 35 looks at Freight transport modes and shows that the Planned measures shift Light trucks to Improved, Advanced and Hybrid types, and decreases gasoline, diesel and LPG consumption while increasing biodiesel use. The Planned measures also shift most demand to Heavy long-haul trucks, and to reach the NDC target, biodiesel use increases, along with continued shift to Improved long-haul trucks and Advanced short-haul trucks.

Planned measures favor Improved and Hybrid technologies for Shipping and to meet the NDC target, most Ships are shifted to Hybrids. For Off-road vehicles, the Baseline scenario selects mostly Improved vehicles, and in the Planned measures a small number of conventional vehicles are added due to the increased availability of biofuels. However, these are mostly eliminated to reach the NDC target.

Table 35: Freight Transport Change in Improved Technology Adoption

Change in Energy Use by Technology Type (PJ)					
Quality	**Technology**	**Planned - Baseline**	**Enhanced - Planned**	**NDC - Enhanced**	**NDC - Baseline**
Light Trucks	Advanced Vehicles	50,582	0	-12,587	37,995
	Conventional Vehicles	-126,694	0	689	-126,006
	Hybrid Vehicles	19,196	0	40,124	59,320
	Improved Vehicles	56,916	0	-28,225	28,691
Medium & Heavy trucks	Advanced Vehicles	2,421	0	9,814	12,235
	Conventional Vehicles	-146,252	0	-162,631	-308,883
	Hybrid Vehicles	-8,523	0	72,973	64,450
	Improved Vehicles	27,547	0	79,844	107,391
Ship	Conventional Vehicles	-6,517	0	2,820	-3,697
	Hybrid Vehicles	3,418	0	-260	3,158
	Improved Vehicles	3,099	0	-2,560	538
Off-road	Conventional Vehicles	8	0	-5	3
	Improved Vehicles	-8	0	5	-3
		Positive	Negative		

To summarize, the key Planned measures in the Transport sector include targets for Electric vehicles for LDVs, Taxis, Minibuses and Buses, public transit measures, and mode shifts from Truck to Rail. Needed Enhanced measures include increased incentives for Electric vehicles, especially for LDVs, Taxis, Minibuses and Buses, and to allow more liquid biodiesel use for Trucks of all classes, Shipping and Off-road. An important ancillary measure would be incentives to increase domestic biofuel production to avoid the need for imports.

10.3 Transport Sector Indicators

The share of passenger transport demand (Mpkm) satisfied by various types of Taxis, Buses, Minibuses and LDVs was used to calculate approximate vehicle numbers by dividing the demand by the occupancy (passengers per vehicle) and average driving distance per vehicle (km/yr). The results by vehicle type are presented for each mode discussed above.

10.3.1 Light Duty Vehicles

As shown in Figure 50, the Planned policies bring in mostly plugin Hybrids up thru 2040 and all Electric vehicle after that, with a 55% share of Electric vehicles in 2050. However, the NDC target scenario brings in all Electric vehicles starting at 5% in 2021 going steadily to 60% in 2050, and bypasses Hybrids and early Plugin hybrids. The fleet of Electric vehicles goes from about 50,000 in 2021 to 740,000 in 2050.

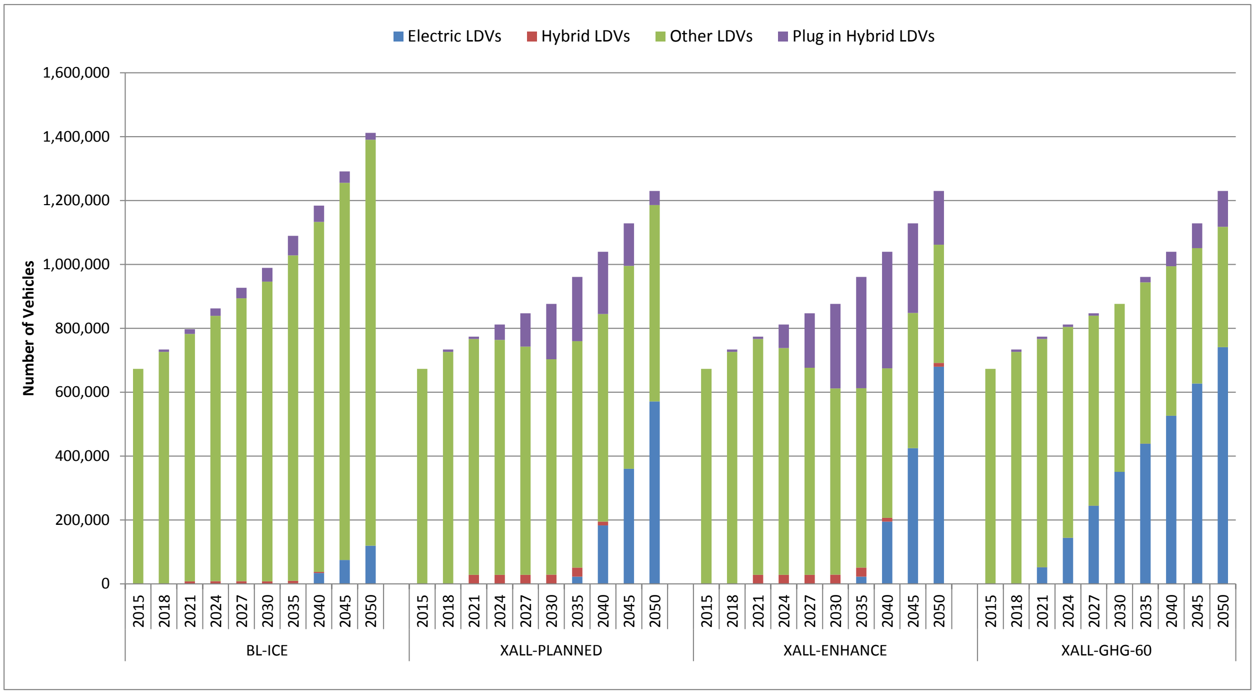


Figure 50: Share of Light Duty Vehicles by Technology Type

10.3.2 Taxis

As shown in Figure 51, the Planned policies bring in Hybrids in 2021, but after that primarily add Electric and Plug-in vehicles, which grow to 100% of the stock by 2040. The NDC target scenario brings in the Electric and Plugin vehicles starting in 2021 and grows to 100% in 2030. The total fleet of Taxis grows from about 9,000 in 2015 to 16,000 in 2050.

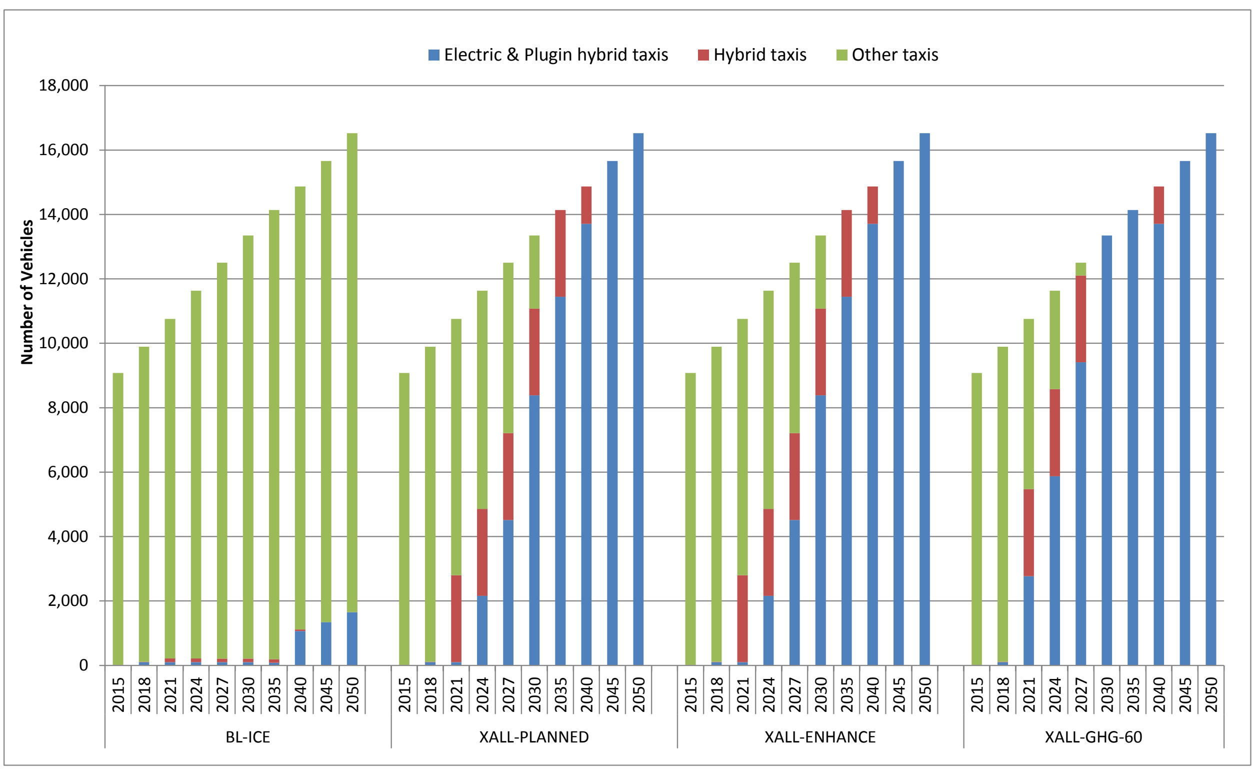


Figure 51: Share of Taxis by Technology Type

10.3.3 Minibuses

As shown in Figure 52, the Planned policies bring in Hybrids and Electric vehicles starting in 2021 in approximately equal shares, and make up 100% of the fleet by 2035. Starting in 2040 there is a definite preference for the Electric and Plugin hybrid vehicles. The NDC target scenario brings in only the Electric and Plugin vehicles which grow to 100% share in 2030. The total fleet of Minibuses grows from about 7,500 in 2015 to 10,500 in 2050.

10.3.4 Buses

The results for Buses, shown in Figure 53, appears quite different from the other passenger transport modes, because starting in 2021, the combination of mode-shift measures, including the Integrated Transit system policy, which brings in larger buses with greater driving distances and higher passenger loads, results in a decrease in demand thru 2030 and an increase after that to 2050. Given that demand profile, the Planned policies employ the Improved and Advanced diesel/biodiesel buses with a very small number of Hybrids starting in 2021. The NDC target scenario rapidly brings in Electric buses, which grow to 100% share in 2030 and 2035, but after there is a resurgence of diesel/biodiesel buses. The total fleet of Buses starts at about 20,000 in 2015, drops to about 15,000 in 2030 and grows to about 20,000 by 2050. The share of biodiesel in the total Bus fleet is 44% in 2050.

The rationale for the decrease in Electric buses starting in 2040 appears to be an economic tradeoff between the cost of biofuels and the cost of adding additional electricity generating capacity coupled with the fact that the economic life of Electric buses is only 12 years, whereas it is 17 years for diesel buses. Therefore, this particular model result should be ignored for two reasons. Once the infrastructure investments are made in Electric buses, these would not be abandoned, and by 2040 it seems unlikely that the economic life of Electric buses would not be increased. A useful sensitivity run for the Analysis Team would be to examine the impact of increasing the Electric bus life to 17 year after 2030.

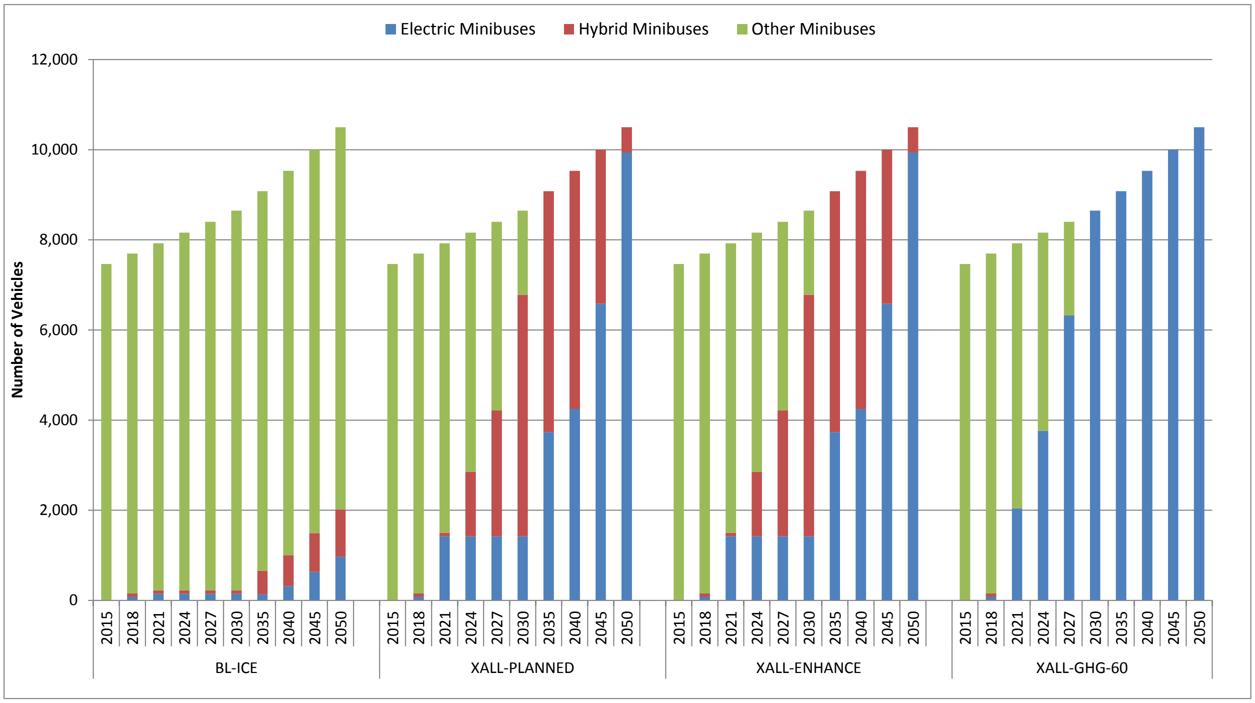


Figure 52: Share of Minibuses by Technology Type

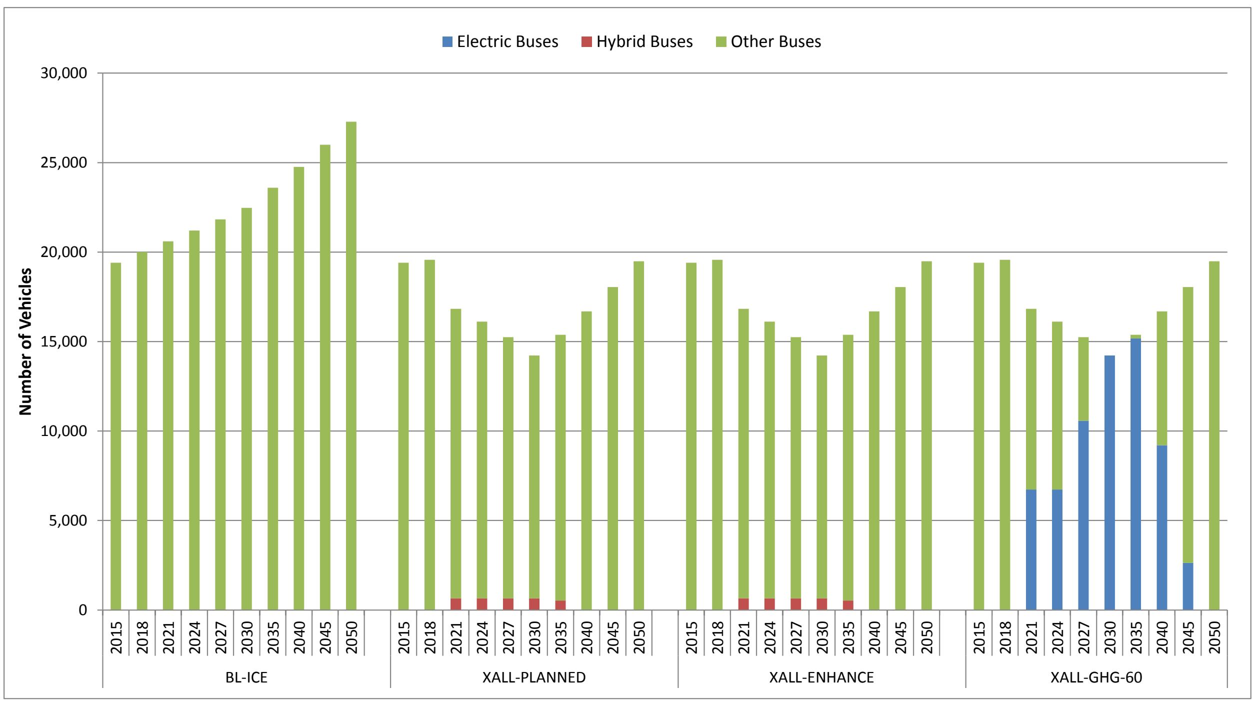
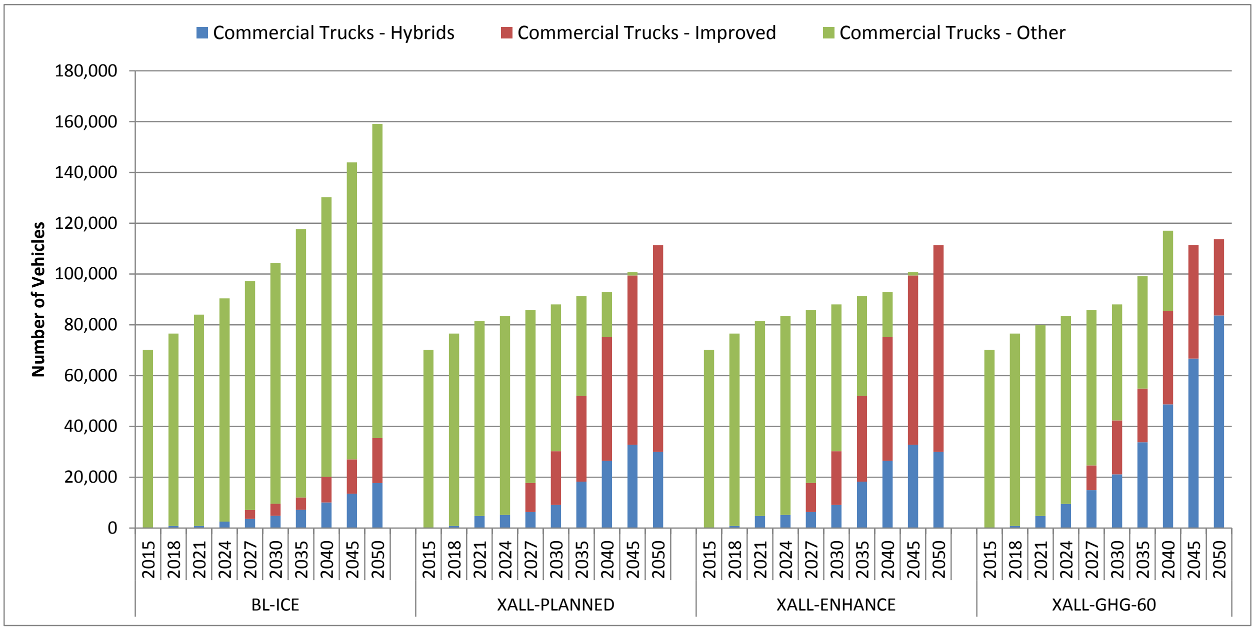


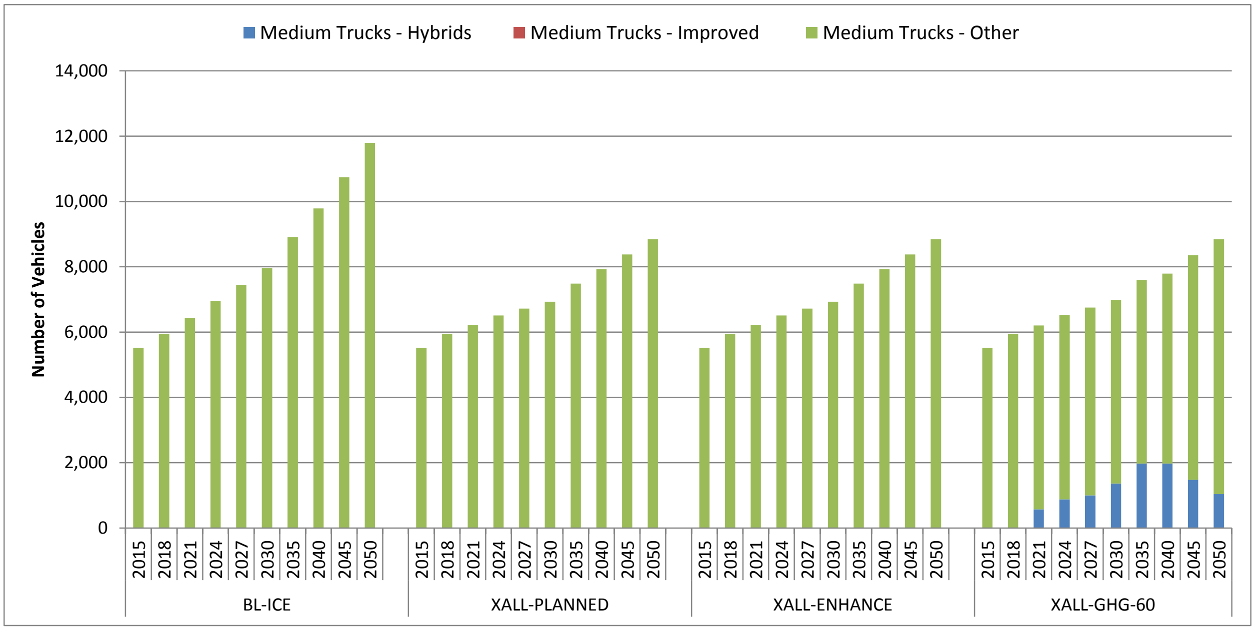
Figure 53: Share of Buses by Technology Type

10.3.5 Trucks

The share of Freight transport demand (Mtkm) satisfied by Commercial (Light), Medium and Heavy trucks was used to calculate approximate vehicle numbers by dividing the demand by the average load (tons per vehicle) and average driving distance per vehicle (km/yr). The results by technology type are presented in for each truck type in Figure 54. Note that all trucks types show a reduced demand growth in the policy scenarios because of the Truck to Rail mode shift measure.

For Commercial trucks, the Planned policies bring in Hybrid and Improved diesel/biodiesel at a ratio of about one third Hybrids and together account for the total fleet by 2045. The NDC target scenario shifts the Hybrid share to three quarters of the fleet. For Heavy trucks, the Planned policies primarily add Hybrids, but the NDC target brings in primarily the Improved diesel/biodiesel trucks. Note, the analysis did not include an electric option for any of the truck types. For the Medium trucks, the Planned policies do no impact, but the NDC target scenario brings in Hybrids to less than one quarter of the fleet.





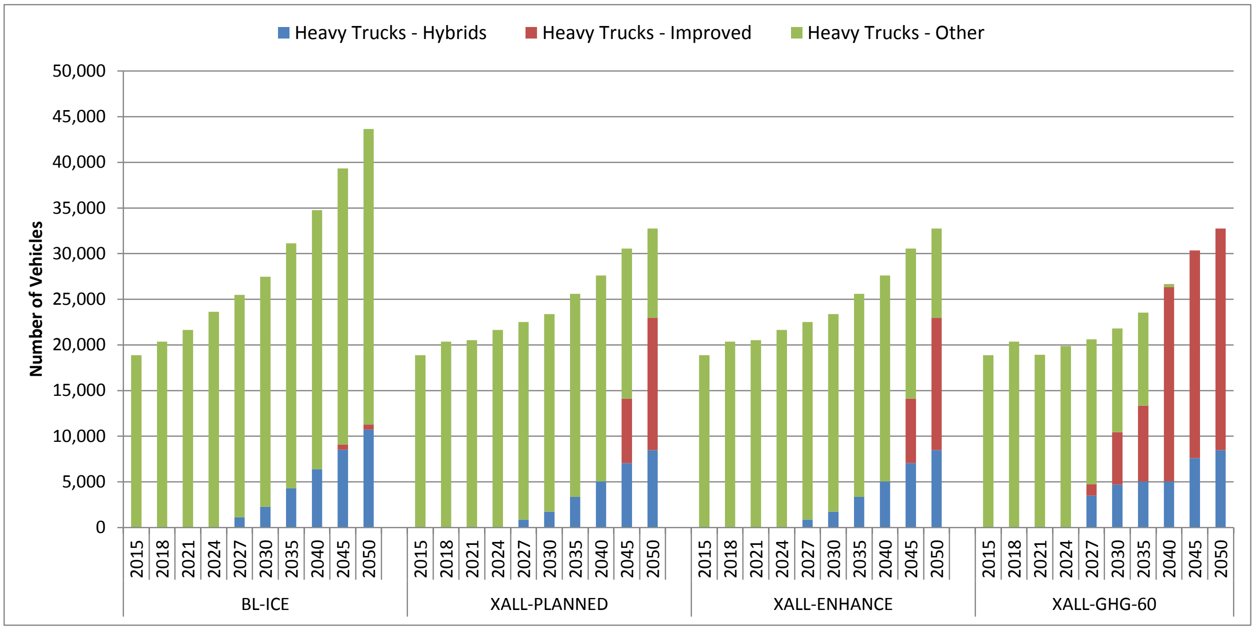


Figure 54: Share of Light, Medium and Heavy Trucks by Technology Type

10.4 Industry Sector Measures

The changes in overall Industry sector energy use show an increased role for biofuels and the need to identify additional measures to reduce the use of petroleum coke and LPG, both of which are switched to electricity in the NDC scenario. As with the Transport sector, Table 36 is used to examine technology improvement changes, but only the Chemicals subsector is shown as being representative of the sector. Note that the Industry sector has only Standard and Improved technology qualities (no Better or Advanced options at this time).

Table 36 shows that for the Chemicals subsector, the Planned measures shift new device purchases from Standard technology to Improved quality. Steam generation and Process Heat shift from fuel oil, LPG and diesel to electricity. Identified Enhanced measures have little additional impact, while to meet the NDC target, diesel and LPG use are further reduced by switching to electricity.

For each of the other Industry subsectors, the Planned measures shift technology selection from Standard to Improved quality. A summary of the main actions in each of the subsectors is given in Table 37.

Overall Planned Industry sector measures include targets for utilization of biomass residues in the Agro-industry and measure to reduce fossil fuel use in Other (cement) sub-sector. Key Enhanced measures are needed to further decrease the use of LPG, fuel oil and petroleum coke. Additional measures should increase incentives for use of solid biomass and liquid biofuels, especially for process heat and steam generation and should develop a domestic biofuel market to support stable long-term pricing.

Table 36: Change in Industry Chemicals Demand Device Use, 2015-2050 (PJ))

Change in Energy Delivery by Technology Type (PJ)						
End-use	**Quality**	**Technology**	**Planned - Baseline**	**Enhanced - Planned**	**NDC - Enhanced**	**NDC - Baseline**
Facilities/other	Improved	ICHELCOT-IM	8.19	0.00	0.00	8.19
		ICHOILDSLOT-IM			0.00	0.00
		ICHOILKEROT-IM	0.00	0.00	0.00	0.00
	Standard	ICHELCOT-ST	-8.19	0.00	0.00	-8.19
		ICHOILKEROT-ST	0.00	0.00	0.00	0.00
Machine drive	Improved	ICHELCMD-IM	25.39	0.00	-1.20	24.19
		ICHOILLPGMD-IM	0.00			0.00
	Standard	ICHELCMD-ST	-26.02	0.00	8.31	-17.72
Process heat	Improved	ICHELCPH-IM	1.68	0.00	5.51	7.18
		ICHOILDSLPH-IM			0.00	0.00
		ICHOILLPGPH-IM	4.59	-0.07	-5.27	-0.75
	Standard	ICHELCPH-ST	0.40	-0.07	3.11	3.44
		ICHOILLPGPH-ST	-7.45	0.14	-1.87	-9.17
Steam	Improved	ICHELCST-IM	2.76	0.19	-0.40	2.55
		ICHOILDSLST-IM	-0.64	0.00	0.35	-0.29
		ICHOILFOIST-IM	6.29	-0.19	0.05	6.14
		ICHOILLPGST-IM	0.00	0.00	0.00	0.00
	Standard	ICHELCST-ST	2.77	-0.19	0.42	3.00
		ICHOILDSLST-ST	-0.68	0.00	-0.35	-1.02
		ICHOILFOIST-ST	-9.40	0.19	2.28	-6.93
		ICHOILLPGST-ST	-0.69	0.00	0.00	-0.69
		Positive	Negative			

Table 37: Change in Industrial Subsector Structure

Subsector	Impact Summary
Chemical	Planned measures shift Steam generation and Process Heat from fuel oil, LPG and diesel to electricity; identified Enhanced measures have little additional impact, while to meet the NDC target, diesel and LPG use are further reduced by switching to electricity.
Food and Tobacco	Planned measures maintain LPG and Fuel oil for Process Heat and Steam production; identified Enhanced measures shift a small amount of LPG and Fuel oil to electricity, and to meet the NDC target, most of the remaining fuel use is shifted to electricity.
Pulp & Paper	Planned measures shift Machine drive to cogeneration from organic residues and Steam production to electricity, fuelwood and fuel oil; to meet the NDC target, cogeneration from organic residues is increased along with improved technology use for fuelwood and fuel oil boilers.
Textiles	Planned measures shift Machine drive, Process Heat and Steam production to electricity, and diesel, fuel oil and LPG use are reduced; to meet the NDC target, more improved Machine drive technologies are needed along with shifting more Steam production to electricity.
Wood Products	Planned measures continue to use fuel oil and LPG for Process Heat, and shift Steam production to electricity and improved fuelwood boilers; to meet the NDC target, more

	fuel oil and LPG use are switched to electricity.
Other	Planned measures continue to use LPG, fuel oil and petroleum coke for Process Heat with a large shift to improved use of fuelwood; Steam production continues to use coal, LPG and fuel oil; to meet the NDC target, LPG and petroleum coke are shifted to electricity for Process heat, and coal use is shifted to electricity for Steam production.

10.5 Industry Sector Indicators

The general trend in each of the Industry subsectors is typified by the Food and Tobacco subsector, as shown in Figure 55. The Planned policies bring in the Improved technologies starting at about 10% market share in 2021 and increasing to 80% of the market by 2050. The addition of the NDC target does not change this result significantly. Looking at the main end-use applications (Process heat, Steam, and Machine drive), we see a similar trend as shown for Steam in Figure 56. The Planned policies show a strong preference for Improved technologies, and by 2035 they dominate the market. However, adding the NDC target does not significantly change the trend. In fact, there is a slight increase in Standard technology purchases early in response to the shifting from fuel use to electricity.

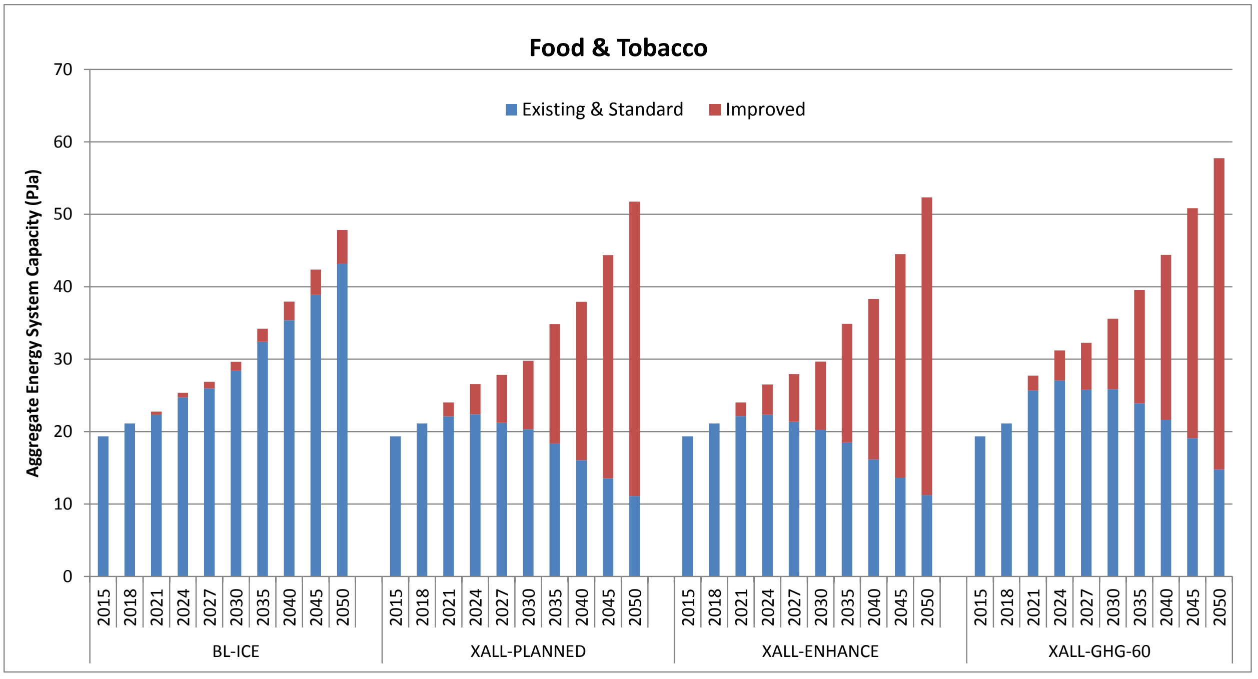


Figure 55: Capacity Share of Standard versus Improved Industry Technology Types

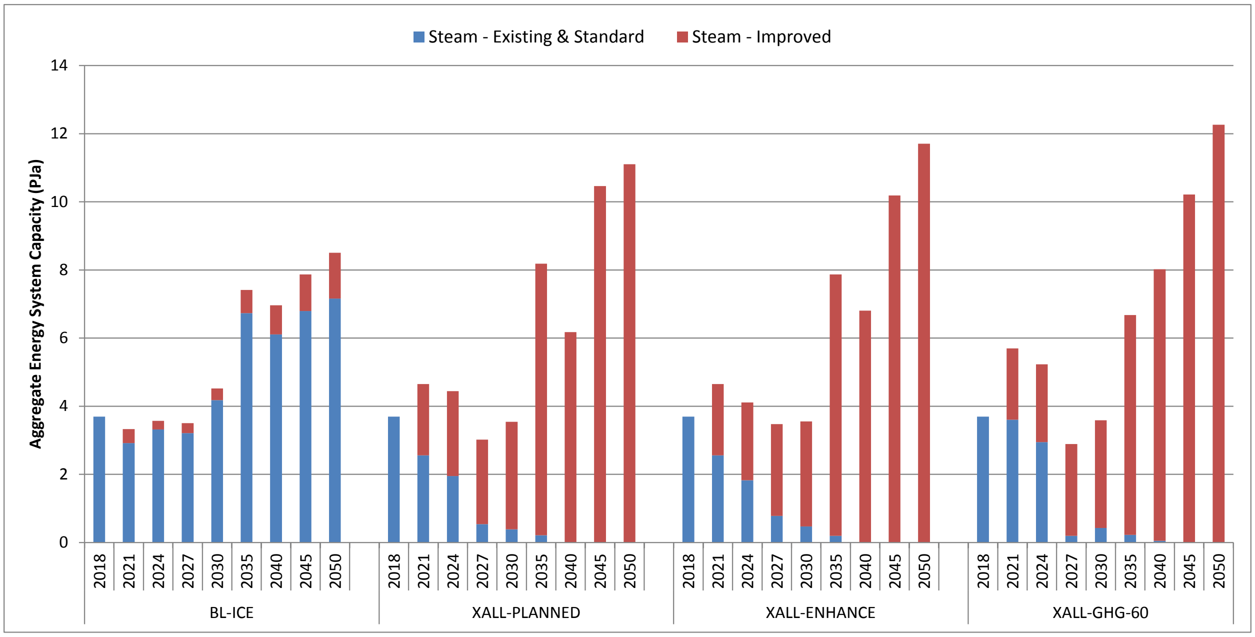


Figure 56: Share of Standard versus Improved Industry Steam End-Use Types

10.6 Buildings Sector Measures and Indicators

Key Planned measures include incentives for Advanced technologies for Space Cooling, Water Heating and Cooking, LED Public Lighting, and public building efficiency retrofits. These measures (including appliance and building standards) achieve almost all the potential emission reductions in the sector. Enhanced measures are needed to increase Improved technologies for general Lighting and Cooling, and reduce LPG use for Cooking.

Figure 57 shows that for Commercial buildings, the Planned policy measures bring in Improved space cooling devices starting in 2021, but rapid growth of market share does not start until 2027. Adding the NDC target to the scenario does not result in any significant change.

Figure 58 shows that for Residential buildings, the Planned policy measures rapidly bring in Improved space cooling devices starting in 2021, and growth Better devices starting around 2027. Adding the NDC target to the scenario starts the growth of Better devices in 2021, but they reach the same market share in 2050 as in the Planned policy scenario.

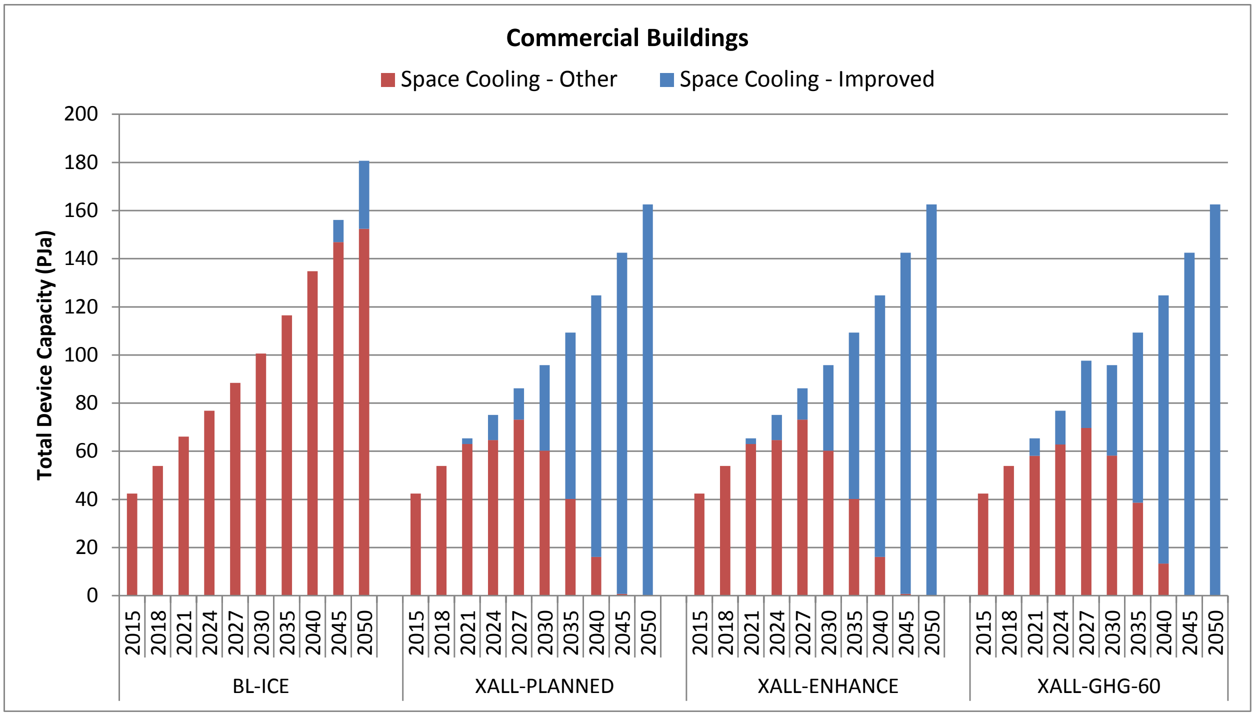


Figure 57: Share of Improved Space Cooling for Commercial Buildings

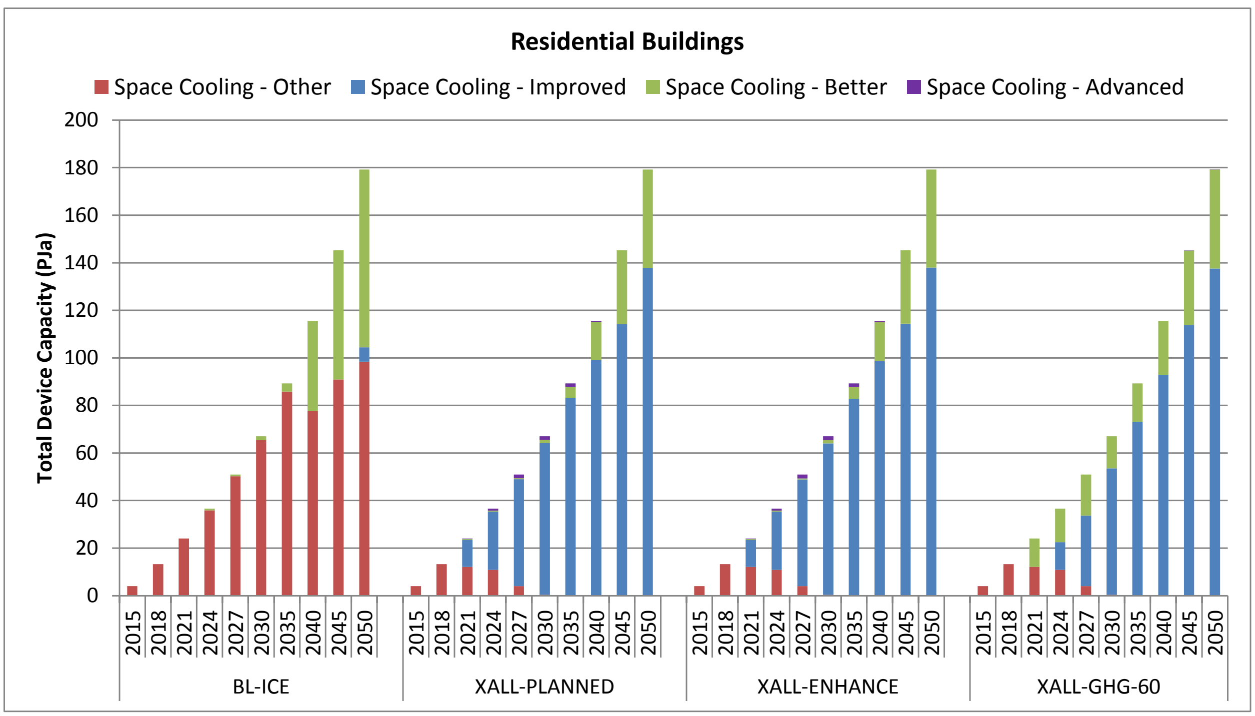


Figure 58: Share of Improved, Better & Advanced Space Cooling for Residential Buildings

11 Conclusions and Next Steps

This study has successfully constructed a TIMES-CR model and performed a detailed, quantitative analysis investigating the optimal strategies for Costa Rica to meet its ambitious NDC goals as cost-effectively as possible. Innovative metrics were used to assess the mitigation measures and actions to be undertaken, and recommendations on Enhanced policy measures necessary to do so were identified in Section 9. This study has created a solid analytic foundation in Costa Rica for continued analysis of the policies that will effectuate the transition to the low carbon future envisaged in their NDC.

The Costa Rica PMR and AT are positioned to become leaders among developing countries on how sophisticated, well established, proven analytical methods can be applied to better inform decision-making and shape the country's future responsibly. The country is on the cusp of creating the in-country capacity needed to perform future analyses to evaluate GHG mitigation policies and measures on an ongoing basis, so as to be able to make stronger NDC commitments over time, as called for by the Paris Accord.

Given the accomplishments of this study, and the capacity built to date, the following lists of next steps were developed in discussion with the PMR and AT. The goal of the next steps is to cement the role of TIMES-CR as an integral part of the country's decision-making process and ensure that the necessary in-country skills to do so are in place. To accomplish this, the proposed next steps are organized into the following three categories:

- Enhancement of TIMES-CR;
- Advanced Capacity Building;
- Employing Advanced TIMES Modeling Techniques;

11.1 Enhancement of TIMES-CR

While the TIMES-CR model is fully operational, a number of areas were identified in consultation with the AT that should be incorporated into TIMES-CR to improve the model by infusing additional local knowledge and data. A preliminary list of these enhancements includes:

- Developing the non-energy sector data to support adding non-energy sector GHG baseline emissions and mitigations measures, allowing for comprehensive analysis of all GHG mitigation options,
- Providing further detail in the Industry sector to distinguish the Coffee and Cement subsectors: two areas targeted by NAMA measures (that are currently imbedded in Food and Other subsectors respectively);
- Expanding the suite of future technology options available in each of the demand sectors;
- Incorporation of more electric storage options (both central and decentralized), including at tighter integration of the electric vehicle fleet with the power sector;
- Enhancement of the representation of the hydro power plants to better capture reservoir and seasonal storage capacity;
- Incorporation of regional trade in electricity, and
- Treatment of international sale and trade in emission reduction credits.

The resulting expanded and improved TIMES-CR model will better represent the Costa Rica energy system, be more robust in terms of the future technology options, and begin to look at the relationship of the country to Central America and the wider carbon market.

11.2 Advanced Capacity Building

The AT has a basic understanding of the TIMES-CR model and how to work with the components of the model management systems (ANSWER-TIMES, VEDA-BE and the Analytics graphing workbook (AXLS)). However, familiarity with the model input templates and database and the ability to make changes to the model data, introduce those changes into ANSWER, run the model, and examine the results to assess the correctness and consequence of any such changes has not been fully realized, as to date the AT has not been asked to take over full responsibility for TIMES-CR. Furthermore, while the AT has observed the process of conducting an analysis and interpreting the model results, transforming them into ranked priorities for decision-makers, again to date they have only followed along and not carried out such activities themselves.

The following activities are proposed to advance the skills of the AT to ensure the establishment of the necessary in-country capacity to steward TIMES-CR on a sustainable basis. The focus will be on learning-by-doing rather than classroom presentations. The main activities to be pursued include:

- Engaging the AT in all aspects of enhancing the initial TIMES-CR model;
- Working with the AT to refine the Planned mitigation measures design and identify Enhanced measures to be considered;
- Introduce the AT to more advanced aspects of TIMES modeling techniques that both improve the representation of the country's energy system and the ability conduct robust policy assessments (see next section), and
- Oversee the use of the updated TIMES-CR model by the AT to conduct an advanced assessment of the Costa Rica least-cost NDC mitigation pathway (see the Application of TIMES-CR section below).

In addition, the key core members of the AT should be exposed to the mathematics that underpin the TIMES methodology to gain a fuller understanding of how the model "thinks," and therefore what it can and cannot do. However, to ensure the longevity of the AT and thereby sustainability of TIMES-CR, the roles and responsibilities of the various AT members must be appropriately designated and a strategy for bringing new experts (and students) onboard when/as necessary over time will be developed to ensure continuity and continual use of TIMES-CR. Critical to this task will be securing the necessary commitment from the Ministries and institutions involved to ensure longevity of the process.

11.3 Employing Advanced TIMES Modelling Techniques

To date only the basic core capabilities of TIMES have been used when running TIMES-CR. This is an essential first step when building a TIMES model and training newcomers in its use. However, there are some important more advanced features of TIMES that can be employed to add sophistication to the representation of the Costa Rica energy sector, as well as robustness to the analysis, particularly given the wide range of uncertainties with respect to future commodity costs, technology costs and performance, behavior, the viability of certain industries, and the implementation of policies. The introduction and application of each of these features would serve to demonstrate and advance the kinds of NDC analysis that TIMES-CR can accommodate. Among the most important advancements under consideration are:

- Improving the Transport sector by setting up an endogenous mode-shift mechanism where the transport modes (e.g., cars and buses) compete for specific transport types (e.g., urban passenger demand);
- Introducing hurdle rates (technology specific discount rates), and other (World Bank) ideas, to reflect aspects of consumer behavior as it relates to technology(demand device) choice;
- Introduction of elastic demand that endogenizes the future demand for energy services, making their level responsive to changes in the cost of meeting those demand under various policy realms;
- Employing discrete investment decision-making for key major projects and infrastructure to endogenize the when or not to build Diquis HPP, inter-city rail, LNG terminal, long distance (international) transmission lines, etc., and
- Conducting sensitivity analyses to address uncertainty by employing stochastics to identify hedging strategies that are robust under a wide range of assumptions for certain key assumptions (e.g., price of solar/wind/storage, construction or not of the Diquis HPP, level of GHG mitigated, international carbon price, and the impact of climate change on water availability for hydropower).

Appendix A: TIMES-CR Database

A.1 Overview of Model Structure

The TIMES-CR model database consists of a set of Excel workbook templates that comprise the source input files that are read into the ANSWER-TIMES model management software. This Appendix focuses on the core components comprising the Baseline scenario, while Appendix C covers the mitigation measures and policies scenarios.

The components of the database are described in VBA-enabled Excel workbooks[30] (templates) that fall into the following categories:

- EB – Energy Balance for the 1st year of the model and current load curve;
- LoadCalib – Hourly electricity load curve transformation to a load duration curve, along with the timing of the electricity demand to the individual sectors;
- SUP – Resource supply and imports;
- BY – Base year existing technologies and calibration procedure;
- NT – New technology options;
- Demand – Demand drivers and projections;
- UC – Fuel switching and technology improvement user controls, and
- ZZDMY – "Backstop" processes for energy and demand commodities.

There are BY, NT and UC workbooks for each sector as defined below:

- Agriculture demand devices [AGR];
- Commercial demand devices and conservation measures [COM];
- Industrial structure and processes, including refineries [IND];
- Non-energy/Other [OTH-NON] (BY only);
- Electric generation technologies [PP];
- Residential demand devices and conservation measures [RSD], and
- Transportation vehicles by mode [TRN].

Figure 59 is an elaboration of Figure 10, in that it includes the key naming elements of templates represented by each of the model data categories.

[30] See *ANSWERv6-TIMES Smart Excel Workbook Manual* for details on working with / operating the templates.

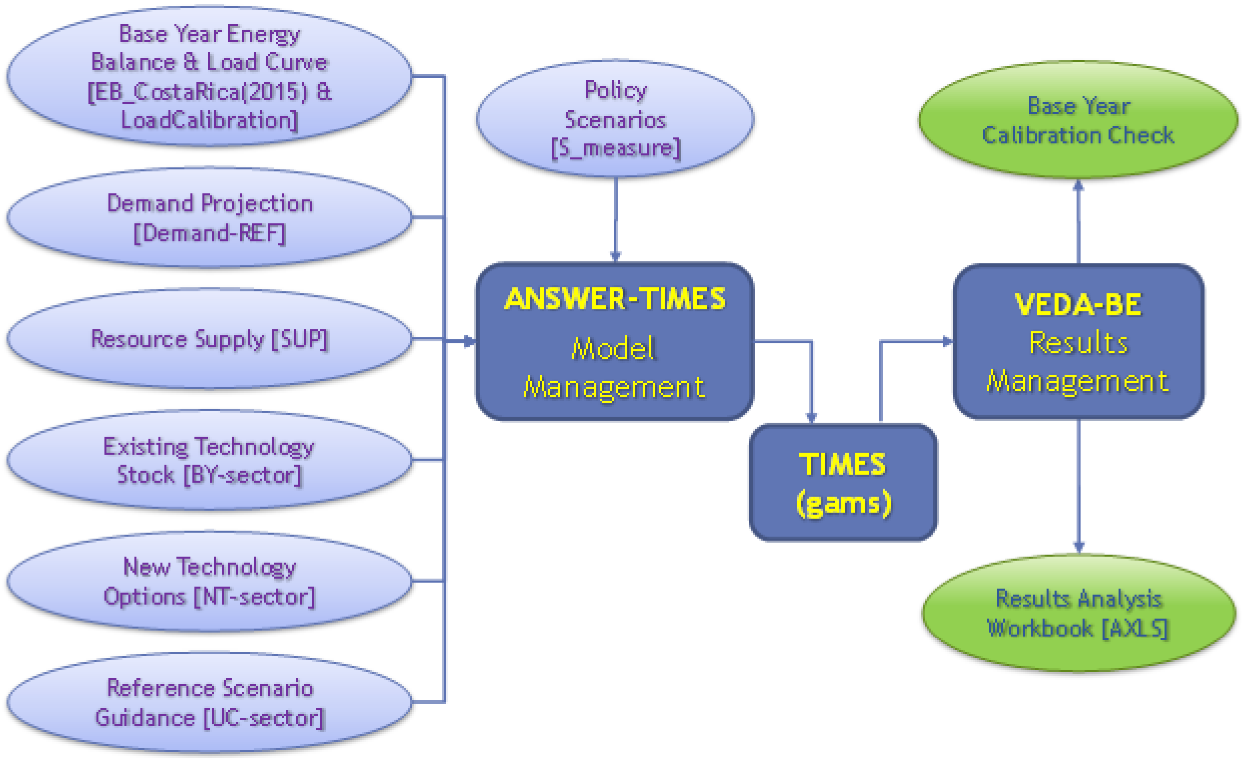


Figure 59: TIMES-CR Model Structure Overview

In addition to the templates mentioned above, there are supporting workbooks to check how the base year results compare to the energy balance (VBE_CalibrationCheck_REF) and the Analytics scenario graphing workbook (AXLS) for comparing run results. For each mitigation measure or policy there are scenario templates (S_measure) for setting up and checking the various alternate scenarios.

The ANSWER BASE scenario is manually loaded with the Global parameters related to discounting (year and global rate), and annual time slices. These time slices are established in the LoadCurve workbook, but are also linked to the EB workbook where each BY and the Demand Projection workbook links to obtain the relevant time slice information.

A.2 TIMES-CR Template Summaries

Table 38 lists the core model templates for the TIMES-CR Baseline scenario.

Table 38: TIMES-CR Baseline Model Input Templates

Excel Template	Description
EB_CostaRica(2015).xlsm	Energy balance data file that is a common repository for each of the sector base year templates energy production/consumption information, along with the time slice data grabbed from the LoadCalib workbook.
CostaRica_LoadCalibration_Simple.xls	Workbook that facilitates the calculation of time slices for the year (seasonal and time of day) based on the base year load curve and the derivation of an appropriate load duration

	curve for the model, along with the timing of the electricity consumption for each demand sector.
AT_CostaRica_SUP.xlsm	Cost and available supply of all domestic and imported energy resources over the entire time horizon, along with bounds for renewable sources.
AT2_CostaRica_BY-<demand sector>.xlsm,	Base year existing technology operating costs and characteristics, along with decomposition procedure to determine device stock and associated first year useful energy service demand. <demand sector> = AGR, COM, IND, OTH-NON, RSD or TRN
AT2_CostaRica_BY-PP.xlsm	Base year existing power plants and calibration procedure for Power plant availability factors
AT2_CostaRica_Demand-REF.xlsm	Overall demand drivers and sector-specific drivers for development of the future useful energy demand projections.
AT2_CostaRica_NT--<demand sector>.xlsm,	Cost, efficiency, start date and operating characteristics for new technology options for each demand sector. <demand sector> = AGR, COM, IND, RSD or TRN
AT2_CostaRica_NT-PP.xlsm	Cost, efficiency, start date, availability and bounds for new power plant options.
AT_CostaRica_UC-<demand sector>/50/90.xlsm	User constraints to limit the allowable rate of fuel switching and technology improvement in each demand sector to 10/50/90% by 2050.
REF_BOUNDLO.xlsm	Ensures minimum operation of existing power plants.
AT_CostaRica_ZZDMY.xlsm	Backstop technologies that help in debugging model infeasibilities.

In addition, there are a pairs of result handling workbooks used to check the calibration of the model (VBE_CalibationCheck_REF) and the TIMES-CostaRica_AXLS interactive scenario graph comparison workbook (mentioned in Section 3.1). An example of the CalibrationCheck workbook is given below, and most all the figures and tables in this report (listed in Table 11, along with the Metrics tables) came directly from the AXLS.

A.3 Dependencies Table

As mentioned earlier, there are interdependencies (links) between many of the workbooks. These are mainly used to semi-dynamically manage which suite of technologies that are to be included in the model according to the Energy Balance, and any subsequent introduction of a new energy form not currently used in the country. It is very important to be fully aware of these interdependencies to ensure that whenever a “parent” template is changed that all dependent “child” templates are also opened and saved to refresh links and update dependent data.

The relationship between the various templates is reflected in Figure 60, where the arrow points to the immediate “parent” of each dependent “child,” where of course child templates are also sensitive to any changes made to their “grandparent” templates as well. Thus if a change is make to the Energy Balance, then the Supply and BY templates are directly affected, which when updated require the “grandchildren” Demand, NT and UC templates also need to be refreshed (and their associated BY).

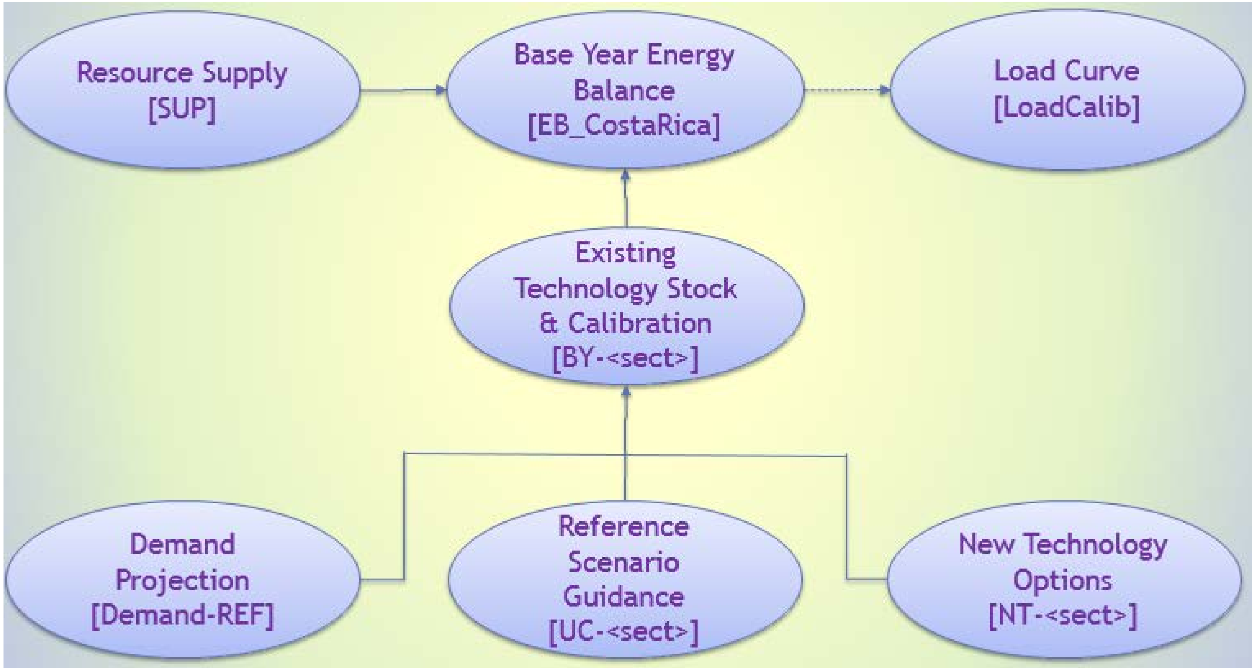


Figure 60: TIMES-CR Template Interdependencies

Fortunately, the ANSWER model management system assists with this requirement by checking each time a template is imported whether any "parent" template is younger (newer) than its dependent children. This checking is controlled by the TIMES-CR_Dependency Table, which when specified on the Import Model Data from Excel form (see Figure 61), with the Check Dependency Information checked, does exactly that. ANSWER performs this checking according to the list of children / parents table found on the XLS Links sheet in the Dependency workbook. [Note that if new core templates are added to the model structure this oversight workbook should be augmented accordingly.]

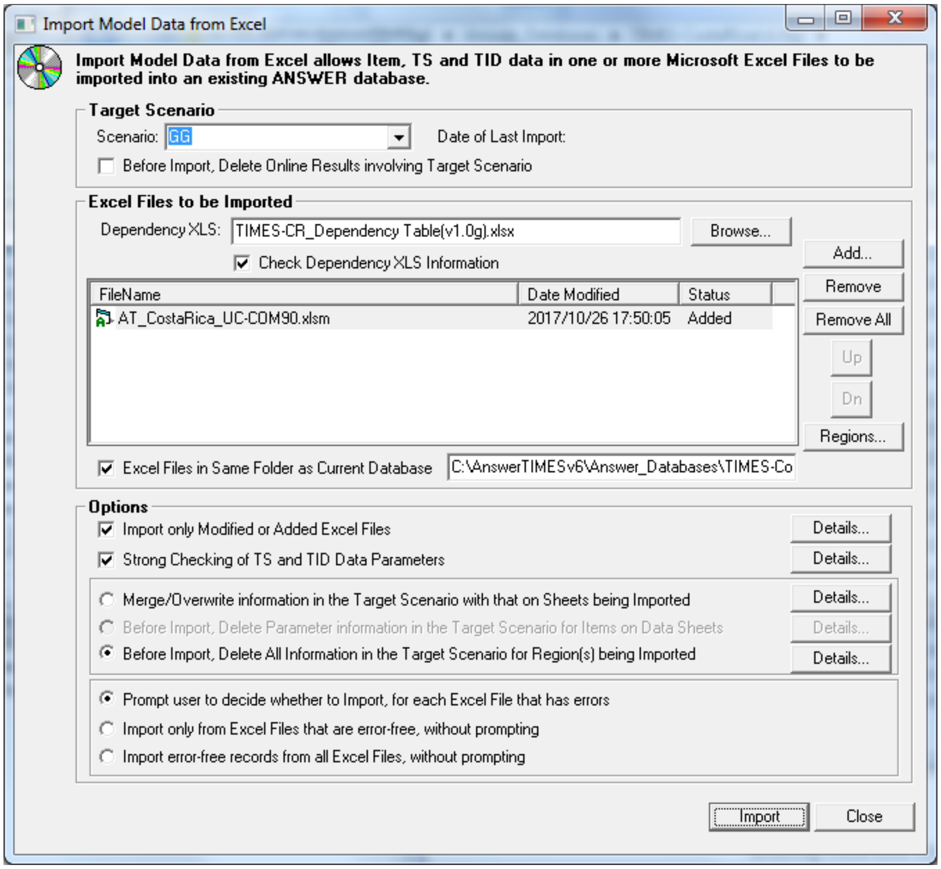


Figure 61: TIMES-CR Model Structure Overview

If there is a violation for any dependent template ANSWER alerts the user with a message along the lines below, producing a log that the user can check to decide whether or not the template being imported now may be affected by the violation. The user can then decide whether to proceed (fixing the dependency problem later) or sort out the dependency violations before continuing. In general, to ensure the database is in proper shape all dependencies should be properly addressed on a regular basis.

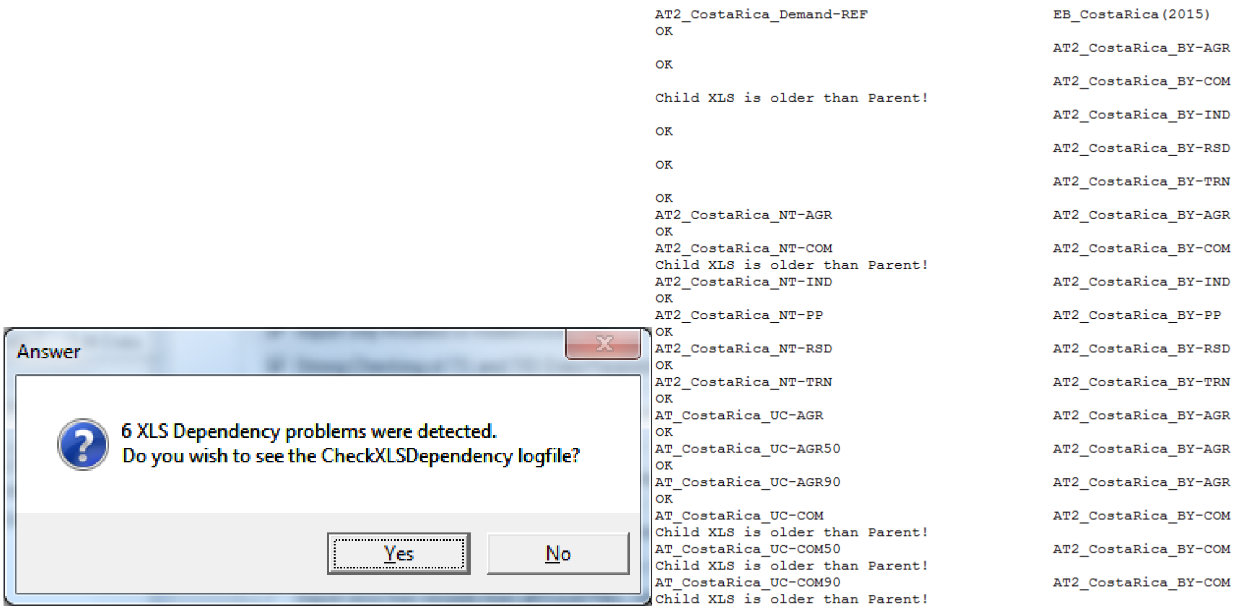


Figure 62: Template Dependency Violation Warning and Log

A.4 Template Structure

The key ANSWER-TIMES workbooks consist of the BY and NT technology templates, and Table 39 identifies the general worksheets that are found in each sector-based workbook. The worksheets in italics are the ones loaded into the ANSWER and thereby establishing the TIMES-CR model.

Table 39: Structure of BY and NT Model Input Workbooks

Worksheet	Description
ANSv2-692-Home	ANSWER-TIMES template sheet that is used to add new ANSWER-TIMES smart sheet to the current workbook, or turn an existing XLS/XLSM into a "smart" workbook.
SETUP	Selection of the commodities and processes available in the TIMES-Starter model for use in TIMES-CR. Also includes periods and USD price conversion factors through a link to the Energy Balance workbook. The Setup sheet links to the EB tab to identify the energy commodities used in the sector.
EB	Sector based Energy Balance information from the Energy Balance workbook. [BYs only]
Source Data	Copies of any source data used for end-use shares, technology limits, etc.
Calibration	The calculation sheet where the energy balance is apportioned by end-use service and the initial year technology stock established for each sector. [BYs only]
Commodities	Defines all energy carriers, demand services, emissions and materials by their name, description, units and set memberships. These entries are controlled by the SETUP sheet, in most cases.
CommData	Specifies base year demand levels, time-slice demand fractions for end-use services supplied by electricity, and data for mapping sector emissions to overall GHG emissions.
Processes	Defines all process technologies by their name, description, units and set memberships. These entries are controlled by the SETUP sheet, in most cases.

Worksheet	Description
ProcData_<sect>	One or more sheets with the data for the main technologies in the sector.
ProcData_XPRCs	Data for the sector-based fuel distribution processes.
EPA-Tech Data_<qual>	Declaration and data sheets from the EPA-US9r providing the source values for the technology options.
Other Tech data	Declaration and data sheets from the Pak-IEM, Energy Community-EE databases, etc., providing source values for technology options not in the EPA database.

ANSWER-TIMES supports two kinds of smart workbooks, the so-called ver2 spreadsheets used for the BY and NT templates, as well as most of the Scen workbooks, and an older ver1 form that needs to be used for the SUP and UC templates (owing to limitations in the ver2 templates that don't accommodate the trade and UC parameters). The main difference between the ver1 and ver2 spreadsheets is that the Commodity/Process declaration sheets are replaced by a single Items sheet, and the ProcData sheets are split according to time dependent and time independent parameters.

Section 4 provided a good look at the various components of the TIMES-CR model from the perspective of the underlying RES structure. The rest of this Appendix presents a brief descriptions of each of the main types of templates listed in Table 38 that comprising the dataset that populates the model.

A.5 Energy Balance and Load Calibration Templates

The preparation of the TIMES-CR model started from the proper specification of the national Energy Balance for 2015 and the associated electricity hourly load curve for that year. Figure 63 shows a portion of the TIMES-CR 2015 Energy Balance. The intersections in the Energy Balance determine what energy forms, power plant types, and demand sectors are actually found in Costa Rica, and thereby control which commodities and processes are included in the model, as described further when discussing calibration in the demand template, Appendix A.8.1. The user may adjust the names of the individual energy carries to align with those in the country, as long as the naming convention guidelines discussed in Section 3 are adhered to. The empty columns (mainly biofuels) are included because they are to be considered as options in the future. Note that the Energy Balance template also contains various other important information such as the modeling years, time slices (from links to the LoadCalib template, discussed next), units, conversion factors, emission rates, etc.

The LoadCalib template, shown in Figure 64, first accepts the (8760) hourly load curve and through an interactive process looks for identify and map the shape of the curve (including the peak) into a load duration curve needed by TIMES to oversee the timing of the demand for electricity, and thereby generation capacity. This starts by the user identifying the seasons to be handled (orange cells in the top part of the figure), then the hours splits comprising each day (the 2nd box orange cell), resulting in an approximate fit of the typical and peak day demand (as seen in the line graph). Finally, for each sector and end-use service demand an indication of the timing of electricity consumption (the yellow cells at the 3rd level of the figure) result in the shaping of the sector demand (figure on the last row) and finally the individual end-use service electricity use timing fractions (not shown). As mentioned above the global and end-uses fractions are linked to the Energy Balance sheet for use in the power and demand templates as needed.

Country (Region) Name	CostaRica	GASNAT	BIOIWA	BIOMSW	BIOPSF	BIOGAS	BIOGSL	BIOJKE	BIODSL	BIOCHA	NUCLER	RNWHYD	RNWGEO	RNWSOL	RNWTWO	RNWWIN	ELC	LTH	
PJ	**Sector Name**	Natural Gas	Industrial Waste	Municipal Waste	Firewood	Biogases	Biogasoline	Bio Jet Kerosene	Biodiesels	Charcoal	Nuclear	Hydro	Geothermal	Solar	Tide, Wave and Ocean	Wind	Electricity	Heat	Total of All Energy Sources
Product Short Name		NATGAS	INDWASTE	MUNWASTER	PRIMSBIO	BIOGASES	BIOGASOL	BIOJETKERO	BIODIESEL	CHARCOAL	NUCLEAR	HYDRO	GEOTHERM	SOLARPV	TIDE	WIND	ELECTR	HEAT	
Data in Physical Units Column Number		42	43	44	46	47	48	49	50	53	54	55	56	57	59	60	65	66	
Production		-	-	-	11.053	0.009	-	-	-	-	-	36.045	62.097	0.009	-	3.886		-	130.694
Imports		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.942	-	104.526
Exports		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-1.741	-	-1.772
International marine bunkers		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
International aviation bunkers		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Stock changes		-	-	-	-	-0.004	-	-	-	-	-	-4.502	-13.443	-	-	-	-	-	-17.429
Total primary energy supply		-	-	-	11.053	0.004	-	-	-	-	-	31.542	48.654	0.009	-	3.886	0.200	-	216.018
Transfers		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-0.002
Statistical differences		-	-	-	-0.000	-0.000	-	-	-	-	-	-0.000	-	-	-	-	0.000	-	0.080
Transformation Processes and Losses		-	-	-	-0.227	-0.001	-	-	-	0.057	-	-31.542	-48.654	-0.009	-	-3.886	33.742	-	-52.784
Main activity producer electricity plants	PWR	-		-	-	-0.001					-	-31.542	-48.654	-0.009		-3.886	38.477	-	-47.878
Captive power plants (auto-producers)	PWR	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Non-specified (transformation)		-	-	-	-0.227	-	-	-	-	0.057	-	-	-	-	-	-	-	-	-0.171
Other		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Losses (from pipelines and transmission)		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-4.735		-4.735
Final consumption		-	-	-	10.826	0.003	-	-	-	0.057	-	-	-	-	-	-	33.942	-	163.1518
Industry	IND	-	-	-	4.593	-	-	-	-	-	-	-	-	-	-	-	6.742	-	39.296
Chemical and petrochemical		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.355	-	1.870
Food and tobacco		-	-	-	0.342	-	-	-	-	-	-	-	-	-	-	-	2.258	-	22.089
Paper, pulp and print		-	-	-	0.374	-	-	-	-	-	-	-	-	-	-	-	0.422	-	1.257
Wood and wood products		-	-	-	3.700	-	-	-	-	-	-	-	-	-	-	-	0.129	-	4.021
Textile and leather		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.235	-	0.810
Other		-	-	-	0.177	-	-	-	-	-	-	-	-	-	-	-	2.343	-	9.250
Transport	TRN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	81.526
Road		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	71.678
Domestic aviation		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7.448
Rail		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	0.064
Domestic navigation		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.091
Other transport		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.244
Other		-	-	-	6.233	0.003	-	-	-	0.057	-	-	-	-	-	-	27.200	-	40.824
Residential	RSD	-	-	-	5.151	0.003	-	-	-	0.057	-	-	-		-	-	12.992		20.791
Commercial	COM	-	-	-	1.082	-	-	-	-	-	-	-	-		-	-	12.815		15.36027
Agriculture	AGR	-	-	-		-	-	-	-	-	-	-	-	-	-	-	1.139	-	3.327254
Fishing	AGR	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Non-specified (other)	OTH	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.253	-	1.346
Non-energy use	NON	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.506
Non-energy use industry/transformation/en	NON	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.506
Non-energy use in transport	NON																		

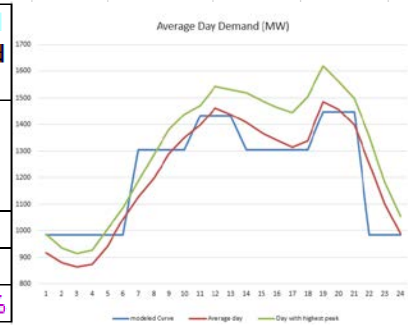
SETUP | Energy Balance | CR-EB(15) | Example IEA balance | TimePeriods & FRs | Mapping_Table | Definitions | Conversion factors | Emission fa ...

Figure 63: Energy Balance Workbook

date	1.hour	2.hour	23.hour	24.hour	row number	sum(row)	1595.344160
12/31/2015	976.2896	932.223	1133.118	1039.181	2	28476	
12/30/2015	969.0554	925.5752	1174.96	1056.767	3	29507	
12/29/2015	939.6434	898.5423	1171.997	1047.905	4	29288	
12/28/2015	849.4746	808.0995	1141.101	1012.962	5	28404	
12/27/2015	883.6169	843.4799	1035.542	921.8473	6	25313	
12/26/2015	856.7984	819.4581	1070.774	960.8508	7	26206	
12/25/2015	947.0096	884.5033	1033.237	925.1447	8	24297	
12/24/2015	967.6133	898.749	1111.632	1021.232	9	28480	
12/23/2015	962.4999	905.2005	1183.439	1062.53	10	30262	

	End date	Start date	Start row	End row	Days	Days frac	Max Power MW	Row (Max)	Column (Ma	For Graphs row of max	Energy GWh
Annual	12/31/2015	1/1/2015	2	366	365		1619.0352	18	19		10,672
Wet	11/30/2015	6/1/2015	33	215	183	50%	1612	214	19	214	5,387
Dry2	5/31/2015	2/1/2015	216	335	120	33%	1618.69	283	19	283	3,508
Dry1	12/31/2015	12/1/2015	2	32	31		1619.04	18	19		910
Dry1	1/31/2015	1/1/2015	336	366	31		1552	355	19		867
Dry1 Agg					62	17%	1619.0352	18	19	18	1,777

Slice	Hourly Definition	Duration (h)	Average load (MW)	Maximum Peak	Reserve margin	Modeled Reserved Margin
Day	6am-10am, 1pm-6pm	9	1303.9			
Night	9pm-6am	9	985.1			
Afternoon peak	10am-1pm	3	1432.6			
Evening peak	6pm-9pm	3	1446.8	1619	10%	23%



			shares in day	0.375	0.375	0.125
	Annual Consumption	Daily Consumption (Asuming no significant	Daily Consumption	Shares (%)		
	PJ	PJ	Mwh	Day	Night	Afternoon Peak
From EB	33.94	0.09	25,832.59			
Agriculture	1.14	0.00	866.95	37.5%	37.5%	12.5%
Commercial	12.82	0.04	9,752.70	46.5%	29.0%	19.5%
Industry	6.74	0.02	5,131.22	37.5%	37.5%	12.5%
Residential	12.99	0.04	9,887.58	46%	34%	15%
Transport	0.00	0.00	1.32	37.5%	37.5%	12.5%
Other	0.25	0.00	192.82	37.5%	37.5%	12.5%
Total:	33.94					
Commercial	12.82	0.04	9,752.70	46.5%	29.0%	19.5%
Commercial Cooling	2.35	0.01	1,790.60	46.0%	20.0%	19.0%
Commercial Water Heating	0.14	0.00	110.30	46.0%	20.0%	19.0%
Commercial Cooking	0.45	0.00	346.22	46.0%	20.0%	19.0%
Commercial Lighting	4.85	0.01	3,693.54	44.0%	19.0%	20.0%
Commercial Refrigeration	1.01	0.00	767.54	37.5%	37.5%	12.5%
Commercial Office Equipment	2.42	0.01	1,843.26	46.0%	20.0%	19.0%
Commercial Public Lighting	0.84	0.00	642.51	0.0%	75.0%	0.0%
Commercial Misc Electricity	0.73	0.00	558.74	37.5%	37.5%	12.5%
Residential	12.99	0.04	9,887.58	46.2%	34.4%	15.4%
Residential Cooling	0.22	0.00	168.09	46.0%	20.0%	15.0%
Residential Water Heating	1.60	0.00	1,220.13	46.0%	20.0%	15.0%
Residential Refrigeration	4.47	0.01	3,400.34	37.5%	37.5%	12.5%
Residential Lighting	0.94	0.00	713.88	45.0%	19.0%	16.0%
Residential Cooking	2.43	0.01	1,852.93	46.0%	20.0%	15.0%
Residential ELC Appliances	3.33	0.01	2,532.21	37.5%	37.5%	12.5%

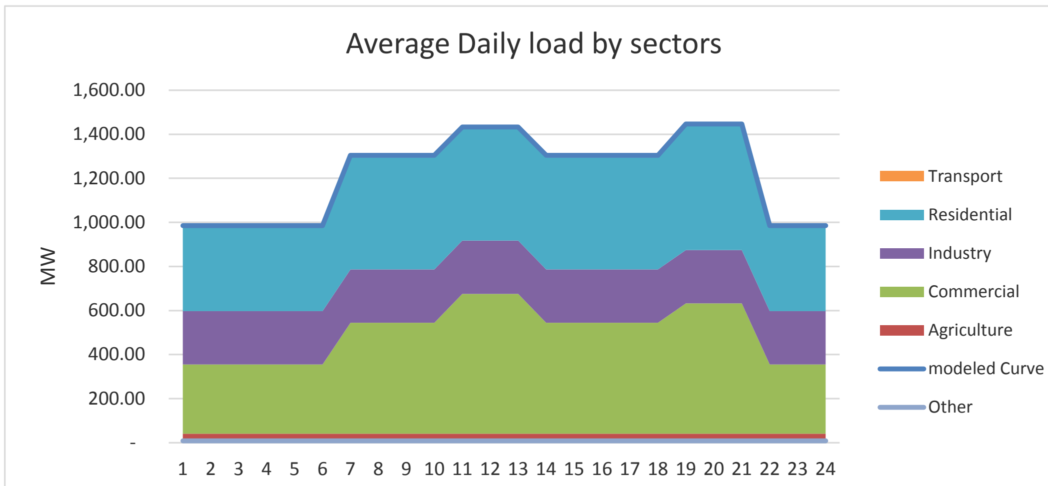


Figure 64: Load Calibration Workbook

A.6 Resource Supply

The resource supply and imports options are dynamically established via the EB sheet of the Supply (SUP) template through its links to the Energy Balance workbook. See Figure 65. Col A of the SETUP sheet reads the EB sheet and activates a resource commodity (from the full complement in the STARTER database) if it has a non-zero value in the EB. If the resource is zero in the EB, then the commodity is not activated (an"*" in the 1st column converts the row from data to a comment).

	COAANT	BIORRV	BIORBG	BIORCC	BIOORV	OILCOI	OILAVG	OILGSO	OILLPG	OILGSL	OILJET	OILKER	OILDSL	OILFOI	OILPCO
PJ	Coal	Organic Residues	Bagasse	Coffee Husk	Other organic residues	Crude Oil	Aviation Gasoline	Gasoil	LPG	Gasoline	Jet Fuel	Kerosene	Diesel	Fuel Oil	Petroleum Coke
Supply	0.014	0	11.268823	0.3713707	5.9553073	0.07908	0.048368	-0.00043	6.817763	37.99893	7.886841	-0.006978	41.54486	5.478845	3.211698
Production	0	0	11.268823	0.3713707	5.9553073	0	0	0	0	0	0	0	0	0	0
Imports	0.014	0	0	0	0		0.046151	0	6.620246	37.06555	7.972689	0	42.40429	5.24994	3.211698
Exports	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.03122	0
Stock changes	0	0	0	0	0	0.07908	0.002217	-0.00043	0.197517	0.933381	-0.08585	-0.006978	-0.85942	0.260125	0
Transfers	0	0	0	0	0	-0.07908	0	0.250843	0	0	-0.31048	0.310476	-0.17397	0.000116	0

	GASNAT	BIOIWA	BIOPSF	BIOGAS	BIOGSL	BIODSL	D	RNWGEO	RNWSOL	RNWWIN	ELC	
PJ	Natural Gas	Industrial Waste	Firewood	Biogases	Biogasoline	Biodiesels	Hydro	Geothermal	Solar	Wind	Electricity	Total of All Energy Sources
Supply	0	0	11.05309	0.004432	0	0	31.54246	48.6539742	0.009122	3.886228	0.200449	216.0182
Production	0	0	11.05309	0.008874	0	0	36.0445	62.0965923	0.009122	3.886228	0	130.6939
Imports	0	0	0	0	0	0	0	0	0	0	1.941722	104.5263
Exports	0	0	0	0	0	0	0	0	0	0	-1.74127	-1.77249
Stock changes	0	0	0	-0.00444	0	0	-4.50204	-13.442618	0	0	0	-17.4295
Transfers	0	0	0	0	0	0	0	0	0	0	0	-0.00209

Figure 65: Supply Template EB Sheet

The main data associated with each resource supply option is a price and any limit on annual production, which starts from the level provided in the Energy Balance and is then subject to the 2050 escalator specified on the SETUP sheet (or directly on the load sheet). The top of Figure 66 provides a snapshot of the prices and the bottom the limits.

Region	Region2	Parameter	Process	Commodity	Timeslice	Imp / Exp	2015	2018	2021	2024	2027	2030	2035	2040	2045	2050	
* Electricity & Heat																	
CostaRica	IMPEXP	IRE_PRICE	IMPELCT-1	ELCT	ANNUAL	IMP	37.28	37.66	38.05	38.43	38.82	39.20	40.39	41.86	43.32	44.78	
*Coal																	
CostaRica	IMPEXP	IRE_PRICE	IMPSUPCOAANT-1	SUPCOAANT	ANNUAL	IMP	2.60	2.77	2.93	3.10	3.26	3.42	3.62	3.80	3.98	4.16	EIA coal $ * SetupFactor
* Oil																	
CostaRica	IMPEXP	IRE_PRICE	IMPSUPOILCOI-1	SUPOILCOI	ANNUAL	IMP	7.61	7.95	8.30	8.64	8.98	9.32	10.17	11.08	12.00	12.92	EIA * SetupFactor
CostaRica	IMPEXP	IRE_PRICE	IMPSUPOILAVG-1	SUPOILAVG	ANNUAL	IMP	32.04	33.60	35.17	36.73	38.29	39.86	43.42	47.19	50.95	54.72	Related to jet fuel
*		IRE_PRICE	IMPSUPOILGSO-1	SUPOILGSO	ANNUAL	IMP	11.91										
*		IRE_PRICE	IMPSUPOILETH-1	SUPOILETH	ANNUAL	IMP	11.91										
CostaRica	IMPEXP	IRE_PRICE	IMPSUPOILLPG-1	SUPOILLPG	ANNUAL	IMP	10.93	11.61	12.28	12.96	13.63	14.30	15.72	17.49	19.26	21.03	Related to natural gas
CostaRica	IMPEXP	IRE_PRICE	IMPSUPOILGSL-1	SUPOILGSL	ANNUAL	IMP	33.88	34.42	34.96	35.51	36.05	36.60	38.99	41.91	44.82	47.73	
CostaRica	IMPEXP	IRE_PRICE	IMPSUPOILJET-1	SUPOILJET	ANNUAL	IMP	24.45	25.64	26.83	28.03	29.22	30.41	33.13	36.01	38.88	41.75	
*		IRE_PRICE	IMPSUPOILKER-1	SUPOILKER	ANNUAL	IMP	8.95	9.50	10.05	10.61	11.16	11.71	12.87	14.32	15.76	17.21	Related to natural gas
CostaRica	IMPEXP	IRE_PRICE	IMPSUPOILDSL-1	SUPOILDSL	ANNUAL	IMP	31.84	33.08	34.33	35.57	36.81	38.06	40.51	43.02	45.54	48.05	
CostaRica	IMPEXP	IRE_PRICE	IMPSUPOILFOI-1	SUPOILFOI	ANNUAL	IMP	16.47	17.36	18.26	19.15	20.04	20.93	22.82	24.91	27.00	29.09	
CostaRica	IMPEXP	IRE_PRICE	IMPSUPOILPCO-1	SUPOILPCO	ANNUAL	IMP	11.91										
*		IRE_PRICE	IMPSUPOILNSO-1	SUPOILNSO	ANNUAL	IMP	11.91										
* Natural gas																	
*		IRE_PRICE	IMPSUPGASNAT-1	SUPGASNAT	ANNUAL	IMP	8.32	8.84	9.35	9.86	10.38	10.89	11.97	13.31	14.66	16.01	
* Nuclear																	
*		IRE_PRICE	IMPSUPNUCLER-1	SUPNUCLER	ANNUAL	IMP	0.655	0.796	0.968	1.176	1.429	1.737	2.110	2.564	3.116	3.787	Data from USNM-60
* Renewables																	
*		IRE_PRICE	RNWSUPBIOIWA-1	SUPBIOIWA	ANNUAL	IMP	11.91										
*		IRE_PRICE	RNWSUPBIOMSW-1	SUPBIOMSW	ANNUAL	IMP	2.04	2.48	3.02	3.67	4.46	5.42	6.58	8.00	9.72	11.81	Related to biomass price
CostaRica	MINRNW	IRE_PRICE	RNWSUPBIOPSF-1	SUPBIOPSF	ANNUAL	IMP	2.14	2.606	3.167	3.848	4.677	5.683	6.906	8.393	10.199	12.394	Data from USNM-60
CostaRica	MINRNW	IRE_PRICE	RNWSUPBIOGAS-1	SUPBIOGAS	ANNUAL	IMP	11.90	12.64	13.37	14.10	14.84	15.57	17.11	19.04	20.96	22.89	Related to natural gas
CostaRica	MINRNW	IRE_PRICE	RNWSUPBIOGSL-1	SUPBIOGSL	ANNUAL	IMP	48.43	49.21	49.99	50.76	51.54	52.32	55.75	59.91	64.08	68.24	Related to gasoline
CostaRica	IMPEXP	IRE_PRICE	IMPSUPBIOGSL-1	SUPBIOGSL	ANNUAL	IMP	48.92	49.70	50.49	51.27	52.06	52.84	56.31	60.51	64.72	68.92	1% hgher than domestic
CostaRica	MINRNW	IRE_PRICE	RNWSUPBIOJKE-1	SUPBIOJKE	ANNUAL	IMP	34.95	36.66	38.36	40.07	41.78	43.48	47.37	51.48	55.58	59.69	Related to jetfuel
CostaRica	IMPEXP	IRE_PRICE	IMPSUPBIOJKE-1	SUPBIOJKE	ANNUAL	IMP	35.30	37.03	38.75	40.47	42.19	43.92	47.84	51.99	56.14	60.29	1% hgher than domestic

	Parameter	Process	Commodity	Timeslice	BND type	or Value	2015	2050
* Electricity & Heat								
	ACT_BND	IMPELCT-1	-	ANNUAL	UP	15	1.94172171	2.33
	COM_PEAK	-	ELCT	-	-	1		
	COM_PKRSV	-	ELCT	-	-	0	23%	
*Coal								
	ACT_BND	IMPSUPCOAANT-1	-	ANNUAL	UP	0	0.014000087	
* Oil								
	ACT_BND	IMPSUPOILCOI-1	-	ANNUAL	UP	0	0	
	ACT_BND	IMPSUPOILAVG-1	-	ANNUAL	UP	15	0.046150876	0.14
*	ACT_BND	IMPSUPOILGSO-1	-	ANNUAL	UP	15	0	0.00
*	ACT_BND	IMPSUPOILETH-1	-	ANNUAL	UP	15	0	0.00
	ACT_BND	IMPSUPOILLPG-1	-	ANNUAL	UP	0	6.62024601	
	ACT_BND	IMPSUPOILGSL-1	-	ANNUAL	UP	0	37.06555198	
	ACT_BND	IMPSUPOILJET-1	-	ANNUAL	UP	0	7.972689298	
*	ACT_BND	IMPSUPOILKER-1	-	ANNUAL	UP	0	0	
	ACT_BND	IMPSUPOILDSL-1	-	ANNUAL	UP	0	42.40428598	
	ACT_BND	IMPSUPOILFOI-1	-	ANNUAL	UP	0	5.249939537	
	ACT_BND	IMPSUPOILPCO-1	-	ANNUAL	UP	0	3.211698254	
*	ACT_BND	IMPSUPOILNSO-1	-	ANNUAL	UP	0	0	
* Natural gas								
*	ACT_BND	IMPSUPGASNAT-1	-	ANNUAL	UP	0	0	
* Renewables								
*	ACT_BND	RNWSUPBIOIWA-1	-	ANNUAL	UP	0	0	
*	ACT_BND	RNWSUPBIOMSW-1	-	ANNUAL	UP	15	0	0.00
	ACT_BND	RNWSUPBIOPSF-1	-	ANNUAL	UP	15	11.05308881	22.11
	ACT_BND	RNWSUPBIOGAS-1	-	ANNUAL	UP	15	0.008974243	4.01
	ACT_BND	RNWSUPBIOGSL-1	-	ANNUAL	UP	15	0	12.26
	ACT_BND	IMPSUPBIOGSL-1	-	ANNUAL	UP	0	0	
	ACT_BND	RNWSUPBIOJKE-1	-	ANNUAL	UP	15	0	1.59
	ACT_BND	IMPSUPBIOJKE-1	-	ANNUAL	UP	0	0	
	ACT_BND	RNWSUPBIODSL-1	-	ANNUAL	UP	15	0	8.48

Figure 66: Supply Template Data Sheets

A.7 Power Sector Templates

The Power Sector has two primary workbooks, the BY-PP for the depiction of the current installed capacity and the NT-PP for the future plant options. As mentioned for Supply and discussed in more detail below for the demand devices, the types of power plants in terms of the fuels used are controlled by the entries in the Energy Balance. But then the individual plants (or plant types) to the included in the model need to be identified on the SETUP sheet and their existing installed capacity and basic performance characteristics provided, in this case from detailed data provided by ICE, on the Calibration sheet (see Figure 67). This information is then carried over to the various ProcData_<PP type> sheets for loading into ANSWER.

selected		Calibration of power and heat generation	Fuel	Decomissioning year	Existing Capacity	Fuel consumption	Electricity Produced (Gross)	Self-Consumption	Electricity Produced (Net)	Base Year Capacity factor	Availability for future years	Efficiency		
						Est/known	Est/known elc prod	Est/known elc prod	Est/known elc prod	Calc. from Elc and Cap	Max capacity factor AF	Based on elc:fuel ratio	Standard Estimate	Model input
	Electricity Only Power Plants				GW	PJ	PJ	PJ	PJ	%	%	%	%	%
	* Hydro													
	EERNWHYD-DM-X0	Hydro - Dam (Existing)	PWRRNWHYD	2060	0.324	5.445	5.013	0.057	4.956	48.5%	48.5%	91.0%	100.0%	91.0%
	EERNWHYD-RR-X0	Hydro - Run-of-River (Existing)	PWRRNWHYD	2060	1.248	18.627	17.149	0.196	16.953	43.1%	43.1%	91.0%	100.0%	91.0%
	EERNWHYD-RG-X0	Hydro - Regulating (Existing)	PWRRNWHYD	2060	0.363	7.470	6.877	0.079	6.799	59.3%	59.3%	91.0%	100.0%	91.0%
		Total Hyrdo			0.000	0.000	0.000	0.000	0.000					
	* Gas													
*	EEGASNAT-CC-X0	Natural Gas - Combined cycle (Existing)	PWRGASNAT	2050						-	90.0%	-	48.4%	-
*	EEGASNAT-CT-X0	Natural Gas - Combustion turbine (Existing)	PWRGASNAT	2050						-	90.0%	-	30.0%	-
		Total Gas			0.000	0.000	0.000	0.000	0.000					
	* Biomass													
*	EEBIOGAS-EN-X0	Biogases - Engine/Reciprocating (Existing)	PWRBIOGAS	2050	0.000	0.000	-	-	-	-	90.0%	-	36.0%	-
*	EEBIOGAS-EN-PX0	Biogases - Private Engine/Reciprocating (Existing)	PWRBIOGAS	2060						-	90.0%	-	30.0%	-
*	EEBIOGAS-GT-X0	Biogases - Gas turbine (Existing)	PWRBIOGAS	2050						-	90.0%	-	30.0%	-
*	EEBIOGAS-ST-X0	Biogases - Steam turbine (Existing)	PWRBIOGAS	2050						-	90.0%	-	27.1%	-
*	EEBIOGAS-CC-X0	Biogases - Combined cycle (Existing)	PWRBIOGAS	2050						-	90.0%	-	45.0%	-
*	EEBIOMSW-ST-X0	Municipal Waste - Steam turbine (Existing)	PWRBIOMSW	2050						-	90.0%	-	20.0%	-
		Total			0.000	0.0000000	0.000	0.000	0.000					
	* Renewables													
*	EEBIOPSF-IG-X0	Firewood - Integrated Gasif. Combined cycle (Existi	PWRBIOPSF	2050						-	90.0%	-	25.3%	-
	EERNWGEO-ST-X0	Geothermal - Steam turbine (Existing)	PWRRNWGEO	2060	0.217	48.654	4.95	0.057	4.896	71.4%	90.0%	10.1%	35.1%	10.1%
*	EERNWGEO-ST-PX0	Geothermal - Private Thermal Central (Existing)	PWRRNWGEO	2060	0.000	0.000	0.00	0.000	0.000	-	90.0%	-	35.1%	-
	EERNWSOL-PV-X0	Solar - Photovoltaics (Existing)	PWRRNWSOL	2037	0.001	0.005	0.00551	0.000	0.005	17.3%	17.3%	100.0%	100.0%	100.0%
	EERNWWIN-ON-X0	Wind - Onshore (Existing)	PWRRNWWIN	2060	0.278	3.886	3.89	0.044	3.842	43.8%	43.8%	98.9%	100.0%	98.9%
*	EERNWWIN-ON-PX0	Wind - Private Onshore (Existing)	PWRRNWSOL	2060	0.000		-	0.000	0.000	-	-	-	100.0%	-
*	EERNWWIN-OF-X0	Wind - Offshore (Existing)	PWRRNWWIN	2050						-	0.00%	-	100.0%	-
		Total			0.497	52.546	8.844	0.101	8.743					
	* Other					EB off 0								
*	EEBIORRV-ST-PX0	Organic Residues - Private Steam turbine (Existing)	PWRBIORRV	2050						-	-	-		-
	EEBIORBG-ST-PX0	Bagasse - Steam turbine (Existing)	PWRBIORBG	2060	0.040	0.597	0.30	0.003	0.293	23.2%	90.0%	49.0%		49.0%
*	EEBIOORV-ST-PX0	Other organic residues - Combined cycleSteam turt	PWRBIOORV	2060				0.000	0.000	-	-	-		-
	EEOILDSL-GT-X0	Diesel - Gas turbine (Existing)	PWROILDSL	2060	0.344	0.014	0.004	0.000	0.0041	0.0%	90.0%	29.2%	29.5%	29.2%
	EEOILDSL-EN-X0	Diesel - Engine/Reciprocating (Existing)	PWROILDSL	2016	0.024	0.041	0.003	0.000	0.0030	0.4%	90.0%	7.3%	-	7.3%
	EEOILFOI-GT-X0	Fuel Oil - Gas turbine (Existing)	PWROILFOI	2060	0.000	0.000	0.000	0.000	0.0000	-	90.0%	-	40.0%	-
	EEOILFOI-EN-X0	Fuel Oil - Private Engine/Reciprocating (Existing)	PWROILFOI	2060	0.228	0.892	0.38	0.004	0.378	5.3%	90.0%	42.3%	40.0%	42.3%
		Total			0.636	1.545	0.685	0.008	0.678					
		Total Electricity Only Plants			3.068	85.633	38.569	0.441	38.128					
		Total from Energy Balance				85.633	38.569	0.445	38.128					

Figure 67: Existing Power Plant Calibration

There are two additional templates associated with the power sector and implement portions of the ICE expansion plan. S_ICE-27 implements the plan thru 2027 and S_ICE-24 limits the implementation to 2024. If neither scenario is specified in the run list, then no parts of the ICE expansion plan are implemented.

A.8 Demand Sector Template Examples (Agriculture)

As discussed earlier, for each demand sector (other than Non-energy/Other) there are three input data templates that characterize the existing and new technology options and provide guidance for the baseline or policy scenarios. This section uses the Agriculture sector to provide an example of each to explain their basic role and setup.

A.8.1 BY Calibration and Device Specification

As noted above, the SETUP sheet refers to the EB sheet to determine which demands are active in the 1st year of the model and what fuels they consume to identify what devices are to be included in the model. This is done by dynamically conditionally excluding unused devices from the database by commenting them out (with a "*" in column A of the SETUP sheet).

Then, as mentioned in Section 5.1 when discussing the calibration of the Baseline scenario, each demand sector uses a decomposition procedure to move from the aggregate information embodied in the Energy Balance to the device and end-use service demands needed in the model. This is accomplished on the EB and Calibration sheets found in each BY demand sector template, shown in Figure 68 and Figure 69 respectively. On the EB sheet, the FEC to the sector in the base year is split to each demand service that consumes that energy (the yellow cells).

		OILAVG	OILGSL	OILKER	OILDSL	OILFOI	OILJET	GASNAT	RNWSOL	ELC	LTH	
PJ	Sector Name	Aviation Gasoline	Gasoline	Kerosene	Diesel	Fuel Oil	Jet Fuel	Natural Gas	Solar	Electricity	Heat	Total of All Energy Sources
Agriculture	AGR	0.0023663	0.22476	0.086597	1.70863	0	0.16573	0	0	1.13917	0	3.327254
Fishing	AGR	0	0	0	0	0	0	0	0	0	0	0.000000
Total		**0.002366**	**0.22476**	**0.086597**	**1.70863**	**0**	**0.16573**	**0**	**0**	**1.13917**	**0**	**3.327254**
Split each by end-use												
AWP	Agriculture Water Pumping		2%		2%					20%		
ATH	Agriculture Tractors - Hauling		0%		98%							
AOE	Agriculture Other Use	100%	98%	100%			100%			80%		
	Check if 100%	**100%**	**100%**	**100%**	**100%**	**0%**	**100%**	**0%**	**0%**	**100%**	**0%**	
FEC by end-use												
AWP	Agriculture Water Pumping	0	0.0045	0	0.03417	0	0	0	0	0.22783	0	**0.2665014**
ATH	Agriculture Tractors - Hauling	0	0	0	1.67446	0	0	0	0	0	0	**1.6744565**
AOE	Agriculture Other Use	0.002366	0.22027	0.086597	0	0	0.16573	0	0	0.91133	0	**1.3862961**
	Total	**0.002366**	**0.22476**	**0.086597**	**1.70863**	**0**	**0.16573**	**0**	**0**	**1.13917**	**0**	**3.327254**
	Diff from EB (Check if zero)	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Figure 68: Energy Balance Decomposition

Then on the Calibration sheet, data is inherited from the STARTER database for efficiency and capacity factor, which can be overridden if better local data is available, and the resulting existing capacity and useful energy service delivered in the first year determined. Note that if more than one existing device type servicing a demand uses the same fuel, then the split been them must be provided (the yellow cells).

Selected?	AWP	Agriculture Water Pumping	PIEM Lookup	Efficiency	Capacity Factor	Share of FEC	Final energy (PJ)	Useful Energy (PJ)	Installed Capacity (PJ/a)	Fuel
	AWPOILGSL-X0	Agriculture Water Pumping: Gasoline- Existing 00	AWPLDO-E	0.09	0.06	1	0.004495226	0.0004	0.006	OILGSL
	AWPOILDSL-X0	Agriculture Water Pumping: Diesel- Existing 00	AWPHSD-E	0.09	0.06	1	0.034172582	0.0030	0.047	OILDSL
	AWPELC-X0	Agriculture Water Pumping: Electricity- Existing 00	AWPELC-E	0.36	0.11	1	0.227833555	0.0813	0.724	ELC
							0.2665	**0.0847**		
						from EB	0.266501362			
						check if zero	0.0000			
Selected?	ATH	Agriculture Tractors - Hauling		Efficiency	Capacity Factor	Share of FEC	Final energy (PJ)	Useful Energy (PJ)	Installed Capacity (PJ/a)	Fuel
*	ATHOILGSL-X0	Agriculture Tractors - Hauling: Gasoline - Existing 00	ATHHSDS-E	0.20	0.12	1	0	0.0000	0.00	OILGSL
	ATHOILDSL-X0	Agriculture Tractors - Hauling: Diesel - Existing 00	ATHHSDL-E	0.25	0.12	1	1.674456495	0.4186	3.39	OILDSL
							1.6745	**0.4186**		
						from EB	1.674456495			
						check if zero	0.0000			
Selected?	AOE	Agriculture Other Use		Efficiency	Capacity Factor	Share of FEC	Final energy (PJ)	Useful Energy (PJ)	Installed Capacity (PJ/a)	Fuel
·	AOEBIOPSF-X0	Agriculture Other Use: Firewood to Agriculture- Existing 00	AOEBIOPSF-X0	1.00	1.00	1	0	0.0000	0.00	BIOPSF
·	AOEGASNAT-X0	Agriculture Other Use: Natural Gas to Agriculture- Existing 00	AOEGASNAT-X0	1.00	1.00	1	0	0.0000	0.00	GASNAT
	AOEOILAVG-X0	Agriculture Other Use: Aviation Gasoline to Agriculture- Existing 00	AOELDO-E	1.00	1.00	1	0.002366323	0.0024	0.00	OILAVG
	AOEOILGSL-X0	Agriculture Other Use: Gasoline to Agriculture- Existing 00	AOELDO-E	1.00	1.00	1	0.220266068	0.2203	0.22	OILGSL
	AOEOILKER-X0	Agriculture Other Use: Kerosene to Agriculture- Existing 00	AOELDO-E	1.00	1.00	1	0.086597284	0.0866	0.09	OILKER
	AOEOILJET-X0	Agriculture Other Use: Jet Fuel to Agriculture- Existing 00	AOEHFO-E	1.00	1.00	1	0.165732241	0.1657	0.17	OILJET
	AOEELC-X0	Agriculture Other Use: Electricity to Agriculture- Existing 00	AOELDO-E	1.00	1.00	1	0.911334218	0.9113	0.91	ELC
							1.3863	**1.3863**		
						from EB	1.386296135			
						check if zero	0.0000			

Figure 69: Demand Device Efficiency, Installed Capacity and Delivered Useful Energy

Completing the picture in the BY templates are the suite of worksheets that are processed by ANSWER and loaded into the database. These correspond to the declaration sheets (Commodity and Processes), 1st year useful energy demand level (CommData) and the ProcData_<sector_qual> sheet(s) with the actual technology characterization data to be used by the model [not shown].

A.8.2 Future Demand Technology Options

New devices are taken from the repository of future technology options in the STARTER database according to what devices (and their fuels) are activated in the BY template, augmented by any new fuels (and/or demands) that may appear in the future. New devices are characterized as Standard (-ST), Improved (-IM), Better (-BE) and Advanced (-AD) depending upon what is available or likely to be available in the country, where for the Agriculture sector only Standard and Improved options are currently provided, as seen in Figure 70.

ProcData	CostaRica							*						
Check Sheet	ProcName, ProcDesc, Units			CommIN	CommOUT					LIFE	INVESTMENT	FIXED O&M	VAR O&M	AVAILABILITY
Parameter									NCAP_START	NCAP_TLIFE	NCAP_COST	NCAP_FOM	ACT_COST	NCAP_AFA-UP
Qualifier1														
Qualifier2														
	ProcName	ProcDesc	ProcUnits	CommIN	CommOUT	Activity I/O	Tech Lookup		TID					
* New Technologies														
* Agriculture Water Pumping														
	AWPOILGSL-ST	Agriculture Water Pumping: Gasoline to Agriculture-Standard	PJ,PJa	AGROILGSL	AWP		AWPLDO-N		2018	15	9.650	0.1	0.05	0.064
	AWPOILGSL-IM	Agriculture Water Pumping: Gasoline to Agriculture-Improved	PJ,PJa	AGROILGSL	AWP		AWPLDO-N		2021	15	10.615	0.1	0.05	0.064
	AWPOILDSL-ST	Agriculture Water Pumping: Diesel to Agriculture-Standard	PJ,PJa	AGROILDSL	AWP		AWPHSD-N		2018	15	9.650	0.1	0.05	0.064
	AWPOILDSL-IM	Agriculture Water Pumping: Diesel to Agriculture-Improved	PJ,PJa	AGROILDSL	AWP		AWPHSDE-N		2021	15	29.059	0.1	0.05	0.064
	AWPELC-ST	Agriculture Water Pumping: Electricity to Agriculture-Standard	PJ,PJa	AGRELC	AWP		AWPELC-N		2018	15	10.818	0.1	0.05	0.112
	AWPELC-IM	Agriculture Water Pumping: Electricity to Agriculture-Improved	PJ,PJa	AGRELC	AWP		AWPELCE-N		2021	15	16.782	0.1	0.05	0.112
* Agriculture Tractors - Hauling														
	ATHOILGSL-ST	Agriculture Tractors - Hauling: Gasoline to Agriculture-Standard	PJ,PJa	AGROILGSL	ATH		ATHHSDS-N		2018	15	39.143	0.1	0.05	0.116
	ATHOILGSL-IM	Agriculture Tractors - Hauling: Gasoline to Agriculture-Improved	PJ,PJa	AGROILGSL	ATH		ATHHSDS-N		2021	15	43.057	0.1	0.05	0.116
	ATHOILDSL-ST	Agriculture Tractors - Hauling: Diesel to Agriculture-Standard	PJ,PJa	AGROILDSL	ATH		ATHHSDL-N		2018	15	32.619	0.1	0.05	0.123
	ATHOILDSL-IM	Agriculture Tractors - Hauling: Diesel to Agriculture-Improved	PJ,PJa	AGROILDSL	ATH		ATHHSDL-N		2021	15	35.881	0.1	0.05	0.123
* Agriculture Other Use														
	AOEELC-ST	Agriculture Other Use: Electricity to Agriculture-Standard	PJ,PJa	AGRELC	AOE		AOEELC-N		2018	15	13.5	0.1	0.05	1.000
	AOEELC-IM	Agriculture Other Use: Electricity to Agriculture-Improved	PJ,PJa	AGRELC	AOE		AOEELC-N		2021	15	14.85	0.1	0.05	1.000
	AOEOILAVG-ST	Agriculture Other Use: Aviation Gasoline to Agriculture-Standard	PJ,PJa	AGROILAVG	AOE		AOELDO-N		2018	15	15	0.1	0.05	1.000
	AOEOILAVG-IM	Agriculture Other Use: Aviation Gasoline to Agriculture-Improved	PJ,PJa	AGROILAVG	AOE		AOELDO-N		2021	15	16.5	0.1	0.05	1.000
	AOEOILKER-ST	Agriculture Other Use: Kerosene to Agriculture-Standard	PJ,PJa	AGROILKER	AOE		AOEHFO-N		2018	15	16.5	0.1	0.05	1.000
	AOEOILKER-IM	Agriculture Other Use: Kerosene to Agriculture-Improved	PJ,PJa	AGROILKER	AOE		AOEHFO-N		2021	15	18.15	0.1	0.05	1.000
	AOEOILJET-ST	Agriculture Other Use: Jet Fuel to Agriculture-Standard	PJ,PJa	AGROILJET	AOE		AOELDO-N		2018	15	15	0.1	0.05	1.000
	AOEOILJET-IM	Agriculture Other Use: Jet Fuel to Agriculture-Improved	PJ,PJa	AGROILJET	AOE		AOELDO-N		2021	15	16.5	0.1	0.05	1.000
	AOEOILGSL-ST	Agriculture Other Use: Gasoline to Agriculture-Standard	PJ,PJa	AGROILGSL	AOE		AOELDO-N		2018	15	15	0.1	0.05	1.000
	AOEOILGSL-IM	Agriculture Other Use: Gasoline to Agriculture-Improved	PJ,PJa	AGROILGSL	AOE		AOELDO-N		2021	15	16.5	0.1	0.05	1.000
	AOEBIOORV-ST	Agriculture Other Use: Other organic residues to Agriculture-Standard	PJ,PJa	AGRBIOORV	AOE		AOEHFO-N		2021	15	16.5	0.1	0.05	1.000
	AOEBIOORV-IM	Agriculture Other Use: Other organic residues to Agriculture-Improved	PJ,PJa	AGRBIOORV	AOE		AOEHFO-N		2021	15	18.15	0.1	0.05	1.000

ANSv2-692-Home | SETUP | Commodities | Processes | ProcData_AGR | PIEM_AGR-New

Figure 70: New Technology Specification

Note that the data is grabbed from the new technology repository according to the Tech Lookup column (corresponding to the name of the device in the STARTER database), unless overwritten where better local data is available (the yellow cells above).

A.8.3 UC Guidance

The UC guidance template has three roles: to control fuel and device type switching and the rate of uptake of new devices. For the 1st two groups, links to the BY templates determine the 1st period fuel consumption and device type shares, with the user than setting the allowed shares in the last model period. The new device penetration limits start from an assumed low level today and gradually rise to the user specified 2050 level. See Figure 71.

TS&TID DATA	CostaRica												
											LO	UP	
Check Sheet										Fuel Relaxation Factor	10%	3%	
	Parameter	Arg1	Arg2	Arg4	Arg6	I/F Opt				Tech Relaxation Factor	10%	10%	
											AD	BE	IM
Populate DataYears										Max 2050 share	x%	y%	10%
	Parameter	Constraint Name	Process or TechFilter	Commodity	Type	I/E Opt or Value	2018	2030	2050	Override			
*AGR Fuel shares by DM													
	UCRULE_MARK	AWP-F-OILGSL-LO	AWP-F-OILGSL	AWP	LO	5	0.00		0.004				
	UCRULE_MARK	AWP-F-OILDSL-LO	AWP-F-OILDSL	AWP	LO	5	0.04		0.032				
	UCRULE_MARK	AWP-F-ELC-LO	AWP-F-ELC	AWP	LO	5	0.95		0.855				
*	UCRULE_MARK	ATH-F-OILGSL-LO	ATH-F-OILGSL	ATH	LO	5	0.00		0.000				
	UCRULE_MARK	ATH-F-OILDSL-LO	ATH-F-OILDSL	ATH	LO	5	0.99		0.891				
	UCRULE_MARK	AOE-F-BIOORV-UP	AOE-F-BIOORV	AOE	UP	5	0.00		0.000				
*	UCRULE_MARK	AOE-F-GASNAT-LO	AOE-F-GASNAT	AOE	LO	5	0.00		0.000				
	UCRULE_MARK	AOE-F-OILAVG-LO	AOE-F-OILAVG	AOE	LO	5	0.00		0.002				
	UCRULE_MARK	AOE-F-OILGSL-LO	AOE-F-OILGSL	AOE	LO	5	0.16		0.142				
	UCRULE_MARK	AOE-F-OILKER-LO	AOE-F-OILKER	AOE	LO	5	0.06		0.056				
	UCRULE_MARK	AOE-F-OILJET-LO	AOE-F-OILJET	AOE	LO	5	0.12		0.107				
	UCRULE_MARK	AOE-F-ELC-LO	AOE-F-ELC	AOE	LO	5	0.65		0.586				
*AGR Improved technology shares													
	UCRULE_MARK	AWP-Q-IM-UP	AWP-Q-IM	AWP	UP	5	1%		10%				
	UCRULE_MARK	ATH-Q-IM-UP	ATH-Q-IM	ATH	UP	5	1%		10%				
	UCRULE_MARK	AOE-Q-IM-UP	AOE-Q-IM	AOE	UP	5	1%		10%				

Figure 71: Control of the Baseline Model Behavior

Note that the Agriculture sector does not have multiple device types, so there are no device type constraints in the example shown above.

A.9 Demand Project Workbook

The process of establishing the useful energy demand service projections that drive the TIMES-CR model was presented in Section 294.2.5. A single demand projection workbook handles this by taking the 1st year energy service levels determined from the calibration of each sector, and then applying appropriate drivers and elasticities to prepare a forecast of likely future demand for energy services. The workbook is organized with the sheets listed in Table 40, where only the worksheets in italics are loaded directly into ANSWER.

Table 40: Structure of Demand Input Workbook

Worksheet	Description
ANSv2-692-Home	ANSWER-TIMES template sheet that is used to add new ANSWER-TIMES smart sheet to the current workbook, or turn an existing XLS/XLSM into a “smart” workbook.
Demand Drivers	The demand drivers (e.g., GDP, population, etc.) prepared from the source data and/or set by the user (yellow cells).
Source Data	Historical GDP, projected GDP growth and Population.

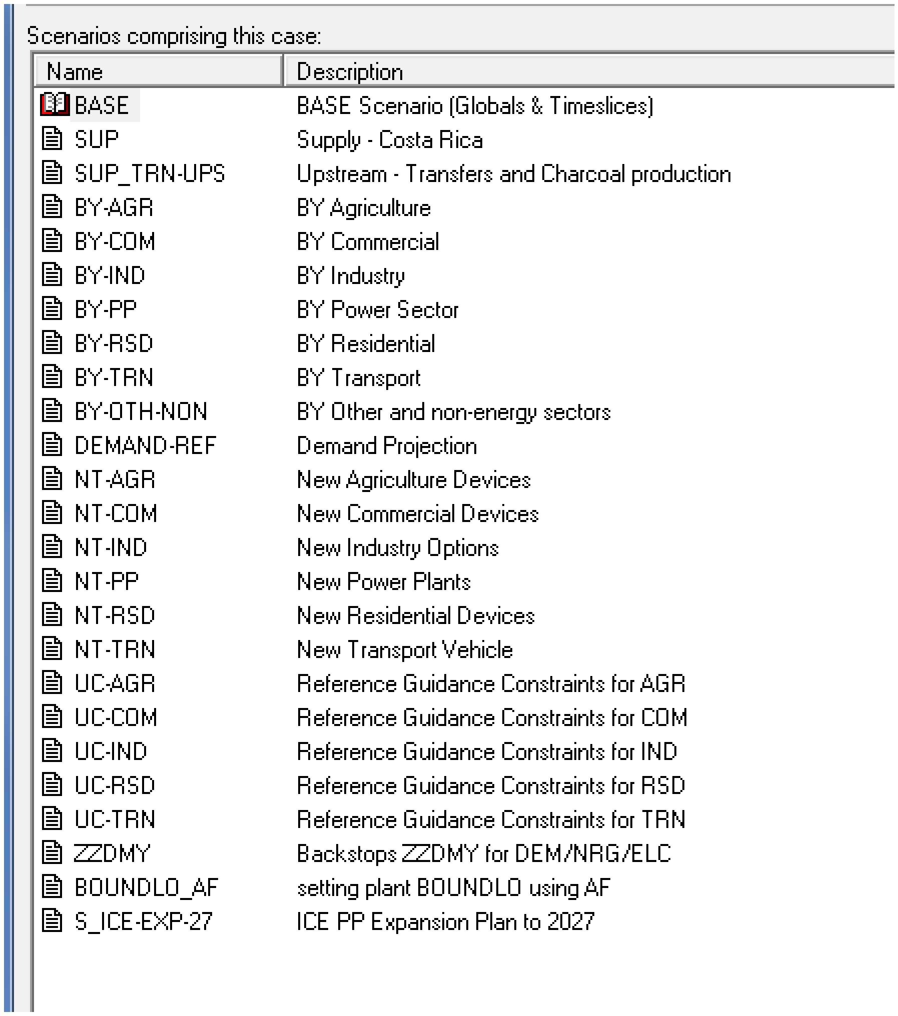
Worksheet	Description
Base year calibration data	The useful energy demand services delivered in the 1st year of the model as determined for the end-use by the BY calibration process.
<Sector> Demand	The autonomous energy efficiency improvement (aeei) and elasticity for each sector, which are applied along with the appropriate driver to the 1st year demand resulting in the demand forecast
Commodities	The list of energy service demands.
Demand_Projections	The demand projections as prepared on each of the <Sector_ Demand sheets.
Useful Energy Demand	Graphs for each sector of the useful energy demand services.
Useful Energy Intensities	Graphs for each sector of the energy intensity of each demand services.

A.10 Remaining Baseline Workbooks

The remaining workbook comprising the Baseline scenario consist of REF-Bound_LO-AF template to ensure that existing power plants are used in the early periods and the ZZDMY backstop template, which employs an important modeling technique to avoid the most common infeasibilities that can arise when running a TIMES model. The ZZDMY processes ensure that every energy carrier and demand has an unlimited supply (at an extremely high price) so that there will never be a shortage within the model regardless of the actual limits imposed on supply or technologies. The user can immediately recognize if the ZZDMY process is activated by a tremendous jump in the total system cost. By then examining which commodities the process produces, the area of the RES that is having problems can be identified, and the hassle of the model stopping and not generating results due to an infeasibility is avoided.

A.11 Handling Baseline Templates in ANSWER

Each of the model input templates identified in Table 38 (and discussed above) are loaded into corresponding scenarios in ANSWER (dropping the AT2_CostaRica or other prefix) to comprise the Baseline scenario. ANSWER remembers which template(s) is(are) loaded into each scenario and provides an indication of whether or not a template has been changed since last loaded when selected for importing via the Import Model Data facility. The scenarios are then combined to conduct model runs, where those constituting the Baseline scenario are presented in Figure 72. Note that the order of the scenarios in the run list is important to ensure that TIMES processes the model input data properly, as GAMS reads the scenarios in the order specified in the run list.



Scenarios comprising this case:

Name	Description
BASE	BASE Scenario (Globals & Timeslices)
SUP	Supply - Costa Rica
SUP_TRN-UPS	Upstream - Transfers and Charcoal production
BY-AGR	BY Agriculture
BY-COM	BY Commercial
BY-IND	BY Industry
BY-PP	BY Power Sector
BY-RSD	BY Residential
BY-TRN	BY Transport
BY-OTH-NON	BY Other and non-energy sectors
DEMAND-REF	Demand Projection
NT-AGR	New Agriculture Devices
NT-COM	New Commercial Devices
NT-IND	New Industry Options
NT-PP	New Power Plants
NT-RSD	New Residential Devices
NT-TRN	New Transport Vehicle
UC-AGR	Reference Guidance Constraints for AGR
UC-COM	Reference Guidance Constraints for COM
UC-IND	Reference Guidance Constraints for IND
UC-RSD	Reference Guidance Constraints for RSD
UC-TRN	Reference Guidance Constraints for TRN
ZZDMY	Backstops ZZDMY for DEM/NRG/ELC
BOUNDLO_AF	setting plant BOUNDLO using AF
S_ICE-EXP-27	ICE PP Expansion Plan to 2027

Figure 72: Baseline Scenario Run Specification

Appendix B: All Mitigation Measures

As discussed in Section 8, a comprehensive list of mitigation measures was prepared by the PMR, from which a subset of measures listed in Table 19 were prepared for evaluation using TIMES-CR. The complete list of candidate measures relevant to the energy sector from which those in Table 19 were derived are presented in this Appendix. Note that the Mitigation Measure Number (MM No.) can be used to reference the source documents with the full supporting assumptions and data.

TIMES Scenario	TIMES Measure	MM No.	Type	Document	Objective	Action	Goal (Impact)
GHG Emissions cap	NDC Target	1	Public Policy	INDC	To keep the increase in the mean global temperature under 2°C and to consider to set this limit to 1.5°C	Up to today the INDC does not have its own mitigation actions, it better defines key sectors of the expected actions to be implemented within the INDC framework: Reducing energy demand and GHG emissions (energy efficiency and conservation, sectoral strategies low in carbon), decarbonization of the energy supply mix (power, biofuels), substitution of fuels for final use (buildings, transport, industry), handling carbon sinks (planning of the land use, reforestation, avoided deforestation)	To reach an absolute maximum of the emissions of 9.374.00 net TCO2eq by 2030, with a proposed path of per capita emissions to 1.73 net tons per casita by 2030; 1.19 net tons per capita by 2050 and -0.27net tons per capita by 2100

GHG Emissions cap	Sub-goals for Total GHG Emissions cap	2	Public Policy	INDC	Carbon neutrality of the country by 2021 with respect to the 2005 emissions	Up to today the INDC does not have its own mitigation actions, it better defines key sectors of the expected actions to be implemented within the INDC framework: Reducing energy demand and GHG emissions (energy efficiency and conservation, sectoral strategies low in carbon), decarbonization of the energy supply mix (power, biofuels), substitution of fuels for final use (buildings, transport, industry), handling carbon sinks (planning of the land use, reforestation, avoided deforestation)	44% of abatement of GHG emissions compared to the Business As Usual scenario (BAU), and represents a reduction of emissions of GHG of 25% compared with the 2012 emissions. To meet this goal, Costa Rica will need to reduce 170.500 tons of GHG each year until 2031
GHG Emissions cap	Near-term Goals	92	Public Policy	National Development Plan	Articulate the different territorial, sectoral, public and private initiatives to reduce GHG emissions	National Program for the Reduction of Greenhouse Gas Emissions (GHG)	To avoid the emission of 7 664 930 ton of CO2 between 2015 and 2018: -2015: 575 900 ton of CO2 avoided -2016: 624 700 ton of CO2 avoided -2017: 5 636 380 ton of CO2 avoided -2018: 827 950 ton of CO2 avoided

GHG Emissions cap	Sub-goals for Sectoral variations	80	Public Policy	National Development Plan	To foment the action facing global climate change through the citizens participation, the technological change, innovation processes, research and knowledge to ensure the welfare, the human security and the country's competitiveness	Encourage actions to reduce emissions in key sectors (transport, energy, agriculture, solid waste) to catalyze the process of transformation towards low emissions development and the country's Carbon Neutrality target in the framework of National Contributions to the UNFCCC Of the United Nations for Climate Change (UNFCCC)	Sectoral goal: to keep the variation in annual sectoral emission reduction rates to within 5.25%
GHG Emissions cap	Energy Sector target	272	Technical document	BUR	Ensure the supply and use of energy in the quantity, quality and diversity of sources, compatible with the sustainable development of Costa Rican society.	National Energy Plan 2015-2030	2,350,000 t CO_2e of emissions reduced to the year 2021, according to the reference scenario projected from 2010.
Power Generation	RE Electricity	82	Public Policy	National Development Plan	To supply the energy demand of the country by means of an energy matrix that assures the optimal and continuous supply of electricity and fuel promoting the efficient use of energy to maintain and improve the competitiveness of the country.	Increase of clean energy in the energy matrix to reduce its vulnerability by supplying the energy demand.	To increase the % of renewable electricity production: 2015: 90% Renewable, 10% Thermal. 2016:92% Renewable, 8% Thermal. 2017: 98% Renewable, 2% Thermal. 2018: 97% Renewable, 3% Thermal.
Power Generation	RE Capacity Goal	94	Public Policy	National Development Plan	Promote the use of renewable energy	Impulse of renewable energy sources and their rational use	By 2018 to rise in 731, 9 MW the installed capacity of clean energy production.

Power Generation	PV Installations	95	Public Policy	National Development Plan	Promote the use of renewable energy	Impulse of renewable energy sources and their rational use	To install 1000 units of photovoltaic systems between 2015-2018
Power Generation	Distributed Generation	103	Technical document	National Communication		Pilot Plan for distributed generation for Self-consumption, from ICE	Primarily Distributed PV for RSD and COM Buildings
Power Generation	Distributed Generation	107	Technical document	National Communication	Stimulate the installation of generation systems in the short term, currently covering only the generation systems for self-consumption.	Distributed Energy Generation Program	
Power Generation	Distribution Efficiency	150	Public Policy	National Energy Plan	Reduce the technical losses in the supply chain	Elaborate a plan of reduction of technical losses by distributing company based on previous studies on possible improvements	July 2016: Previous studies on possible improvements already made December 2016: A plan to reduce technical losses by distributing company already elaborated
Power Generation	Generating Efficiency	153	Public Policy	National Energy Plan	Improve the efficiency of the equipment used to provide electrical service	Establish internal institutional guidelines for energy efficiency for equipment used in the energy supply chain	By July 2017 have an energy efficiency guideline for equipment in the supply chain already established
Power Generation	Near-term Expansion Plan	179	Public Policy	National Energy Plan	Plan and develop the National Electricity System	Execute the works of generation projects necessary to meet the demand, following the recommendations of the Generation Expansion Plan	In the period 2015-2018 to have incorporated 731.9 MW into the system as follows: -December 2015: 234.6 MW -December 2016: 478.5 MW -December 2017: 15.2 MW -December 2018: 3.6 MW

Power Generation	Bio-waste Utilization	205	Public Policy	National Energy Plan	Gradually incorporate NCRE into the electricity system, considering criteria of: strategic convenience, cost, environmental, social, among others	Develop a pilot project with other types of waste (other than bagasse)	By July 2017 have 1 biomass / waste pilot project already developed Assumed to be primarily bagasse, coffee and palm oil waste.
Power Generation	Large-scale Solar	206	Public Policy	National Energy Plan	Gradually incorporate NCRE into the electricity system, considering criteria of: strategic convenience, cost, environmental, social, among others	Develop a pilot project with 5MW of solar power	By July 2018 have 1 pilot project already developed
Renewable Energy	RE Share of Final Energy	81	Public Policy	National Development Plan	To supply the energy demand of the country by means of an energy matrix that assures the optimal and continuous supply of electricity and fuel promoting the efficient use of energy to maintain and improve the competitiveness of the country.	Increase of clean energy in the energy matrix to reduce its vulnerability by supplying the energy demand.	Between 2015 - 2018 to increase to 27.9% the renewable energy. 2015: 26,7% 2016: 27,6% 2017: 29,0% 2018: 28,2%
Renewable Energy	Share of RE Fuels	83	Public Policy	National Development Plan	To supply the energy demand of the country by means of an energy matrix that assures the optimal and continuous supply of electricity and fuel promoting the efficient use of energy to maintain and improve the competitiveness of the country.	Increase of clean energy in the energy matrix to reduce its vulnerability by supplying the energy demand.	Between 2015-2018 to reach a 0.5% of renewable energy in the final consumption of oil products: 2015: 0% (Managing the production of the new gasoline standard with ethanol) 2016:0,5% renewable 2017: 0,8% renewable 2018: 0,8% renewable

Renewable Energy	RE Fuels	96	Public Policy	National Development Plan	Promote the use of renewable energy	Impulse of renewable energy sources and their rational use	By 2018 to mix 5% of ethanol in the sales of gasoline (super) at national level -2015: Managing the production of the new gasoline standard with ethanol -2016: to mix 3% of ethanol in the sales of gasoline (super) at national level -2017 y 2018: to mix 5% of ethanol in the sales of gasoline (super) at national level
Renewable Energy	Biogas Project	106	Technical document	National Communication	Provide technical advice to the agricultural and agro industrial sector for the generation of biogas and energy production from the organic waste of their activities	Biogas Project	What is the source of the biogas? What is the technology (digester/gasifier?) What is the investment cost and efficiency?
Renewable Energy	Biogas Standards	269	Public Policy	National Energy Plan	Encourage the production and use of biogas (synthesis gas) as a substitute for fossil energy sources	Establish the regulation of quality, use, safety in the use of biogas	By July 2017 have a regulation for the quality, use, safety in the use of biogas already approved
Transport	Emission Fee	228	Public Policy	National Energy Plan	Strengthen the financing of actions to reduce emissions by means of an annual fee for emissions derived from the combustion process	Create the regulation for the implementation and application of the fee for emissions from mobile sources	For July 2016 count the regulation for the canon for emissions already approved What does this mean? Regulation?
Transport	Bio-fuels Requirement	260	Public Policy	National Energy Plan	Create the legal, technical and institutional conditions to incorporate biofuels into the energy matrix	Promote the creation of the legal framework that generates the conditions for the incorporation of biofuels into the energy matrix, RECOPE's authorization in the	By December 2016 have a proposal for a legal framework for the incorporation of biofuels in the energy matrix and the empowerment of RECOPE in the incursion of these alternatives already

						incursion of alternative energies, as well as the powers of the entities involved	elaborated
Transport	Bio-fuels Requirement	262	Public Policy	National Energy Plan	Create the legal, technical and institutional conditions to incorporate biofuels into the energy matrix	Create technical standards and regulations on the quality, production, mix and distribution of biofuels	By December 2016 have technical standards for the quality, production, mixing and distribution of biofuels already made
Transport	Transport Emissions	278	Public Policy	National climate change strategy and its action plan	Reduce GHG emissions from the transport sector by implementing a series of measures aimed at improving the accessibility, mobility and use of low carbon technologies.		By 2014 maintain emissions compared to 2005 (3 812, 1 Gg CO2)
Transport	Transport Emissions	279	Public Policy	National climate change strategy and its action plan	Reduce GHG emissions from the transport sector by implementing a series of measures aimed at improving the accessibility, mobility and use of low carbon technologies.		By 2018 reduce emissions by 10% compared to 2005 (3 812, 1 Gg CO2)
Transport	Transport Emissions	280	Public Policy	National climate change strategy and its action plan	Reduce GHG emissions from the transport sector by implementing a series of measures aimed at improving the accessibility, mobility and use of low carbon technologies.		By 2021 reduce by 27% emissions from the transport sector compared to the baseline (3 812, 1 Gg CO2, 2005)

Transport	GAM integrated Transport	281	Public Policy	National climate change strategy and its action plan	Reduce GHG emissions from the transport sector by implementing a series of measures aimed at improving the accessibility, mobility and use of low carbon technologies.	Implementation of the integrated public transport system in the GAM (includes sectorization, extension of the inter-city train)	-2014: have a sectoral route in operation -2018: have 4 sectoral routes in operation -2021: to have 100% of the feeder and intersectoral routes implemented and operating in exclusive lanes.
Transport	GAM integrated Transport	282	Public Policy	National climate change strategy and its action plan	Reduce GHG emissions from the transport sector by implementing a series of measures aimed at improving the accessibility, mobility and use of low carbon technologies.	Implementation of the integrated public transport system in the GAM (includes sectorization, extension of the inter-city train)	To double to 2021 the number of passengers mobilized by the inter-urban train in relation to the base line (1 886 261 according to 2010 MOPT data)
Transport	Congestion Control	284	Public Policy	National climate change strategy and its action plan	Reduce GHG emissions from the transport sector by implementing a series of measures aimed at improving the accessibility, mobility and use of low carbon technologies.	Consolidation and territorial extension of congestion control measures	
Transport	Congestion Control	285	Public Policy	National climate change strategy and its action plan	Reduce GHG emissions from the transport sector by implementing a series of measures aimed at improving the accessibility, mobility and use of low carbon technologies.	Consolidation and territorial extension of congestion control measures	

Transport	Public Vehicle Modernization Program	286	Public Policy	National climate change strategy and its action plan	Reduce GHG emissions from the transport sector by implementing a series of measures aimed at improving the accessibility, mobility and use of low carbon technologies.	Impulse of the Technological Renewal Program for the Modernization and Improvement of the national vehicle fleet	In 2014 cover 5% of the fleet with the Technological Renewal Pilot program of taxis and buses
Transport	Vehicle Modernization Program	287	Public Policy	National climate change strategy and its action plan	Reduce GHG emissions from the transport sector by implementing a series of measures aimed at improving the accessibility, mobility and use of low carbon technologies.	Impulse of the Technological Renewal Program for the Modernization and Improvement of the national vehicle fleet	
Transport	LDV Modernization Program	288	Public Policy	National climate change strategy and its action plan	Reduce GHG emissions from the transport sector by implementing a series of measures aimed at improving the accessibility, mobility and use of low carbon technologies.	Impulse of the Technological Renewal Program for the Modernization and Improvement of the national vehicle fleet	By 2021 achieve that 25% of the cars in circulation are hybrids or electric
Transport	Advanced Vehicle Program	289	Public Policy	National climate change strategy and its action plan	Reduce GHG emissions from the transport sector by implementing a series of measures aimed at improving the accessibility, mobility and use of low carbon technologies.	Impulse of the Technological Renewal Program for the Modernization and Improvement of the national vehicle fleet	By 2021 ensure that 100% of taxis and buses are hybrid vehicles, electric or, operate using LPG or natural gas.

Passenger Transport	Public Transit	47	Projects-Programs	Urban NAMA	To contribute with the development of the CDIs, to modernize and improve the performance and sustainability of the public transportation in the GAM (Big Metropolitan Area) based on the National Transportation Plan, as well as the change of private mobilization systems to public ones and non-motorized systems by implementing an Integrated Public Transportation System (SITP)		26 CDIs Working by 2030
Passenger Transport	Municipal Bus Service	72	Public Policy	National Development Plan	To improve the public passenger transportation for the users of the Greater Metropolitan Area	To modernize the Public Passenger Transportation System by Bus	To have 1 implemented sector by 2018
Passenger Transport	Urban NAMA	44	Projects-Programs	Urban NAMA	To reduce the GHG effects generated by the public transportation and the energy consumption in the commercial buildings, also to reduce the commuting time within the GAM		8 Lines of the Integrated Transportation System working by 2022
Passenger Transport	Rapid Intercity Bus Transport	73	Public Policy	National Development Plan	To improve the public passenger transportation for the users of the Big Metropolitan Area	To implement a Rapid Passengers Transportation (TRP) between San Jose and Cartago	To have the first stage of the TRP (San Jose-Cartago) 100% constructed by 2018

Passenger Transport	Intercity Bus	250	Public Policy	National Energy Plan	Encourage the implementation of measures that optimize the operation of the public passenger transport system	To promote the execution of the Diametral Pavas-Curridabat line	For July 2018, the Diametral Pavas-Curridabat already in operation
Passenger Transport	Public Transit	108	Technical document	National Communication	Modernization and efficiency of public transport.	Project for General Support to the Sectorization of Public Transport, MOPT.	
Passenger Transport	Intercity Rail	112	Technical document	National Communication		Intercity train as a complement to previous actions, which seeks to integrate the four cities and is expected to be dual-track, electric and managed by MIDEPLAN. PNT, MOPT	
Passenger Transport	Vehicle Restrictions	113	Technical document	National Communication		Vehicle restriction and expand the public system, the Pico and Plate Program that daily restricts the access of vehicles to the most congested area of the capital, according to their license plate number. PNT, MOPT	
Passenger Transport	Bus Elc Boarding	115	Technical document	National Communication		Incorporate electronic payment on buses and thereby optimize the time of boarding, this action is coordinated with ARESEP, MOPT and BCCR.PNT, MOPT	

Passenger Transport	Vehicle Eff Standards or incentives	230	Public Policy	National Energy Plan	Encourage the use of efficient vehicular technology available in the market	Develop and implement a work plan for the strengthening of the Efficient Vehicle Acquisition Program (PAVE)	By December 2015 to have the work plan already implemented
Passenger Transport	Vehicle Eff Standards or incentives	231	Public Policy	National Energy Plan	Encourage the use of efficient vehicular technology available in the market	Develop and implement a strategy to implement fiscal and other incentives for the purchase of efficient vehicles	By July 2016 have the strategy already elaborated and implemented
Passenger Transport	Old Vehicle Retirement	232	Public Policy	National Energy Plan	Encourage the disposal of vehicles that have fulfilled their useful life to promote the renewal of the vehicle fleet	Elaborate the technical and legal regulations for the final disposal of vehicles	By July 2017 have a regulation of final disposal of vehicles already made.
Passenger Transport	Eff Vehicle incentives	238	Public Policy	National Energy Plan	To create the technical and normative conditions for the technological diversification of the vehicle fleet	Review the exemption regulation of Law No. 7447 for the inclusion of new automotive technologies and their components	For December 2017 have the exonerations Regulation that incorporates the inclusion of new automotive technologies already updated What new vehicle types? What levels over time?
Passenger Transport	New Vehicle Standards	239	Public Policy	National Energy Plan	Regulate the importation of new and used vehicles	Update the regulation for the importation of private vehicles and motorcycles (new and used) in accordance with the existing legal framework	By July 2016 have the regulation for the importation of vehicles already approved What vehicle types and minimum efficiency levels over time?
Passenger Transport	New Vehicle Standards	240	Public Policy	National Energy Plan	Regulate the importation of new and used vehicles	Update the regulation for the importation of private vehicles and motorcycles (new and used) in accordance with the existing legal framework	By July 2017 have the regulation for the import of vehicles of load already approved What vehicle types and minimum efficiency levels over time?

Passenger Transport	Electric Vehicle incentives	241	Public Policy	National Energy Plan	To create the technical and normative conditions for the technological diversification of the vehicle fleet		Strategy for the introduction of electric vehicles already implemented What types of incentives, Grants, rebates, feebates?
Passenger Transport	Promote Cycling & walking	245	Public Policy	National Energy Plan	Promote non-motorized mobility actions	Promote the creation of infrastructure that provides safety and comfort to pedestrians and cyclists in urban areas of the country	By July 2018 have 1 cycle path per province already created What level of LDV passenger demand will be reduced over time? Private vehicles or taxis? What is the investment cost?
Passenger Transport	Urban bike rentals	246	Public Policy	National Energy Plan	Promote non-motorized mobility actions	Promote the creation of bicycle rental programs in urban areas of the country	For July 2018 have 2 bike rental programs already operating What level of LDV passenger demand will be reduced over time? Private vehicles or taxis? What is the investment cost?
Passenger Transport	Public Transit Elc Charging	249	Public Policy	National Energy Plan	Encourage the implementation of measures that optimize the operation of the public passenger transport system	Implement an electronic charging system for the different modes of mass public transport	By July 2018 have 70% of bus operators with the electronic payment system already operating
Passenger Transport	Public Transit Elc Charging	251	Public Policy	National Energy Plan	Encourage the implementation of measures that optimize the operation of the public passenger transport system	Develop a map of the integrated public transport system and facilitate its access through mobile phone applications	By December 2017 have a website and mobile applications with information for users of public transport already available
Passenger Transport	Bus rapid Transit for GAM	252	Public Policy	National Energy Plan	Encourage the implementation of measures that optimize the operation of the public passenger transport system	Initiate GAM route sectorization in parallel with the adoption of exclusive lanes and passenger exchange terminals	By December 2018 have 3 sectors already operating (Curridabat, Pavas and Desamparados)

Passenger Transport	Rapid Passenger Transport	255	Public Policy	National Energy Plan	Encourage the implementation of measures that optimize the operation of the public passenger transport system		In the long term, the Rapid Passenger Transport System is already operating
Freight Transport	Rail Freight	74	Public Policy	National Development Plan	To improve the capacity to move freight in the country, in order to contribute to the economic development	Progressive rehabilitation of the freight railroad transportation in the country	To have 100 km of the freight railroad network rehabilitated by 2018
Freight Transport	Rail Freight	114	Technical document	National Communication		Electric freight transportation: consists of the National Plan of Logistics and freight, which seeks to create platforms for passage at the borders and ports. It is intended to strengthen the current freight train in the Caribbean and integrate it from Rio Frio to Muelle de San Carlos. The metropolitan freight train is also analyzed.	
Energy Efficiency	Public Buildings Environmental Management Plans	100	Public Policy	National Development Plan	Improve the efficiency of the use of electric energy in the public sector in the framework of the PGAI	Program to strengthen the Institutional Environmental Management Plans (PGAI) to improve the efficiency of electricity consumption in the institutions with the highest electricity consumption in the public sector.	Between 2015- 2018 reach that 20 institutions have energy efficiency regulations

Energy Efficiency	Waste biofuels Utilization	120	Technical document	National Communication		Replacement of industrial fuels for less pollutants ones obtained from process waste in the industrial sector	
Energy Efficiency	Legal Framework	127	Public Policy	National Energy Plan	Modernizing the legal framework for energy efficiency	Develop a proposal to modernize the legal framework for energy efficiency (Law No 7447)	July 2016: have a proposal for a legal framework already developed December 2016: have a Consultation of the proposal already made July 2017: to have made a presentation and follow up to the legislative process
Energy Efficiency	EE Tax Exemptions	134	Public Policy	National Energy Plan	Make efficient equipment more accessible through tax exemption	Update the list of exempt equipment incorporating new efficient technologies	For December 2015 to have an update of the list of exonerated equipment incorporating new efficient technologies (already performed)
Energy Efficiency	Appliance standards	135	Public Policy	National Energy Plan	Regulate the efficiency of consumer equipment	Develop technical regulations for equipment efficiency	For December 2015 have a technical regulation of residential cooling For July 2016 have a technical regulation of commercial refrigeration For July 2016 have a technical regulation of electric cookers For December 2016 have a technical regulation of lighting For July 2017 have a technical regulation of air conditioners For December 2017 have a technical regulation of engines

							For July 2018 tell a technical regulation of electric water heaters
Energy Efficiency	Public Lighting	151	Public Policy	National Energy Plan	Ensure efficient public lighting	Elaborate efficient public lighting plans by each distribution company	By July 2016 have an efficient public lighting plan per company already elaborated
Energy Efficiency	Public Lighting	152	Public Policy	National Energy Plan	Ensure efficient public lighting	Elaborate efficient public lighting norm	By July 2016 have an efficient public lighting norm per company already elaborated
Energy Efficiency	Public Institution Efficiency Standards	160	Public Policy	National Energy Plan	Improve efficiency in the energy consumption levels of the public sector	Incorporate efficiency regulations for the acquisition of equipment in the 20 institutions with the bigger consumption	to add 5 institutions yearly between 2015-2018 until reaching 20 in total
Energy Efficiency	Fixed Source Emission Fee	229	Public Policy	National Energy Plan	Strengthen the financing of actions to reduce emissions by means of an annual fee for emissions derived from the combustion process	Create the regulation for the implementation and application of the fee for emissions from fix sources	For December 2016 count the regulation for the canon for emissions already approved
Energy Efficiency	Cement Industry Fuel switching	277	Technical document	BUR	Develop the system of partial substitution of fossil fuels by alternative fuels of biomass in the production of the cement plant.	Use of biomass residues in the cement production plant (CEMEX)	Average annual reductions: 42,040 t CO2 e / year. Total reductions during the crediting period: 420,397 t

							CO_2 e (10-year Fixed Accreditation Period).
Energy Efficiency	Coffee NAMA	10	Projects-Programs	Coffee NAMA Facility	To produce and to process the coffee in Costa Rica in a sustainable and low carbon way	To promote sustainable coffee low carbon production practices such as the optimization in the use of fertilizers, use of agroforestry among others	The "NAMA Café Support Project" aims to reach 6,000 producers in 5 years, covering up to 25,000 hectares of cultivation, that uses at least 2 emission reduction technologies
Energy Efficiency	Coffee NAMA	11	Projects-Programs	Coffee NAMA Facility	To produce and to process the coffee in Costa Rica in a sustainable and low carbon way	To promote sustainable coffee low carbon production practices such as lowering the water consumption, the waste production and the bioenergy production	The "NAMA Café Support Project" aims to reach 6,000 producers in 5 years, covering up to 25,000 hectares of cultivation, that uses at least 2 emission reduction technologies and promoted practices and up to 50 coffee benefit (facilities) using at least 2 emission reduction technologies

Appendix C: Management of the Mitigation Measures and Policy Scenario Files and Model Runs

As discussed in Section 8 and Appendix B a list of mitigation measures was prepared by the PMR, from which a subset of measures listed in Table 19 were prepared for evaluation using TIMES-CR. Table 41 provides the mapping of the input scenario name with its associated specification template and connects it with the Run Name/Description and summary the nature of the measure involved. The Run Name/Description are what appears in VEDA-BE and the AXLS.

Scenarios are built either in templates or directly in ANSWER, as noted in the Template Name column. All scenario templates begin with Scen_, and all alternate scenarios in ANSWER with S_. The choice of which method to use depends on the nature of the changes to be incorporated in the run. For example, the S_DIST-EFF simply decreases the losses in the electricity distribution process, by upping the efficiency. This can be easily done in ANSWER by copying the grid technology to a new scenario (note: just copy the declaration so that only the changed data is in the alternate scenario) and adjusting the efficiency parameter, as shown Figure 73.

When a policy is to be applied to more than an individual process, for example the S_PV-BLDG scenario that requires the total of distributed PV in the Commercial and Residential sector to reach 100MW by 2050, a user constraint is specified along the lines shown in Figure 74, which force the total installed capacity of the building PV to increase gradually over time.

The data for a number of scenarios are assembled in the *TIMES-CR_Mitigation Measure Definitions* workbook. When a scenario is to be determined based upon a Baseline result, for example the level of emissions are to be reduced by 60% (in line with Costa Rica's 2050 NDC target) this template is used to assemble the needed information and in some cases specify the appropriate TIMES parameters (unless simple enough to just cut and paste into ANSWER from the workbook, as is the case here). The workbook also has a cross check to ensure that the policy run indeed meets the criteria specified.

Figure 75 shows the Baseline emission table and the associated 40/50/60% mitigation targets. Figure 76 shows the 60% scenario data pasted into ANSWER (note that the 2015 level is fixed, while the others are upper limits). Figure 77 shows the checking tables for the 60/50/40% scenarios. Note that the Baseline and checking tables can be updated by setting the appropriate Global scenario filter in VEDA-BE and browsing the "GHG Emission (by gas)" table, then using Copy Data [F7] command and pasting the update results (the yellow blocks) to update the values and check the targets are met.

Once individual scenarios are properly defined and tested they can be combined as desired for combination policies and ensure that the interactions between the various measures are being fully considered.

Figure 73: Example of scenario built in AT (S_DIST-EFF)

Scenario	Parameter		Region	Process	Co	CommGroup	Item5	Ite	I/E	2015	2018	2021	2024	2027	2030	2035	2040	2045	2050
S_DIST-EFF	ACT_EFF	?	COSTARICA	GRD-ELCD-1	-	ACTGRP	ANNUAL	-	0	0.8769	0.8769	0.8809	0.8850	0.8890	0.8931	0.8998	0.9065	0.9133	0.9200
SUP	ACT_EFF	?	COSTARICA	GRD-ELCD-1	-	ACTGRP	ANNUAL	-	0	0.8769									

Figure 74: Example of scenario built in AT (S_PV-BLDG)

Scenario	Parameter		Region	Constraint	Sid	Process	Item5	Ite	I/E	2015	2018	2021	2024	2027	2030	2035	2040	2045	2050
S_PV-BLDG	UC__RHSRT	?	COSTARICA	P_SOLARPV	-	-	-	LO	0	0.0000	0.0086	0.0171	0.0257	0.0343	0.0429	0.0571	0.0714	0.0857	0.1000
S_PV-BLDG	UC_CAP	?	COSTARICA	P_SOLARPV	LHS	EERNWSOL-PV-RTC	-	-	0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
S_PV-BLDG	UC_CAP	?	COSTARICA	P_SOLARPV	LHS	EERNWSOL-PV-RTR	-	-	0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Figure 75: Example of scenarios (S_GHGLIM-60/50/40) specified in Mitigation measures workbook

Country	CostaRica			Updated on Nov 5, 2017								
Reference Scenario CO2 Emissions												
Use this sheet to set GHG Target Levels												
Table Name: GHG Emissions (by gas)												
Active Unit: kt												
Scenario	CommodityDesc\Period	**2015**	**2018**	**2021**	**2024**	**2027**	**2030**	**2035**	**2040**	**2045**	**2050**	**GWP**
BL-ICE	Carbon Dioxide	7,030	7,365	7,649	7,891	8,050	8,247	8,607	9,117	9,934	11,037	1
BL-ICE	Methane	4	4	3	3	3	3	3	3	4	4	21
BL-ICE	Nitrous Oxide	0	0	0	0	0	0	0	1	1	1	310
BL-ICE	Total	7,035	7,370	7,653	7,895	8,053	8,250	8,610	9,121	9,938	11,041	
	CO2 Equuvalent emissions, kt											
	Carbon Dioxide	7,030	7,365	7,649	7,891	8,050	8,247	8,607	9,117	9,934	11,037	
	Methane	84	84	67	70	63	66	69	72	74	78	
	Nitrous Oxide	117	123	125	131	131	137	149	160	174	187	
	Total	7,231	7,572	7,841	8,092	8,245	8,450	8,825	9,349	10,182	11,302	
	Target, % below the Reference	0	5%	20%	28%	36%	44%	48%	52%	56%	60%	
	NDC Target Emissions, Kt	7231.3400	7193.3483	6272.4905	5826.1870	5276.5970	4732.2521	4588.7761	4487.4363	4480.1798	4520.7583	
		0	5%	15%	20%	25%	30%	35%	40%	45%	50%	
	ALT Targat Emissions (30/50)	7231.3400	7193.3483	6664.5211	6473.5411	6183.5121	5915.3151	5735.9701	5609.2954	5600.2247	5650.9479	
	ALT Targat Emissions (25/40)	0	5%	15%	18%	22%	25%	29%	33%	36%	40%	
		7231.3400	7193.3483	6664.5211	6608.4065	6458.3348	6337.8376	6287.5057	6310.4573	6491.1696	6781.1374	

Figure 76: Data entry for S_GHGLIM-60

Scenario	Parameter		Region	F	Ite	Item	I	Item5	Ite	I/E	2015	2018	2021	2024	2027	2030	2035	2040	2045	2050
S_GHGLIM60	COM_BNDNET	?	COSTARICA	-	-	GHG	-	ANNUAL	FX	0	7,231.3400									
S_GHGLIM60	COM_BNDNET	?	COSTARICA	-	-	GHG	-	ANNUAL	UP	0		7,193.3483	6,272.4905	5,826.1870	5,276.5970	4,732.2521	4,588.7761	4,487.4363	4,480.1798	4,520.7583

Figure 77: Cross check for results from runs using S_GHGLIM-60/50/40

CO2LIM Scenario for target on CO2 Emissions

Use this sheet to set check that the CO2 Target Levels are achieved.

Table Name: GHG Emissions (by gas)

Active Unit: kt

Scenario	CommodityDesc\Peric	2015	2018	2021	2024	2027	2030	2035	2040	2045	2050	GWP
ND-GHGLIM-4B	Carbon Dioxide	7030	7365	6492	6420	6260	6130	6070	6104	6280	6567	1
ND-GHGLIM-4B	Methane	4	4	3	3	3	3	3	3	3	3	21
ND-GHGLIM-4B	Nitrous Oxide	0	0	0	0	0	0	1	0	0	0	310
ND-GHGLIM-4B	Total	7035	7370	6495	6423	6264	6133	6074	6108	6284	6570	
ND-GHGLIM-5B	Carbon Dioxide	7030	7365	6493	6288	5994	5715	5519	5392	5375	5416	1
ND-GHGLIM-5B	Methane	4	4	3	3	3	3	3	3	3	3	21
ND-GHGLIM-5B	Nitrous Oxide	0	0	0	0	0	0	1	0	1	1	310
ND-GHGLIM-5B	Total	7035	7370	6496	6291	5997	5718	5522	5395	5379	5419	
ND-GHGLIM-6B	Carbon Dioxide	7030	7365	6113	5659	5120	4573	4426	4325	4268	4290	1
ND-GHGLIM-6B	Methane	4	4	2	2	2	2	2	2	2	3	21
ND-GHGLIM-6B	Nitrous Oxide	0	0	0	0	0	0	0	0	1	1	310
ND-GHGLIM-6B	Total	7035	7370	6115	5662	5123	4576	4429	4327	4271	4293	
ND-GHGLIM-4B	CO2 Equuvalent emissions, kt											
	Carbon Dioxide	7,030	7,365	6,492	6,420	6,260	6,130	6,070	6,104	6,280	6,567	
	Methane	84	84	55	58	58	59	60	63	67	64	
	Nitrous Oxide	117	123	117	131	140	149	157	143	143	150	
	Total	7,231	7,572	6,665	6,608	6,458	6,338	6,288	6,310	6,491	6,781	
	NDC Target as set			6,665	6,608	6,458	6,338	6,288	6,310	6,491	6,781	
	check if scenario <=target			TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	
ND-GHGLIM-5B	CO2 Equuvalent emissions, kt											
	Carbon Dioxide	7,030	7,365	6,493	6,288	5,994	5,715	5,519	5,392	5,375	5,416	
	Methane	84	84	55	57	56	57	58	63	67	63	
	Nitrous Oxide	117	123	117	128	133	143	159	155	158	172	
	Total	7,231	7,572	6,665	6,474	6,184	5,915	5,736	5,609	5,600	5,651	
	NDC Target as set			6,665	6,474	6,184	5,915	5,736	5,609	5,600	5,651	
	check if scenario <=target			TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	
ND-GHGLIM-6B	CO2 Equuvalent emissions, kt											
	Carbon Dioxide	7,030	7,365	6,113	5,659	5,120	4,573	4,426	4,325	4,268	4,290	
	Methane	84	84	52	52	46	45	42	39	50	54	
	Nitrous Oxide	117	123	108	115	110	114	120	124	162	176	
	Total	7,231	7,572	6,272	5,826	5,277	4,732	4,589	4,487	4,480	4,521	
	NDC Target as set			6,272	5,826	5,277	4,732	4,589	4,487	4,480	4,521	
	check if scenario <=target			TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	

Table 41: List of Scenario Templates and AT Scenario Names and Definitions

Policy Area	Scenario Name	Specification Template Name	Run Name	Run Description	Measure Description
Baseline	S_ICE-EXP-27	Scen_ICE Expansion Plan_2027	BL-ICE	Baseline - ICE Expansion Plan - 2027	BAU scenario (Allows 30%, 20% and 10% for improved, better and advanced tech classes) with ICE Expansion Plan to 2027
	S_ICE-EXP-24	Scen_ICE Expansion Plan_2024	BL-ICE-24	Baseline - ICE Expansion Plan - 2024	BAU scenario with ICE expansion plan to 2024 (no Diquis HPP)
	S_NEE-REDD	Constructed in AT	BL-ICE-REDD	Baseline – AFOLU & REDD	BAU scenario with ICE Expansion Plan to 2027 and AFOLU baseline and REDD+ mitigation measure
Supply & Power	S_RPS	Constructed in AT – Data setup in MM workbook	SP-RES-ELC	RE Electricity Share	Maintain RE electricity share at 98% until 2030 and transition to 100% by 2050
	S_DIST-EFF	Constructed in AT	SP-DIST-EFF	Improve Distribution Efficiency	Reduce T&D losses from 12.2% in 2015 to 8% by 2050
	S_GEN-EFF	Constructed in AT	SP-GEN-EFF	Improve Generating Efficiency	Increase efficiency of all hydropower plants from 91% in 2015 to 94% in 2050
	S_PV-BLDG	Constructed in AT	SP-PV-DG	Promote PV Distributed Generation	Install 100 MW of distributed PV systems by 2050
	S_PV-LARGE	Constructed in AT	SP-PV-LARGE	Promote Large-Scale Solar	Install 500 MW of centralized PV systems by 2050
	S_PV-LARGER	Constructed in AT	SP-PV-LARGER	Promote Larger-Scale Solar	Install 1000 MW of centralized PV systems by 2050
	S_STORAGE	Constructed in AT – Data setup in MM workbook	SP-ELC-STRG	Electric Energy Storage	Implement Li-Ion battery storage systems starting in 2024 to improve the utilization of variable wind and solar energy
	S_BIOFUEL-LM	Scen_Biofuels to AGR, COM, IND, PWR, RSD, TRN	SP-BIOF-LIMT	Biofuels Allowed in Petroleum Products - All	Allow biofuels up to the following limits by 2050 across all sectors: Biodiesel-50%, biogasoline-30%, biojetfuel-20%

				Sectors	
	S_BIOFUEL-TG	Constructed in AT	SP-BIOF-TRGT	Biofuels Target in Petroleum Products - All Sectors	Force biofuels to the following levels by 2050 across all sectors: Biodiesel-50%, biogasoline-30%, biojetfuel-20%
	S_RES-FE-TGT	Constructed in AT – Data setup in MM workbook	SP-RESF-TRGT	RE Share of Gross Final Energy	Increase RE share of gross final energy use from 56% in 2015 to 70% in 2050
	S_GEO-LIFE-E	Scen_Geothermal Life Extension	SP-GEO-LIFE	Geothermal Power Plant Life Extension	Retrofit retiring geothermal capacity to extend life by 30 years (Part of Baseline Run)
Efficiency	S_APLSTD-COM	Constructed in AT	EE-APL-COM	COM Appliance Standards	Transition Commercial devices to 100% improved, better and advanced techs by 2030
	S_APLSTD-RSD	Constructed in AT	EE-APL-RSD	RSD Appliance Standards	Transition Residential devices to 100% improved, better and advanced techs by 2030
	S_EE-INCT-90	Scen_EE incentives-COM, Scen_EE Incentives-RSD	EE-TAX-INC10	EE Incentive (10%) for COM & RSD with 90% sector AdvTech	Reduce the cost of improved, better and advanced techs in Commercial & Residential sectors by 10% starting in 2021
	S_EE-INCT-80	Scen_EE incentives-COM, Scen_EE Incentives-RSD	EE-TAX-INC20	EE Incentive (20%) for COM & RSD with 90% sector AdvTech	Reduce the cost of improved, better and advanced techs in Commercial & Residential sectors by 20% starting in 2021
	S_PBLDG-EFF	Constructed in AT – Data setup in MM workbook	EE-PUBLDG-R	Public Building Efficiency Improvement	Reduce Public Build energy use by 15% and all public buildings are retrofitted by 2050 [assumes public buildings represent 10% of Commercial sector demand]
	S_PUB-LITES	Constructed in AT	EE-PUBLTG	LED Public Lighting	Transition to 100% LED Public Lighting by 2024
	S_LIMFEC-IND	Constructed in AT	EE-IND-FOSR	IND Fossil Fuel Reduction	Reduce fossil fuel share in Industry sectors to 25% by 2050
	S_BIO-AG-IND	Constructed in AT	EE-AGIND-BIO	Bioenergy Utilization by AGR & IND	Increase use of organic residues by Agriculture and Industry sectors

	S_CEMENT-NM2	Constructed in AT	EE-CEMENT-P	Cement Industry Fuel switching	Increase bio-energy demand in Cement sector to 75% of all process heat demand to the Other sector by 2050
	S_COFFEE-NM2	Constructed in AT	EE-COFFEE-P	Coffee NAMA	Improve process efficiency in Coffee sector by forcing new Improved boilers and furnaces
	S_EE-TAX-LO	Constructed in AT – Data setup in MM workbook	EE-GHG-TAX-L	Low GHG Levy ($10-150) on Stationary Sources	Apply a Low GHG Levy ($10 To 150/t CO2 eq.) to stationary (Buildings, Industry and Power sector) emission sources
	S_EE-TAX-HI	Constructed in AT – Data setup in MM workbook	EE-GHG-TAX-H	High GHG Levy ($10-300) on Stationary Sources	Apply a High GHG Levy ($10 to 300/t CO2 eq.) to stationary (Buildings, Industry and Power sector) emission sources
Trans-portation	S-TRN-CLU	Scen_TRN_clunkers	TR-LDV-CLUN	LDV clunkers	Force earlier retirement of about 20% of the existing LDVs
	S-TRN-LDV-AN	Scen_TRN-LDV-ADVN	TR-LDV-AD-N	25/50% share of electric and hybrid in LDV New stock	By 2030 achieve 25% (50% by 2050) of **New** cars are hybrids or electric
	S-TRN-LDV-A7	Scen_TRN-LDV-ADVN70	TR-LDV-AD-N	35/70% share of electric and hybrid in LDV New stock	By 2030 achieve35% (70% by 2050) of **New** cars are hybrids or electric
	S-TRN-LDV-AE	Scen_TRN-LDV-ADVN-ELC	TR-LDV-AD-NE	25/50% share of electric in LDV New stock	By 2030 achieve 25% (50% by 2050) of **New** cars are electric
	S-TRN-LDV-AH	Scen_TRN-LDV-ADVN-HYB	TR-LDV-AD-NH	25/50% share of hybrid in LDV New stock	By 2030 achieve 25% (50% by 2050) of **New** cars are hybrids
	S-TRN-PUP-AN	Scen_TRN-BUS_MBUS_TAX-ADV-NEW	TR-PUB-AD-N	100% share of advanced techs in Public Transport New stock	Improve share of Advanced Taxis, Buses and Mini-buses to 100% of new stock by 2050
	S-TRN-UC-BL	Scen_TRN-UC-Largebus			
	S-TRN-MSH-F	Scen_TRN-mode-shift-freight_rail	TR-MSH-FRE	Rail Freight	Improve rail freight capacity to shift 25% of heavy truck demand to rail by 2050.
	S-TRN-MSH-I	Scen_TRN-mode-shift-intercity	TR-MSH-IC	Intercity Rail	Intercity train connecting the four main cities shifts 57 mpkm from LDV to passenger rail in 2030.

	S-TRN-MSH-P	Scen_TRN-mode-shift-pubtra-8	TR-MSH-PUBTR	Integrated Public Transport System	8% increase to Bus demand, and 20% improvement of efficiency per passenger-km. 34% share of large buses.
	S-TRN-MSH-S	Scen_TRN-mode-shift-pubtra-35	TR-MSH-PUBTS	Integrated Public Transport System & Mode shift	35% increase to Bus demand, and 20% improvement of efficiency per passenger-km. 34% share of large buses.
	S-TRN-RAI	Scen_TRN-UC-Largebus			
	S-TRN-MSH-N	Scen_TRN-mode-shift-NMT	TR-MSH-NMT	5% shift of passenger transport to Non-motorized modes (cycling, walking)	Assumes 5% shift to NMT by 2030. 60% is shifted from bus demand, 40% is shifted from LDV demand.
	S-TRN-MSH-D	Scen_TRN-mode-shift-demandmgmt	TR-MSH-DEM	Demand Controlling measures	10% of LDVs are affected. LDV demand reduces by 3% by 2020 and 4% by 2030. 80% of reduced demand is shifted to buses.
	S-TRN-MSH-T	Scen_TRN-mode-shift-tram	TR-MSH-TRAM	5.4% shift from LDV to tram	To improve urban mass transit plans to shift 5.4% of LDV demand to urban trains by 2030
	S-TRN-GREEN	Scen_TRN-Green	TR-GREEN	Green driving	Measure affects 50% of vehicles. LDV and taxi efficiency is increased by 5%, bus, mini-bus and LCV by 2%
	S-TRN-CO2-CA	Scen_TRN-CO2-Cap	TR-CO2-CAP	25%-50% cap of CO2 from Transport	Reduce GHG emissions from the transport sector by 25%/50% by 2030/2050
	S-TRN-GHG-TX	Scen_TRN-GHG-Tax	TR-GHG-TAX	High emissions levy on all Transport GHGs	Gradually increasing levy on emissions from entire transport sector - $10/ton levy in 2018 increasing to $300/ton in 2050
	S-TRN-GHT-50	Scen_TRN-GHG-Tax-50%	TR-GHG-TAX50	Moderate emissions levy on all Transport GHGs with 90% AdvTech	Gradually increasing levy on emissions from entire transport sector - $10/ton levy in 2018 increasing to $150/ton in 2050 with 90% allowed penetration of improved and advanced techs

	S-TRN-MSH-L	Scen_TRN-mode-shift-combined	TR-COMB-M	Combines all TRN technology and mode-shift measures	Combines the TR-LDV-AD-T, TR-PUB-AD-T, TR-LDV-CLUN, TR-WLK-CYC,TR-MSH-PUBTR, TR-MSH-TRAM and TR-EFF-ALL measures
GHG Levy	S_GHGTAX-LO	Constructed in AT – Data setup in MM workbook	GHG-TAX-LO	Low GHG Levy ($10-150/t) on All Sectors	Apply a Low GHG Levy ($10 To 150/t CO2 eq.) to All sectors
	S_GHGTAX-HI	Constructed in AT – Data setup in MM workbook	GHG-TAX-HI	High GHG Levy ($10-300/t) on All Sectors	Apply a High GHG Levy ($10 to 300/t CO2 eq.) to All sectors
NDC Target	S_GHGLIM40	Constructed in AT – Data setup in MM workbook	ND-GHGLIM-40	40% GHG Emission Reduction - 90% AT	25% reduction in GHG emissions from Baseline in 2030 and 40% reduction in 2050 with 90% allowed improved, better and advanced techs by 2050
	S_GHGLIM50	Constructed in AT – Data setup in MM workbook	ND-GHGLIM-50	50% GHG Emission Reduction - 90% AT	30% reduction in GHG emissions from Baseline in 2030 and 50% reduction in 2050 with 90% allowed improved, better and advanced techs
	S_GHGLIM60	Constructed in AT – Data setup in MM workbook	ND-GHGLIM-60	60% GHG Emission Reduction - 90% AT	44% reduction in GHG emissions from Baseline in 2030 and 60% reduction in 2050 with 90% allowed improved, better and advanced techs
Combina-tions	S_ENHANCED	Constructed in AT	XALL-ENHANCE	All EE, SP and TRN Measures	Combines EE, SP and TRN Measures with 90% allowed improved, better and advanced techs and biofuels

Appendix D: Scenario Run Matrices

Building on the table provided in Appendix C, the tables below show which scenarios in the TIMES-CR database are incorporated into each model run. Every model run includes the following core Baseline scenarios (also shown in Figure 60):

BASE, SUP, SUP_TRN-UPS, BY-AGR, BY-COM, BY-IND, BY-RSD, BY-TRN, BY-PP, BY-OTH-NON, DEMAND-REF, NT-AGR, NT-COM, NT-IND, NT-PP, NT-RSD, NT-TRN, ZZDMY, and BOUNDLO_AF.

The additional scenarios incorporated into each run always include one of the BL-ICE scenarios (with the exception on the No ICE run) and an appropriate UC-<sector>/<2050 level> scenario, along with others as presented below according to their policy sector. Note that as mentioned in Appendix A.11 the order in which scenarios are listed for a model run is important and the user needs to keep in mind that if/when GAMS is presented with the same data more than once (e.g., an upper bound on the potential for wind) it overwrites the data such that ONLY the last such value is input to the model, Thus the order in which scenarios are listed to construct runs in TIMES-CR should be retained, and if new scenarios are added, they most likely should be folded in at the bottom of the scenarios listed for a run. A description of these files is included in the Appendix C

D.1 Baseline Scenarios

Scenario Code	Scenario Name	S_ICE-EXP-27	S_ICE-EXP-24	S_NO-ICE	UC-AGR	UC-COM	UC-IND	UC-RSD	UC-TRN
BL-ICE	Baseline - ICE Expansion Plan - 2027	X			X	X	X	X	X
BL-ICE-24	Baseline - ICE Expansion Plan - 2024		X		X	X	X	X	X
BL-NO ICE	Baseline - No ICE Exp Plan			X	X	X	X	X	X

D.2 Supply & Power

Scenario Code	Scenario Name	S_ICE-EXP-27	UC-AGR	UC-COM	UC-IND	UC-RSD	UC-TRN	UC-AGR90	UC-COM90	UC-IND90	UC-RSD90	UC-TRN90	S_BIOFUEL-LM	S_BIOFUEL-TG	S_RPS	S_DIST-EFF	S_GEN-EFF	S_RES-FE-TGT	S_PV-DIST	S_PV-LARGE	S_GEO-LIFE-E	S_STORAGE
SP-RES-ELC	RE Electricity Share	X	X	X	X	X	X								X							
SP-RESF-TRGT	RE Share of Gross Final Energy	X	X	X	X	X	X						X					X				
SP-DIST-EFF	Improve Distribution Efficiency	X	X	X	X	X	X									X						
SP-GEN-EFF	Improve Generating Efficiency	X	X	X	X	X	X										X					
SP-PV-DG	Promote PV Distributed Generation	X	X	X	X	X	X												X			
SP-PV-LARGE	Promote Large-Scale Solar	X	X	X	X	X	X													X		
SP-BIOF-LIMT	Biofuels Share in Petroleum Products - Allowed in All Sectors	X	X	X	X	X	X						X									
SP-BIOF-TRGT	Biofuels Share in Petroleum Products - All Sectors	X	X	X	X	X	X						X	X								
SP-RES-RPS-T	RE Share of Gross Final Energy & RES electricity share	X	X	X	X	X	X						X		X			X				
SP-GEO-LIFE	Geothermal Power Plant Life Extension	X	X	X	X	X	X														X	
SP-STRG	Electric Energy Storage	X	X	X	X	X	X															X
SP-ALL-90	All Supply & Power Measures - 90% AT	X						X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

D.3 Efficiency in Buildings and Industry

Scenario Code	Scenario Name	S_ICE-EXP-27	S_NO-ICE	UC-AGR	UC-COM	UC-IND	UC-RSD	UC-TRN	UC-AGR50	UC-COM50	UC-IND50	UC-RSD50	UC-TRN50	UC-AGR90	UC-COM90	UC-IND90	UC-RSD90	UC-TRN90	S_BIOFUEL-LM	S_APLSTD-COM	S_APLSTD-RSD	S_BLDG-PV	S_CEMENT-NM2	S_COFFEE-NM2	S_EE-INCT-90	S_EE-INCT-80	S_LIMFOS-IND	S_BIO-AG-IND	S_PBLDG-EFF	S_PUB-LITES	S_EE-TAX-LO	S_EE-TAX-HI
EE-AT-50	Allow 50% Adv Tech by 2050	X							X	X	X	X	X																			
EE-AT-90	Allow 90% Adv Tech by 2050	X												X	X	X	X	X														
EE-APL-COM	COM Appliance Standards	X		X	X	X	X	X												X												
EE-APL-RSD	RSD Appliance Standards	X		X	X	X	X	X													X											
EE-APL-STD	COM & RSD Appliance Standards	X		X	X	X	X	X												X	X											
EE-TAX-INC10	EE Incentive (10%) for COM & RSD	X		X	X	X	X	X																	X							
EE-TAX-INC20	EE Incentive (20%) for COM & RSD	X		X	X	X	X	X																		X						
EE-BLDG-PV	COM&RSD BLDG PV	X		X	X	X	X	X														X										
EE-PUBLTG	LED Public Lighting	X		X	X	X	X	X																						X		
EE-PUBLTG-NX	LED Public Lighting - No ICE Exp Plan		X	X	X	X	X	X																						X		
EE-PUBLDG-R	Public Building Efficiency Improvement	X		X	X	X	X	X																					X			
EE-IND-FOSR	IND Fossil Fuel Reduction	X		X	X	X	X	X																			X					
EE-AGIND-BIO	Bioenergy Utilization by AGR & IND	X		X	X	X	X	X																				X				
EE-CEMENT-P	Cement Industry Fuel switching	X		X	X	X	X	X															X									
EE-COFFEE-P	Coffee NAMA	X		X	X	X	X	X																X								
EE-BLDGS-90	All Building Efficiency Measures - 90% AT	X												X	X	X	X	X		X	X	X				X			X	X		
EE-INDALL-90	All Industry Efficiency Measures - 90% AT	X												X	X	X	X	X					X	X			X	X				
EE-ALL-90	All Efficiency Measures - 90% AT	X												X	X	X	X	X		X	X	X	X	X	X		X	X	X	X		
EE-GHG-TAX-L	Low GHG Tax ($10-150) on Fixed Sources	X		X	X	X	X	X																							X	
EE-GHG-TAX-H	High GHG Tax ($10-300) on Fixed Sources	X		X	X	X	X	X																								X
EE-GHGT-L90	Low GHG Tax ($10-150/t) on Fixed Sources - 90% NT	X												X	X	X	X	X													X	
EE-GHGT-H90	High GHG Tax ($10-300) on Fixed Sources - 90% NT	X												X	X	X	X	X														X
EE-GHGT-L90B	Low GHG Tax ($10-150) on Fixed Sources - 90% NT & Biofuels	X												X	X	X	X	X	X												X	
EE-GHGT-H90B	High GHG Tax ($10-300) on Fixed Sources - 90% NT & Biofuels	X												X	X	X	X	X	X													X

D.4 Transport Sector

Scenario Code	Scenario Name	S_ICE-EXP-27	UC-AGR	UC-COM	UC-IND	UC-RSD	UC-TRN	UC-TRN50	UC-TRN90	S_BIOFUEL-LM	S-TRN-LDV-AN	S-TRN-CLU	S-TRN-CO2-CA	S-TRN-GHG-TX	S-TRN-GHT-50	S-TRN-MSH-L	S-TRN-MSH-P	S-TRN-MSH-T	S-TRN-PUP-AD	S-TRN-PUP-AN	S-TRN-UC-RAI	S-TRN-MSH-N	S-TRN-MSH-D	S-TRN-MSH-I	S-TRN-MSH-F	S-TRN-UC-BL	S-TRN-GREEN
TR-LDV-AD-N	25% share of electric and hybrid in LDV New stock	X	X	X	X	X			X		X																
TR-LDV-CLUN	LDV clunkers	X	X	X	X	X	X					X															
TR-PUB-AD-N	100% share of advanced techs in Public Transport New stock	X	X	X	X	X	X													X							
TR-MSH-IC	Intercity Rail	X	X	X	X	X	X														X			X			
TR-MSH-FRE	Rail Freight	X	X	X	X	X	X																		X		
TR-UC90	Reference with TRN UC90	X	X	X	X	X			X																		
TR-MSH-TRAM	5.4% shift from LDV to tram	X	X	X	X	X	X											X			X						
TR-MSH-PUBTR	Integrated Public Transport System	X	X	X	X	X	X										X									X	
TR-MSH-NMT	5% shift of passenger transport to Non-motorized modes (cycling, walking)	X	X	X	X	X	X															X					
TR-EFF-ALL	50% share of ADV techs in all transport modes	X	X	X	X	X		X																			
TR-MSH-DEM	Demand controling measures	X	X	X	X	X	X																X				
TR-GREEN	Green driving	X	X	X	X	X	X																				X
TR-CO2-CAP	25%-50% CO2TRN cap	X	X	X	X	X			X	X			X														
TR-GHG-TAX	High emissions fee on all Transport GHGs	X	X	X	X	X	X							X													
TR-GHG-TAX50	Moderate emissions fee on all Transport GHGs with UC90	X	X	X	X	X			X						X												
TR-GHG-TAX90	High emissions fee on all Transport GHGs with UC90	X	X	X	X	X			X					X													
TR-COMB-M	Combines all TRN technology and mode-shift measures	X	X	X	X	X		X			X	X				X				X	X				X	X	X
TR-COMB-MB	Combines TRN-COMB-M with the Biofuels scenario	X	X	X	X	X		X		X	X	X				X				X	X				X	X	X
TR-COMB-MBT	Combines TRN-COMB-MB with $500/t TRN emissions fee	X	X	X	X	X		X		X	X	X			X	X				X	X				X	X	X

D.5 GHG Taxes

Scenario Code	Scenario Name	S_ICE-EXP-27	UC-AGR	UC-COM	UC-IND	UC-RSD	UC-TRN	UC-AGR90	UC-COM90	UC-IND90	UC-RSD90	UC-TRN90	S_BIOFUEL-LM	S_GHG TAX-LO	S_GHGT AX-HI
GHG-TAX-LO	Low GHG Tax ($10-150/t) on All Sectors	X	X	X	X	X	X							X	
GHG-TAX-HI	High GHG Tax ($10-300/t) on All Sectors	X	X	X	X	X	X								X
GHG-TX-LO-90	Low GHG Tax ($10-150/t) on All Sectors - 90% AT	X						X	X	X	X	X		X	
GHG-TX-HI-90	High GHG Tax ($10-300/t) on All Sectors - 90% AT	X						X	X	X	X	X			X
GHG-TX-L90B	Low GHG Tax ($10-150/t) on All Sectors - 90% AT & Biofuels	X						X	X	X	X	X	X	X	
GHG-TX-H90B	High GHG Tax ($10-300/t) on All Sectors - 90% AT & Biofuels	X						X	X	X	X	X	X		X

D.6 GHG Targets

Scenario Code	Scenario Name	S_ICE-EXP-27	UC-AGR90	UC-COM90	UC-IND90	UC-RSD90	UC-TRN90	S_BIOFUEL-LM	S_GHG LIM40	S_GHG LIM50	S_GHG LIM60
ND-GHGLIM-40	40% GHG Emission Reduction - 90% AT	X	X	X	X	X	X		X		
ND-GHGLIM-4B	40% GHG Emission Reduction - 90% AT w Biofuels	X	X	X	X	X	X	X	X		
ND-GHGLIM-50	50% GHG Emission Reduction - 90% AT	X	X	X	X	X	X			X	
ND-GHGLIM-5B	50% GHG Emission Reduction - 90% AT w Biofuels	X	X	X	X	X	X	X		X	
ND-GHGLIM-60	60% GHG Emission Reduction - 90% AT	X	X	X	X	X	X				X
ND-GHGLIM-6B	60% GHG Emission Reduction - 90% AT w Biofuels	X	X	X	X	X	X	X			X

D.7 Combination Runs

Scenario Code	Scenario Name	S_ICE-EXP-27	UC-AGR90	UC-COM90	UC-IND90	UC-RSD90	UC-TRN90	S_BIOFUEL-LM	S_BIOFUEL-TG	S_RPS	S_DIST-EFF	S_GEN-EFF	S_RES-FE-TGT	S_PV-DIST	S_PV-LARGE	S_GEO-LIFE-E	S_STORAGE
XALL-PLANNED	All Planned EE, SP and TRN Measures	X	X	X	X	X	X			X	X	X	X	X	X		
XALL-ENHANCE	Planned & Enhanced EE, SP and TRN Measures	X	X	X	X	X	X			X	X	X	X	X	X	X	X
XALL-GHG-60	All Measures with Biofuels allowed & 60% GHG Cap	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X
XALL-GHG-60B	All Measures with Biofuels target & 60% GHG Cap	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Scenario Code	Scenario Name	S_APLSTD-COM	S_APLSTD-RSD	S_BLDG-PV	S_CEMENT-NM2	S_COFFEE-NM2	S_LIMFOS-IND	S_BIO-AG-IND	S_PBLDG-EFF	S_PUB-LITES	S_GHG LIM60	S-TRN-LDV-AN	S-TRN-CLU	S-TRN-MSH-L	S-TRN-PUP-AN	S-TRN-UC-RAI	S-TRN-MSH-F	S-TRN-UC-BL	S-TRN-GREEN
XALL-PLANNED	All Planned EE, SP and TRN Measures	X	X	X	X	X		X	X	X		X	X	X	X	X	X	X	
XALL-ENHANCE	Planned & Enhanced EE, SP and TRN Measures	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X
XALL-GHG-60	All Measures with Biofuels allowed & 60% GHG Cap	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
XALL-GHG-60B	All Measures with Biofuels target & 60% GHG Cap	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Appendix E: Examination of Policy Measures

This appendix examines each individual scenario is terms of its changes to specific metrics that are used to characterize the technical, economic and environmental impacts of each policy. These metrics and their definitions are shown in Section 8.1, Table 20.

E.1 Supply and Power Sector

This section examines supply and power sector measures, starting with the RE Electricity Share measure, which maintains the share of renewable electricity at 98% or higher starting in 2018 and gradually increases the minimum share to 99.9% by 2050; the Improve Distribution Efficiency measure, which reduces T&D losses from 12.2% in 2015 to 8% by 2050; and the Improve Generating Efficiency measure, which increases the efficiency of all hydropower plants from 91% in 2015 to 94% in 2050.

As shown in Table 42, the RES Electricity measure has zero impact, as the Baseline case meets this requirement in all periods, as also shown in Figure 78. The Improve Distribution Efficiency measure produces a significant reduction in electricity generation due to the reduced losses, as also shown in Figure 78. This measure also reduces GHG emissions from the Industry sector because the reduced T&D losses lower electricity costs and encourage fuel switching to electricity by industry, as shown in Figure 79. Improve Generating Efficiency measure increases generation from hydropower and reduces generation from wind, as shown in Figure 78. GHG emission reductions are not significant.

Table 42: Supply and Power Sector Measures-1

Metrics / Scenario	Baseline - ICE 2027	RE Electricity Share		Improve Distribution Efficiency		Improve Generating Efficiency	
	Value	Difference	% Change	Difference	% Change	Difference	% Change
System Cost (2015$M)	228,212	0	0.00%	-306	-0.13%	-77	-0.03%
Primary Energy (PJ)	9,975	0	0.00%	-46	-0.46%	-15	-0.15%
Electricity Generation (GWh)	642,439	0	0.00%	-11,440	-1.78%	6,819	1.06%
Final Energy Consumption (PJ)	8,212.05	0.00	0.00%	-6.07	-0.07%	-0.80	-0.01%
PP Builds (GW)	3.92	0.00	0.00%	-0.10	-2.51%	-0.07	-1.84%
Electricity Investment (2015$M)	14,546	0	0.00%	-307	-2.11%	86	0.59%
Demand Device Purchases (2015$M)	290,920	0	0.00%	-11	0.00%	2	0.00%
Fuel Expenditures (2015$M)	184,668	0	0.00%	-497	-0.27%	-8	0.00%
GHG Emissions (kt CO2 eq.)	324,823	0	0.00%	-1,162	-0.36%	3	0.00%

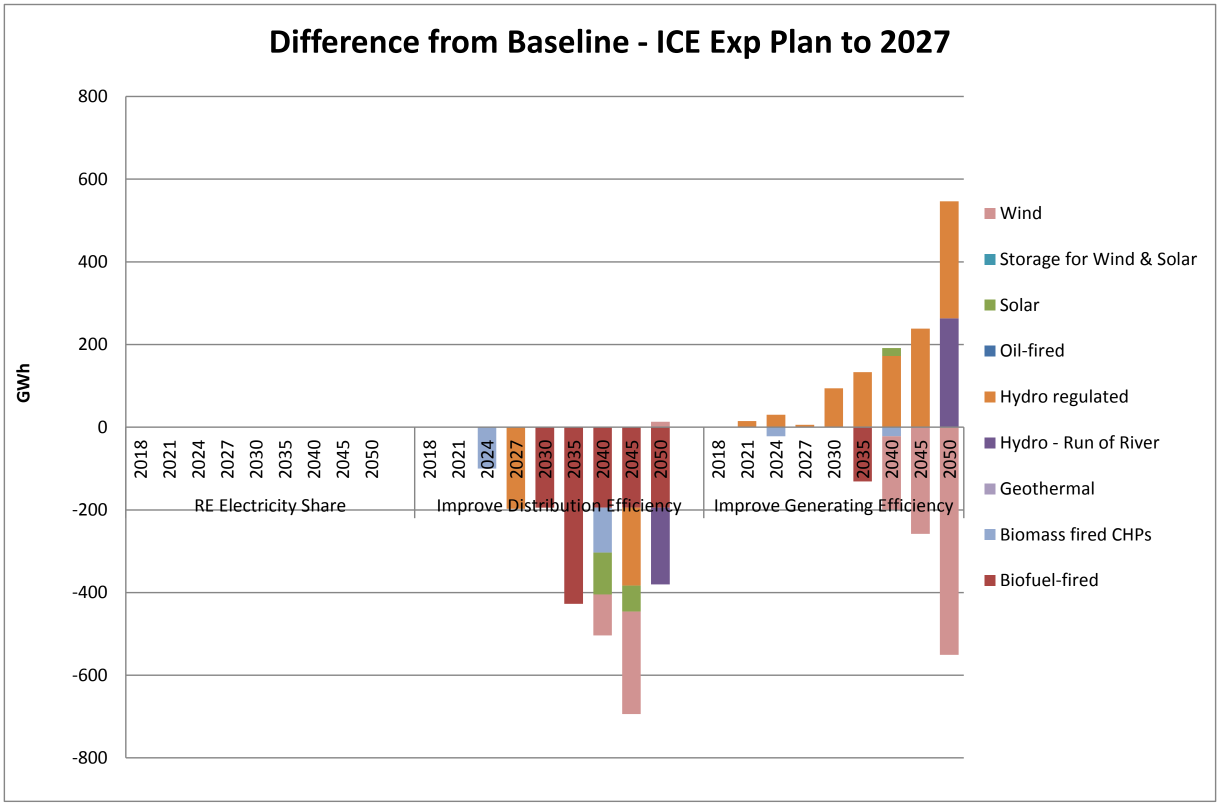


Figure 78: Change in Electricity Generation compared to Baseline

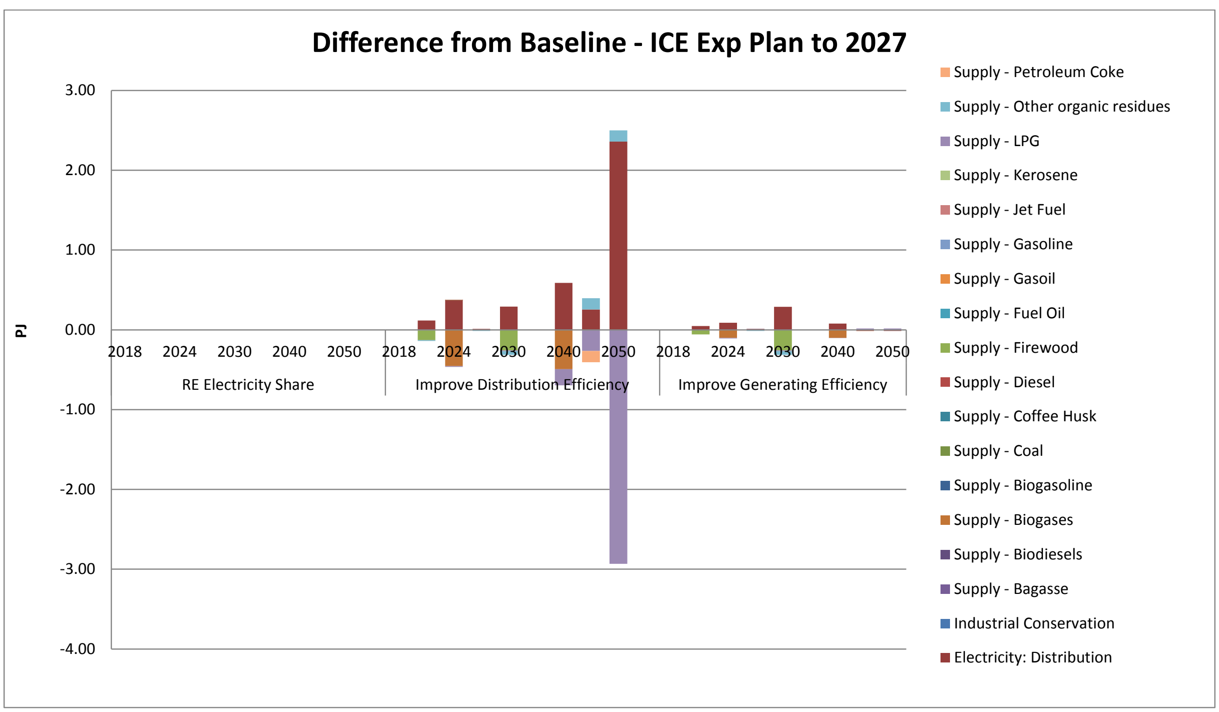


Figure 79: Change in Industry Fuel Use compared to Baseline

The next three measures include Promote PV Distributed Generation, which installs 100 MW of distributed PV systems by 2050; Promote 500 MW Large-Scale Solar centralized PV systems by 2050; and Promote 1000 MW Large-Scale Solar centralized PV systems by 2050.

As shown in Table 43, the Distributed PV Generation measure and both the Large-Scale Solar PV measures increase investment in new power plant but produce relatively small GHG emission reductions. As shown in Figure 80, the Distributed PV measure does not significantly change the building of new power plants and leads to slightly lower electricity generation due to the elimination of some distribution losses. The Large-Scale Solar PV measure displaces almost 300 MW of wind and run-of-river hydropower capacity, and delays 140 MW of regulated hydropower, as also shown in Figure 80. The 1000 MW Solar PV measure starts PV installations in 2021 compared to 2030 in the 500 MW measure, and displaces a little over 300 MW of wind and run-of-river hydropower capacity, and delays 160 MW of regulated hydropower. The small levels of GHG reductions are due to the small amounts of oil-fired generation displaced.

Table 43: Supply and Power Sector Measures-2

Metrics / Scenario	Baseline - ICE 2027	Promote PV Distributed Generation		Promote 500 MW Large-Scale Solar		Promote 1000 MW Large-Scale Solar	
	Value	Difference	% Change	Difference	% Change	Difference	% Change
System Cost (2015$M)	228,212	24	0.01%	25	0.01%	146	0.06%
Primary Energy (PJ)	9,975	0	0.00%	7	0.07%	18	0.18%
Electricity Generation (GWh)	642,439	210	0.03%	1,420	0.22%	2,795	0.44%
Final Energy Consumption (PJ)	8,212.05	-1.53	-0.02%	-1.99	-0.02%	-3.80	-0.05%
PP Builds (GW)	3.92	0.03	0.74%	0.37	9.35%	0.60	15.20%
Electricity Investment (2015$M)	14,546	52	0.36%	415	2.85%	757	5.20%
Demand Device Purchases (2015$M)	290,920	0	0.00%	-49	-0.02%	-15	-0.01%
Fuel Expenditures (2015$M)	184,668	-43	-0.02%	-134	-0.07%	-255	-0.14%
GHG Emissions (kt CO2 eq.)	324,823	-12	0.00%	-201	-0.06%	-391	-0.12%

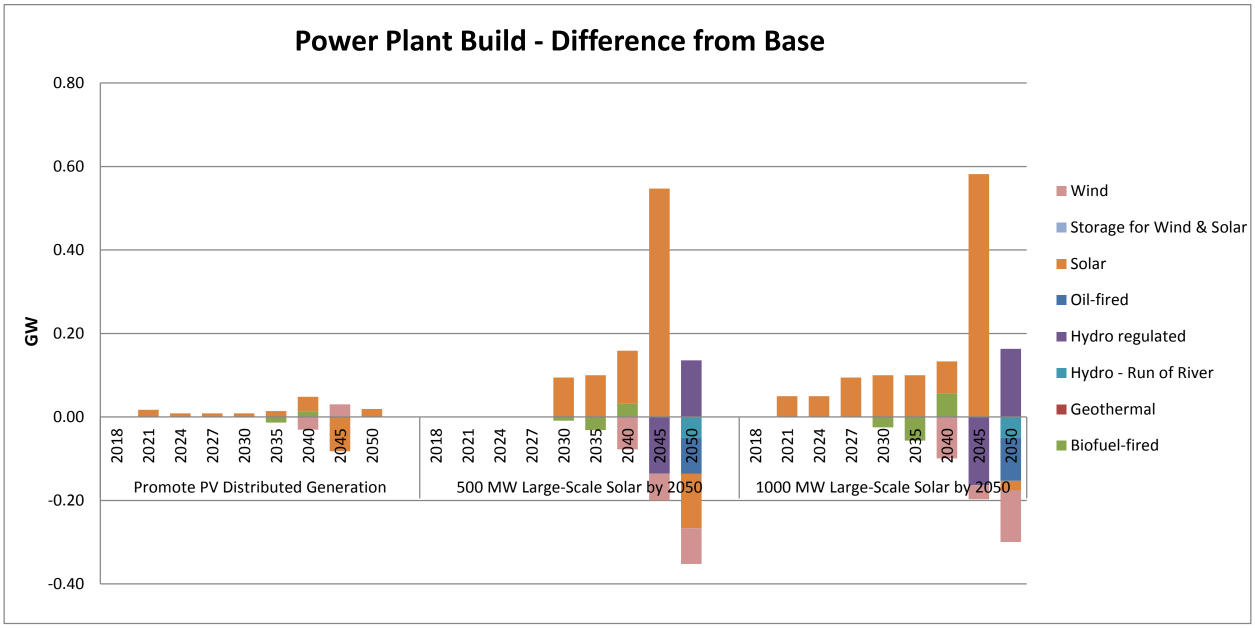


Figure 80: Change in New Power Plant Builds compared to Baseline

The next three measures include Biofuel Shares in Petroleum Products, which allow biofuels all sectors up to the limits: biodiesel-50%, biogasoline-30%, biojetfuel-20% by 2050; Biofuels Targets, which force biofuels to the above levels by 2050 across all sectors; and Electric Energy Storage, which enables lithium-ion (Li-Ion) battery systems to be used in conjunction with the new solar and wind power plants placed on the grid.

As shown in Table 44, simply allowing biofuels to enter the energy system if cost-effective, but with no other driver, produces no uptake of biofuels because the biofuels are assumed to be 10% more costly than conventional fuels. However, the Biofuels Target measure produces a 15% reduction in GHG emissions while increasing fuel expenditures by 11%. Figure 81 shows the displacement of diesel, gasoline, jet fuel and kerosene with their biofuel equivalents. As shown in Figure 82, the Electric Energy Storage measure increases wind capacity by 480 MW, defers 190 MW of regulated hydropower and displaces 270 MW of oil fired capacity and 360 MW of solar capacity. The small levels of GHG reductions are due to the small amounts of oil-fired generation displaced.

Table 44: Supply and Power Sector Measures-3

Metrics / Scenario	Baseline - ICE 2027	Biofuels Allowed		Biofuel targets by type		Electric Energy Storage	
	Value	Difference	% Change	Difference	% Change	Difference	% Change
System Cost (2015$M)	228,212	0	0.00%	6,553	2.87%	-43	-0.02%
Primary Energy (PJ)	9,975	0	0.00%	132	1.33%	4	0.04%
Electricity Generation (GWh)	642,439	0	0.00%	733	0.11%	5,332	0.83%

Final Energy Consumption (PJ)	8,212.05	0.00	0.00%	-9.02	-0.11%	-4.37	-0.05%
PP Builds (GW)	3.92	0.00	0.00%	0.03	0.81%	-0.18	-4.51%
Electricity Investment (2015$M)	14,546	0	0.00%	-41	-0.28%	-339	-2.33%
Demand Device Purchases (2015$M)	290,920	0	0.00%	2,870	0.99%	-50	-0.02%
Fuel Expenditures (2015$M)	184,668	0	0.00%	20,931	11.33%	-477	-0.26%
GHG Emissions (kt CO2 eq.)	324,823	0	0.00%	-50,242	-15.47%	-995	-0.31%

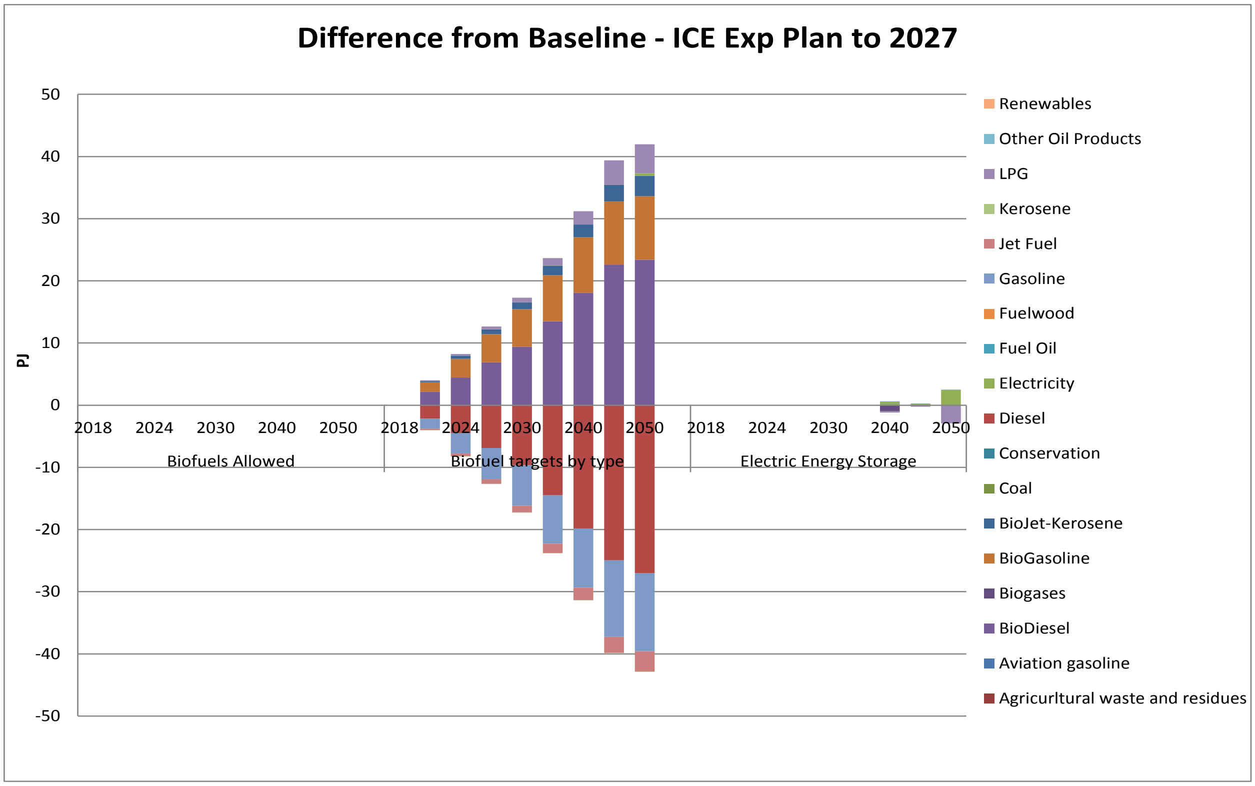


Figure 81: Change in Final Energy Use compared to Baseline

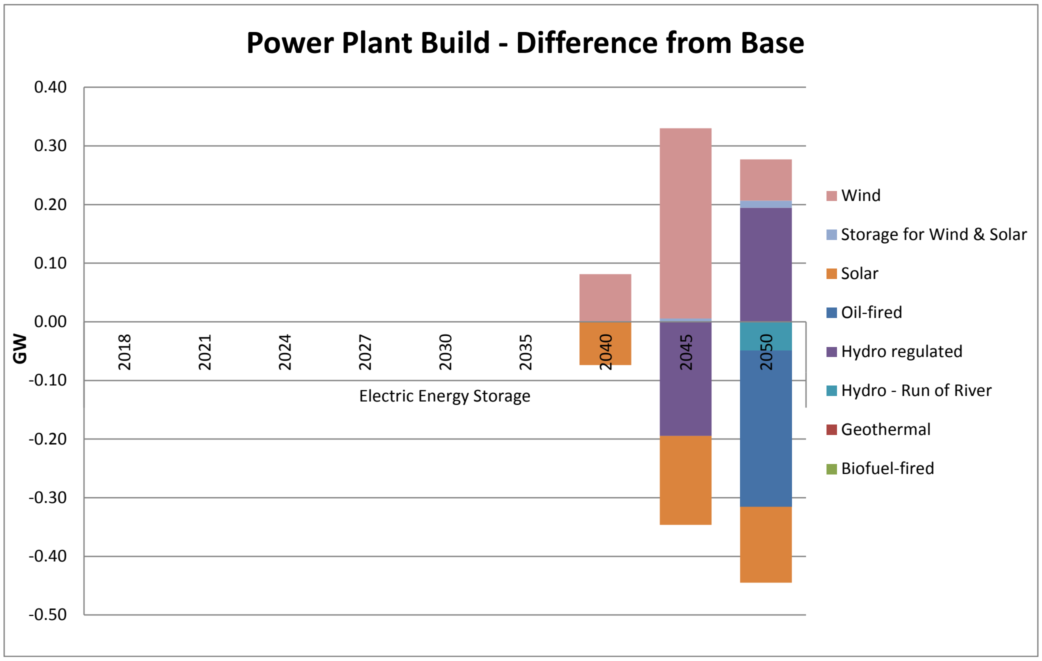


Figure 82: Change in Electricity Generation compared to Baseline

The final set of Supply and Power sector measures examined center around the RE Share of Gross Final Energy, which increases the RE share of gross final energy use from 56% in 2015 to 70% in 2050. It is shown in conjunction with the Biofuel Target measure and the combination scenario of All Planned Supply & Power Measures.

Table 45 shows that increasing the share of RE in GFE use produces more than a 14% reduction in GHG emissions, but increases new power plant builds by over 50% and new power plant investment by almost 70%. The Biofuels Target measure produces about 10% more emission reductions while increasing fuel expenditures by over 11% compared to less than 5% increase when all renewables are promoted. Combining All Planned Supply and Power sector measures produces a 17% reduction in GHG emissions, indicating significant overlap between these two measures. In the combination scenario, fuel expenditures increase due to the higher cost of biofuels, and the power plant investment increases because the RE Share measure builds 850 MW of additional power plants. Figure 83 shows how primary energy use changes between these three scenarios compared to the Baseline. The RE Share measure prefers renewables (geothermal, hydropower, solar & wind) to biofuels. Figure 84, which shows the change in electricity generation, also illustrates that when biofuels are not forced, then electricity generation by wind and geothermal are increased.

Table 45: Supply and Power Sector Measures-4

Metrics / Scenario	Baseline - ICE 2027	Biofuel targets by type		RE Share of Final Energy		All Planned Supply & Power Measures	
	Value	Difference	% Change	Difference	% Change	Difference	% Change

System Cost (2015$M)	228,212	6,553	2.87%	4,776	2.09%	7,069	3.10%
Primary Energy (PJ)	9,975	132	1.33%	1,051	10.54%	843	8.45%
Electricity Generation (GWh)	642,439	733	0.11%	74,187	11.55%	56,968	8.87%
Final Energy Consumption (PJ)	8,212.05	-9.02	-0.11%	103.13	1.26%	60.91	0.74%
PP Builds (GW)	3.92	0.03	0.81%	1.49	37.91%	1.84	46.81%
Electricity Investment (2015$M)	14,546	-41	-0.28%	8,897	61.17%	7,609	52.31%
Demand Device Purchases (2015$M)	290,920	2,870	0.99%	832	0.29%	2,957	1.02%
Fuel Expenditures (2015$M)	184,668	20,931	11.33%	8,962	4.85%	18,581	10.06%
GHG Emissions (kt CO2 eq.)	324,823	-50,242	-15.47%	-46,637	-14.36%	-56,418	-17.37%

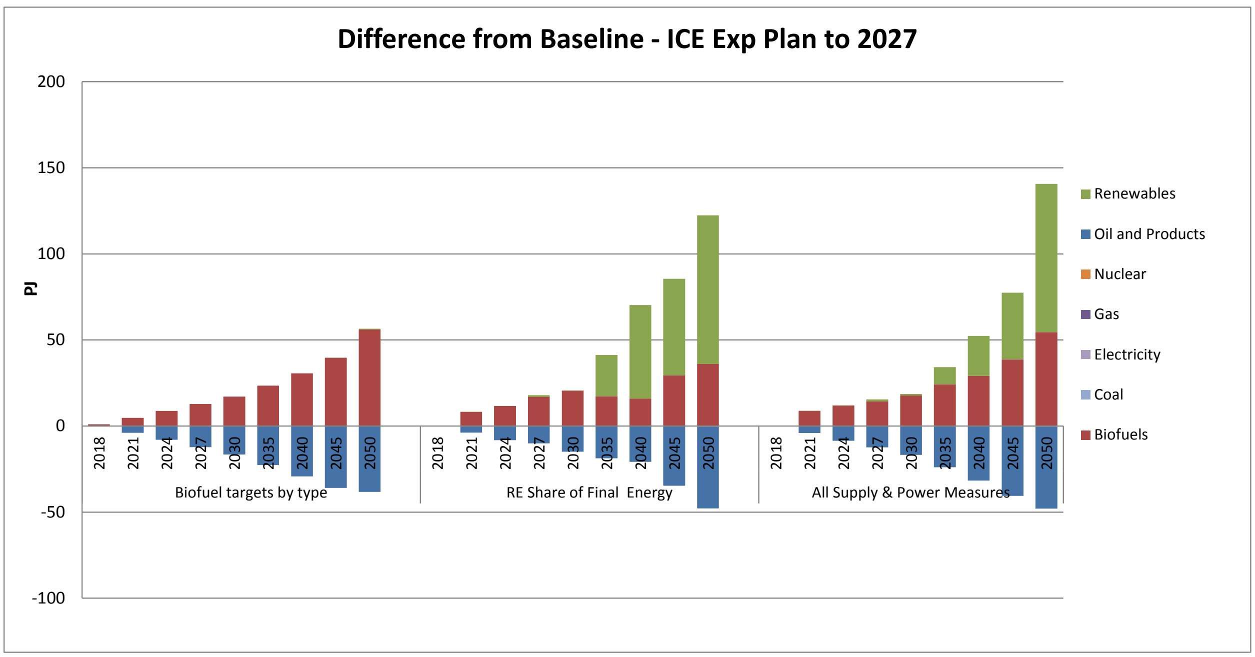


Figure 83: Change in Primary Energy Use compared to Baseline

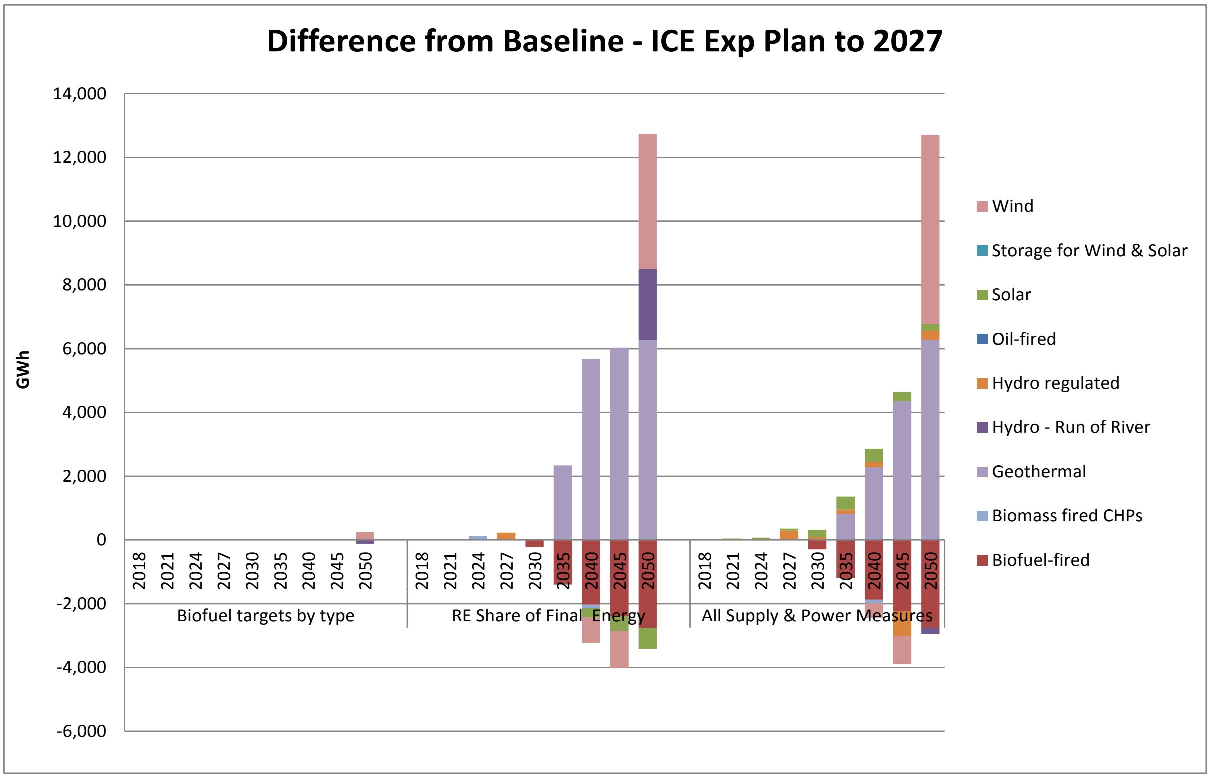


Figure 84: Change in Electricity Generation compared to Baseline

E.2 Efficiency for Buildings and Industry Sectors

This section covers the 24 scenarios that were used to examine the Planned measures with respect to efficiency in Buildings and Industry, including the Agriculture sector.

E.2.1 Commercial and Residential Appliance Efficiency

These measures implement appliance standards for all devices in the Commercial (COM) and Residential (RSD) sectors such that all new appliances must be Improved, Better and Advanced quality types by 2030. As shown in Table 46, these appliance standard measures reduce primary and final energy consumption and electricity demand, and reduce power plant investment requirements and fuel costs, while increasing investment in more efficient demand devices.

Looking only at the Commercial sector, the measure produces a small increase in the system cost of 0.14%, while the Residential standard results in a decrease of 0.15%. Although both measures decrease power plant investment by a similar amount, the more efficient devices in the Commercial sector are more expensive than those in the Residential sector. For the Residential measure and the Combined measure, the reduced investments in new electric supply offset the increased cost of the more efficient residential appliances. The Combined measure produces no net change in the system cost with a 0.3% (almost 1 Mt) cumulative reduction in GHG emissions. The GHG emission reductions are small because most of the energy savings are in the form of electricity.

Table 46: Commercial and Residential Appliance Standards

Metrics / Scenario	Baseline - ICE 2027	COM Appliance Standards		RSD Appliance Standards		COM & RSD Appliance Standards	
	Value	Difference	% Change	Difference	% Change	Difference	% Change
System Cost (2015$M)	228,212	318	0.14%	-347	-0.15%	10	0.00%
Primary Energy (PJ)	9,975	-40	-0.41%	-57	-0.58%	-97	-0.97%
Electricity Generation (GWh)	642,439	-15,110	-2.35%	-16,042	-2.50%	-28,466	-4.43%
Final Energy Consumption (PJ)	8,212.05	-54.52	-0.66%	-73.99	-0.90%	-115.91	-1.41%
PP Builds (GW)	3.92	-0.28	-7.08%	-0.18	-4.60%	-0.55	-13.97%
Electricity Investment (2015$M)	14,546	-568	-3.91%	-430	-2.96%	-962	-6.62%
Demand Device Purchases (2015$M)	290,920	2,270	0.78%	194	0.07%	2,398	0.82%
Fuel Expenditures (2015$M)	184,668	-115	-0.06%	-419	-0.23%	-507	-0.27%
GHG Emissions (kt CO2 eq.)	324,823	-153	-0.05%	-759	-0.23%	-985	-0.30%

E.2.2 Energy Efficiency Subsidy Incentives

An alternative efficiency improvement appliance measure is to provide tax exemptions (incentives) to reduce the cost of Improved, Better and Advanced Energy Efficient (EE) devices in Commercial and Residential sectors starting in 2021. As shown in Table 47, two variants of this measure were run: the first effectively providing a 10% reduction in technology cost, and the other providing a 20% effective cost reduction. The 10% incentive shows a 0.47% reduction in system cost, almost 8% reduction in power plant investment and a 0.55% reduction in GHG emissions. However, the cost of the tax incentive in the form of lost revenue to the government is not included. The 20% incentive produces a 0.69% reduction in system cost, a 10.5% reduction in power plant investment and a 0.68% reduction in GHG emissions. As above, GHG emission reductions are small because most of the energy savings are in the form of electricity.

Table 47: Commercial and Residential Efficiency Subsidy Incentives

Metrics / Scenario	Baseline - ICE 2027	EE Incentive (10%) for COM & RSD		EE Incentive (20%) for COM & RSD	
	Value	Difference	% Change	Difference	% Change
System Cost (2015$M)	228,212	-1,070	-0.47%	-1,582	-0.69%

Primary Energy (PJ)	9,975	-65	-0.65%	-101	-1.01%
Electricity Generation (GWh)	642,439	-29,543	-4.60%	-37,613	-5.85%
Final Energy Consumption (PJ)	8,212.05	-85.09	-1.04%	-118.44	-1.44%
PP Builds (GW)	3.92	-0.66	-16.90%	-0.95	-24.21%
Electricity Investment (2015$M)	14,546	-1,124	-7.72%	-1,534	-10.54%
Demand Device Purchases (2015$M)	290,920	-1,782	-0.61%	-2,547	-0.88%
Fuel Expenditures (2015$M)	184,668	-109	-0.06%	-290	-0.16%
GHG Emissions (kt CO2 eq.)	324,823	-1,782	-0.55%	-2,197	-0.68%

Figure 85 compares the change in final energy use from the Baseline for the combined appliance standard measure and the two EE tax incentive measures. The 10% incentive produces lower reductions of energy use in the early periods as the combined appliance standard measure, but slightly more reductions later, and the 20% incentive measure follows a similar pattern, but with about a 25% greater impact. The 10% and 20% tax incentive measures report a larger reduction in the system cost because the cost to the government of the incentive is not explicitly included. Therefore, the combined appliance standard is preferred to these alternatives.

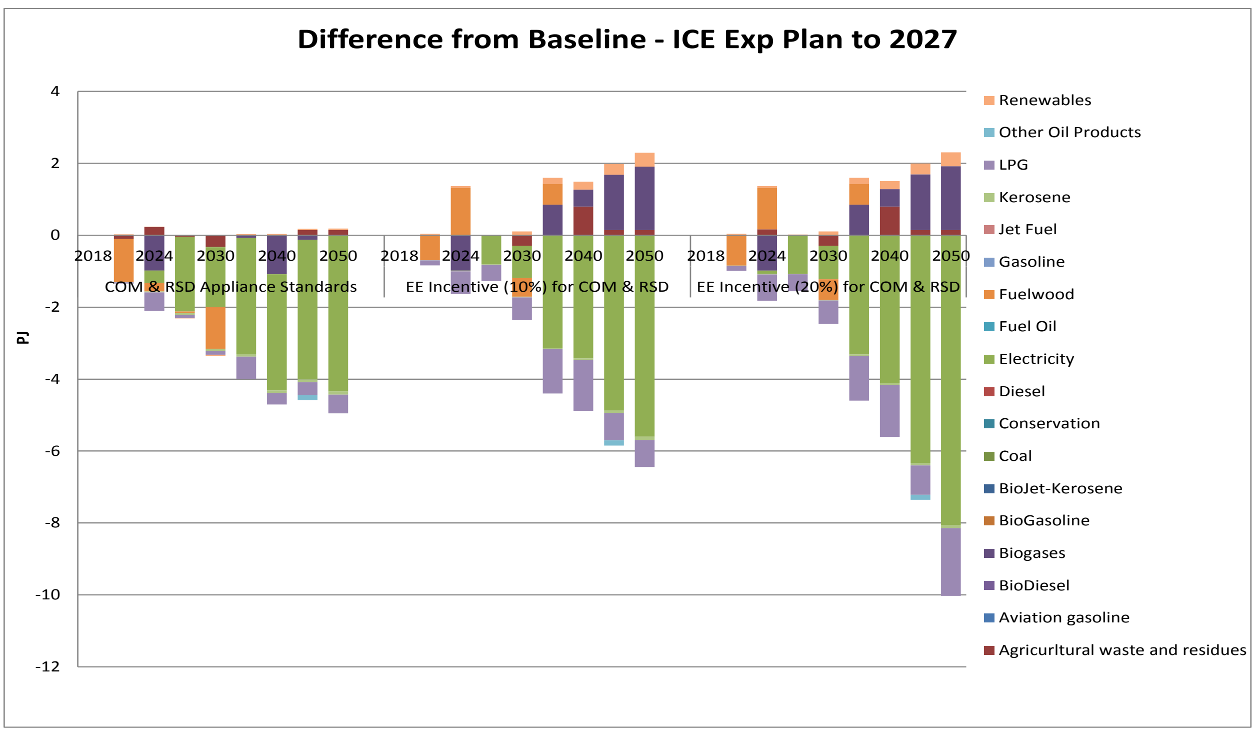


Figure 85: Change in Final Energy Consumption compared to Baseline

E.2.3 Promotion of Advanced Energy Efficiency Devices

As discussed in Section 5.2, the Baseline scenario limits the adoption of new high efficiency (Improved, Better and Advanced) demand technologies to meeting at most 30%, 20% and 10% respectively of their associated demand by 2050. This technology quality constraint is used because experience shows that a slow uptake of advanced technologies (usually more costly to purchase though more efficient to operate) can be expected in the absence of specific policies to promote them. Two measures were examined that allow either 50% or 90% uptake of new high efficiency (Improved, Better and Advanced) demand (sometimes referred to in general as advanced technologies) by 2050 based on mitigation measures that incentivize the adoption of these more efficient demand devices. The design of these advanced technology (AdvTech) quality constraints allows cost-effective Improved, Better, and Advanced devices to be purchased up to their adoption rate limit, but does not force their uptake.

Table 48 shows that the 50% AdvTech measure reduces final energy consumption by almost 0.9% and GHG emissions by over 2.9 Mt, cumulative thru 2050. The 90% AdvTech measure reduces final energy use by 1.7% and GHG emissions by over 7.6 Mt. As shown in Figure 86, this measure is applied to the commercial, residential and industry demand sectors and most of the reductions come from the commercial and industry sectors, with early reductions in the residential sector resulting in some later final energy increases relative to the Baseline. Both AdvTech measures result in significant reductions in fuel expenditures, which result in reductions in energy system cost of 0.4% and 1.0% respectively.

Table 48: Promotion of Energy Efficiency Demand Devices

Metrics / Scenario	Baseline - ICE 2027	Allow 50% AT in 2050		Allow 90% AT in 2050	
	Value	Difference	% Change	Difference	% Change
System Cost (2015$M)	228,212	-868	-0.38%	-2,353	-1.03%
Primary Energy (PJ)	9,975	-58	-0.58%	-119	-1.19%
Electricity Generation (GWh)	642,439	-19,254	-3.00%	-30,621	-4.77%
Final Energy Consumption (PJ)	8,212.05	-72.81	-0.89%	-136.50	-1.66%
PP Builds (GW)	3.92	-0.42	-10.83%	-0.79	-20.22%
Electricity Investment (2015$M)	14,546	-790	-5.43%	-1,323	-9.10%
Demand Device Purchases (2015$M)	290,920	-382	-0.13%	-1,611	-0.55%
Fuel Expenditures (2015$M)	184,668	-1,312	-0.71%	-4,351	-2.36%
GHG Emissions (kt CO2 eq.)	324,823	-2,919	-0.90%	-7,650	-2.36%

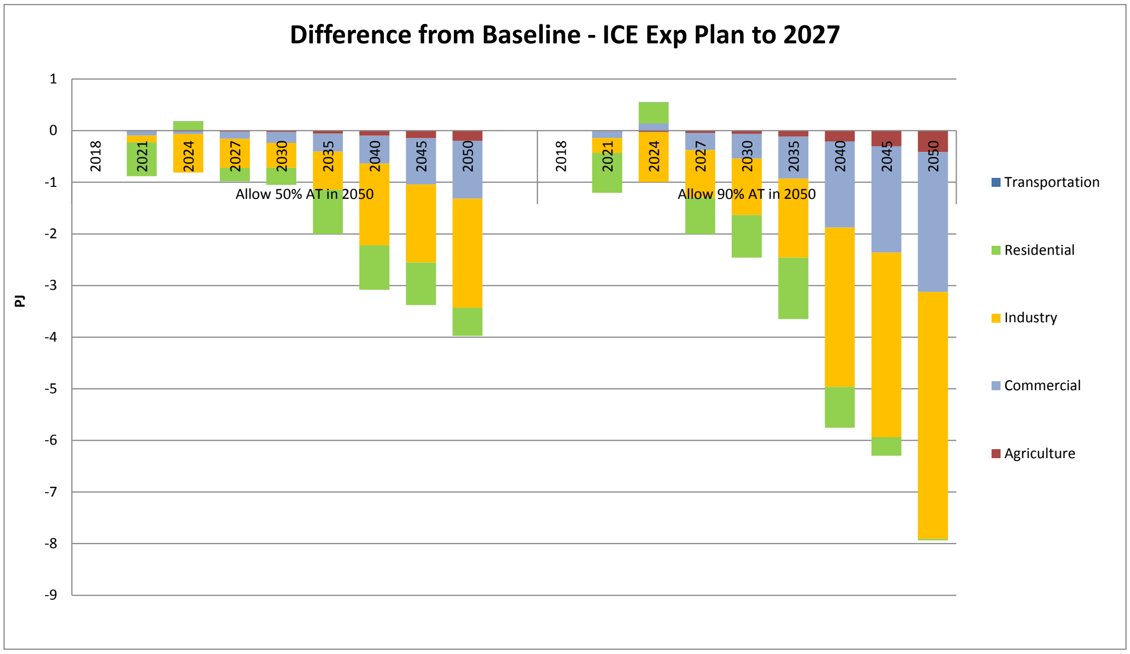


Figure 86: Final Energy Savings for Baseline with 50% and 90% AdvTech measures

E.2.4 Efficiency Measures for Public Buildings and Lighting

The next two scenarios examine improvements to Public Building Efficiency and Public Lighting. The Building Efficiency measure reduces public building energy use by 15% and retrofits all public buildings are retrofitted by 2050. This scenario assumes public buildings represent 10% of Commercial sector demand. The Public Lighting measure transitions to 100% LED Public Lighting by 2024. This scenario was also run using No ICE Expansion Plan to illustrate the impact of using the ICE expansion plan to 2027.

Table 49 shows the Public Building Efficiency measure has a small impact that decreases electricity consumption and power plant builds, but produces little GHG reductions as most of the energy saved is hydropower-based electricity. The LED Public Lighting measure also has no significant impact, with slightly greater reductions in electricity consumption, power plant builds, and GHG emissions. The latter occur as the reduced demand for hydropower-based electricity leads to some fossil-based electricity consumption to be displaced, as shown in Figure 87. This figure also shows that the LED Public Lighting measure with the No ICE Expansion Plan produces reductions in power plant new builds in 2021 and 2024 that are not allowed when the measure is run with the core Baseline scenario. However, the largest differenced occur in 2027 and later due to the significant cost differences between new regulated hydropower and new run-of-river hydropower.

Table 49: Commercial and Residential Building Efficiency Measures

Metrics / Scenario	Baseline - ICE 2027	Public Building Efficiency		LED Public Lighting		LED Public Lighting - No ICE Exp. Plan	
	Value	Difference	% Change	Difference	% Change	Difference	% Change
System Cost (2015$M)	228,212	-173	-0.08%	-204	-0.09%	-1,877	-0.82%
Primary Energy (PJ)	9,975	-15	-0.15%	-26	-0.26%	-299	-3.00%
Electricity Generation (GWh)	642,439	-3,719	-0.58%	-8,012	-1.25%	-20,774	-3.23%
Final Energy Consumption (PJ)	8,212.05	-15.61	-0.19%	-31.10	-0.38%	-48.96	-0.60%
PP Builds (GW)	3.92	-0.07	-1.90%	-0.16	-4.08%	0.00	-0.08%
Electricity Investment (2015$M)	14,546	-250	-1.72%	-377	-2.59%	-3,303	-22.71%
Demand Device Purchases (2015$M)	290,920	-199	-0.07%	-269	-0.09%	-62	-0.02%
Fuel Expenditures (2015$M)	184,668	-84	-0.05%	-22	-0.01%	726	0.39%
GHG Emissions (kt CO2 eq.)	324,823	-27	-0.01%	-68	-0.02%	650	0.20%

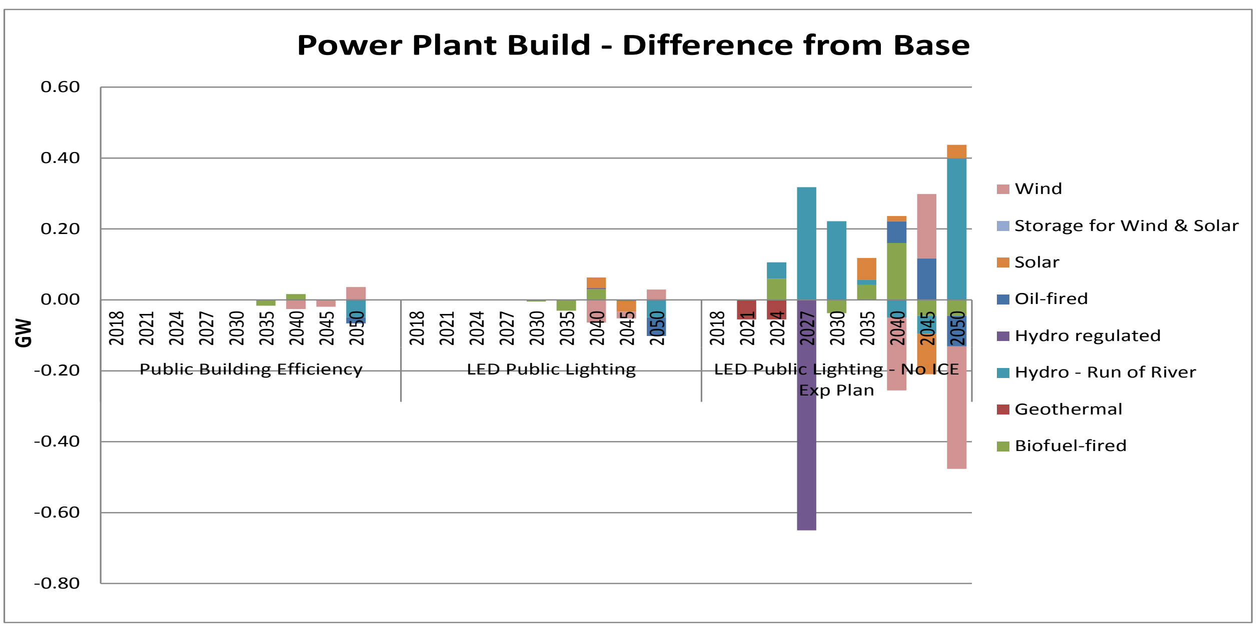


Figure 87: Change in New Power Plant Builds compared to Baseline

E.2.5 Industry Efficiency Measures

The next three measures, shown in Table 50, focus on industrial energy efficiency. Cement Industry Fuel switching increases bio-energy demand in the Cement sector to 75% of all process heat demand in the Other sector by 2050. The Coffee NAMA improves process efficiency in Coffee sector by forcing new improved boilers and furnaces, and the Bioenergy Utilization measure increases use of organic residues by the Agriculture and Industry sectors

The Cement Industry Fuel switching measure produces over a 2% reduction in GHG emissions (7 Mt) due to fuel switching away from other oil products (largely petroleum coke) to fuelwood and agriculture residues, as shown in Figure 88. However, the efficiency improvements in the Coffee NAMA measure reduce only a very small amount of final energy consumption and produce very little GHG emissions reductions. Promoting increased bioenergy use in the Industry and Agriculture sectors increases use of fuelwood, agricultural residues and biogases to displace mostly diesel fuel, other oil products and some electricity. Power plant investment increases because biofuels are diverted from the power sector, resulting in an increased investment in wind power. Cumulative GHG emissions are reduced by 1.2% (3.9 Mt).

Table 50: Industrial Effieicncy Measures

Metrics / Scenario	Baseline - ICE 2027	Cement IND Fuel Switching		Coffee NAMA		Bioenergy Utilization by AGR & IND	
	Value	Difference	% Change	Difference	% Change	Difference	% Change
System Cost (2015$M)	228,212	4,418	1.94%	1	0.00%	-396	-0.17%
Primary Energy (PJ)	9,975	18	0.18%	0	0.00%	49	0.50%
Electricity Generation (GWh)	642,439	2,280	0.35%	-14	0.00%	1,185	0.18%
Final Energy Consumption (PJ)	8,212.05	-6.78	-0.08%	-0.06	0.00%	-5.59	-0.07%
PP Builds (GW)	3.92	0.28	7.19%	0.00	-0.02%	0.50	12.87%
Electricity Investment (2015$M)	14,546	778	5.35%	-3	-0.02%	939	6.46%
Demand Device Purchases (2015$M)	290,920	58	0.02%	0	0.00%	-19	-0.01%
Fuel Expenditures (2015$M)	184,668	1	0.00%	2	0.00%	-1,857	-1.01%
GHG Emissions (kt CO2 eq.)	324,823	-7,046	-2.17%	3	0.00%	-3,946	-1.21%

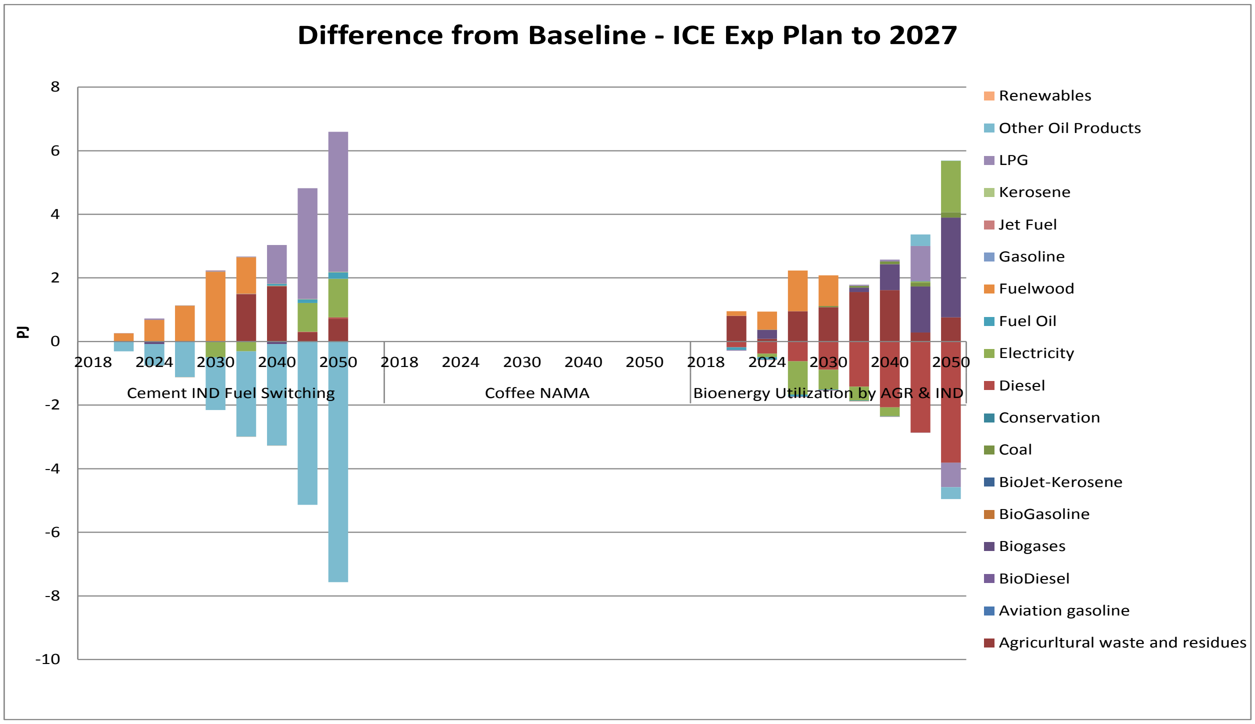


Figure 88: Change in Final Energy Consumption compared to Baseline

E.2.6 All Efficiency Measures

This section discusses combinations of efficiency measures for Buildings, and Industry, and their combination, as shown in Table 51. The combined buildings measures produce a GHG emission reduction of 2.8 Mt, as many of the individual measures produce mostly electricity savings, and because some of the measures, such as retrofitting public buildings, have a relatively small footprint (e.g., public buildings represent only 10% of all commercial buildings). The combination of industrial efficiency measures show a more significant reduction of 13.2 Mt and the combination of all these efficiency measures generate a 5.2% reduction in cumulative GHG emissions (16.9 Mt).

Table 51: Combined Buildings and Industry Efficiency Measures

Metrics / Scenario	Baseline - ICE 2027	All Building Efficiency Measures		All Industry Efficiency Measures		All Energy Efficiency Measures	
	Value	Difference	% Change	Difference	% Change	Difference	% Change
System Cost (2015$M)	228,212	-855	-0.37%	-1,248	-0.55%	-2,326	-1.02%
Primary Energy (PJ)	9,975	-123	-1.23%	-59	-0.60%	-220	-2.21%
Electricity Generation (GWh)	642,439	-41,195	-6.41%	8,893	1.38%	-34,487	-5.37%

Final Energy Consumption (PJ)	8,212.05	-141.61	-1.72%	-90.20	-1.10%	-235.31	-2.87%
PP Builds (GW)	3.92	-0.87	-22.19%	0.36	9.23%	-0.77	-19.61%
Electricity Investment (2015$M)	14,546	-1,416	-9.73%	1,009	6.94%	-1,272	-8.75%
Demand Device Purchases (2015$M)	290,920	230	0.08%	-101	-0.03%	155	0.05%
Fuel Expenditures (2015$M)	184,668	-526	-0.28%	-4,472	-2.42%	-5,384	-2.92%
GHG Emissions (kt CO2 eq.)	324,823	-2,779	-0.86%	-13,189	-4.06%	-16,908	-5.21%

E.2.7 Stationary GHG Levy Measures

This section explores the impact of a GHG levy on stationary sources (power plants, buildings and industry) at a low and high level of levy, without and with biofuels. The Low levy starts at $10/t in 2021 increasing linearly to $150/t in 2050, and the High levy starts the same, but goes to $300/t in 2050.

Table 52 shows the results for the three Low Levy scenarios.

The Low GHG levy measure produces only 1.3% (4.1 Mt) reduction in cumulative GHG emissions, and increases energy system costs by $US2.3 B. Combined with the 90% AdvTechs for the Commercial, Industry and Residential sectors, the Low levy on stationary sources produces a 7.6% reduction in emissions (24.7 Mt), while adding the option to use biofuels has no impact on stationary emissions. Figure 89 illustrates that most of the emission reductions occur in the Industry sector.

The Low levy case with 90% AdvTechs increases electricity generation by 4.3% and power plant investment by $US4.2 B. Figure 90 shows that with 90% AdvTechs, the Low levy scenario produces final energy shifts from LPG, fuel oil and other petroleum products to electricity, fuelwood and agricultural residues. The Low levy raises US$1.6 to 2.2 billion in revenue to the government that could be applied to mitigation measures and mitigation and improved infrastructure. However, the potential impact of re-investing funds from the levy was not included.

Table 52: Stationalry Source GHG Emission Levy – Low

Metrics / Scenario	Baseline - ICE 2027	Fixed Source GHG Levy Low		Fixed Source GHG Levy Low - 90% AT		Fixed Source Low GHG Levy - 90% AT & Biofuels	
	Value	Difference	% Change	Difference	% Change	Difference	% Change
System Cost (2015$M)	228,212	2,267	0.99%	-469	-0.21%	-469	-0.21%
Primary Energy (PJ)	9,975	-6	-0.06%	-140	-1.40%	-140	-1.40%
Electricity Generation (GWh)	642,439	13,938	2.17%	27,674	4.31%	27,674	4.31%

Final Energy Consumption (PJ)	8,212.05	-9.97	-0.12%	-171.52	-2.09%	-171.52	-2.09%
PP Builds (GW)	3.92	0.48	12.34%	1.01	25.66%	1.01	25.66%
Electricity Investment (2015$M)	14,546	2,279	15.67%	4,261	29.29%	4,261	29.29%
Demand Device Purchases (2015$M)	290,920	22	0.01%	-1,583	-0.54%	-1,583	-0.54%
Fuel Expenditures (2015$M)	184,668	-910	-0.49%	-7,677	-4.16%	-7,677	-4.16%
GHG Emissions (kt CO2 eq.)	324,823	-4,140	-1.27%	-24,702	-7.60%	-24,702	-7.60%

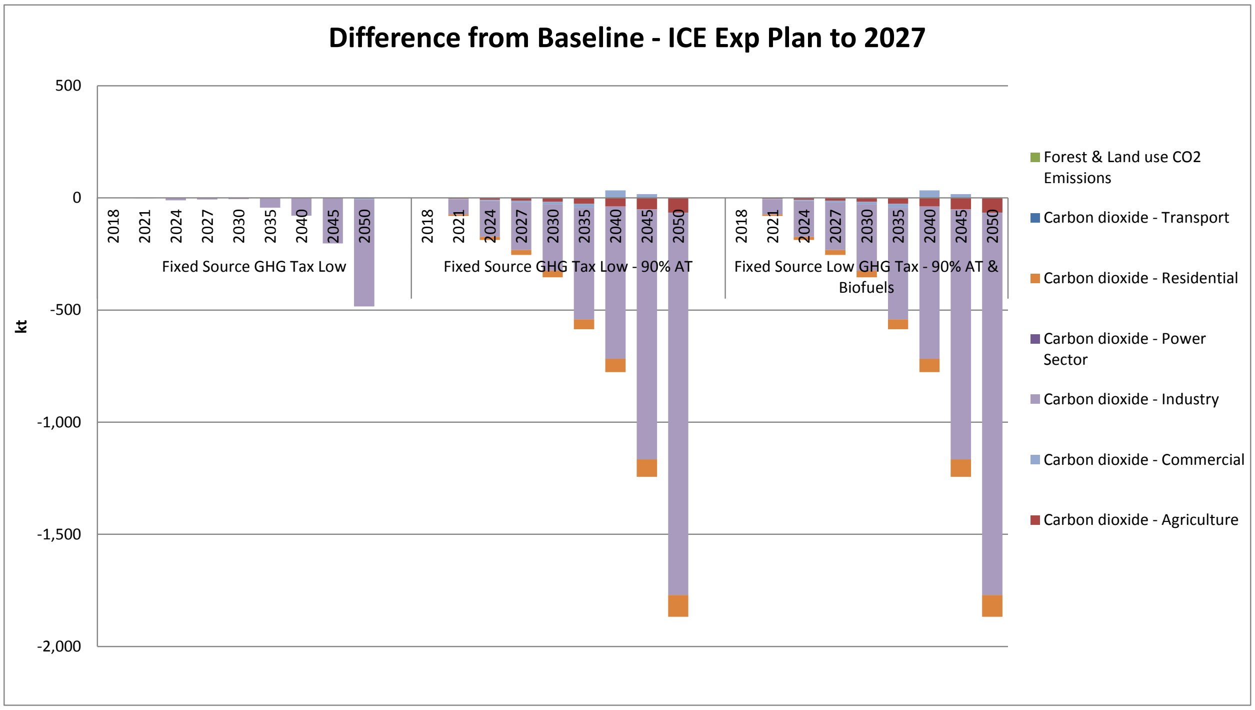


Figure 89: Change in GHG Emissions compared to Baseline for Low Stationary GHG Levy

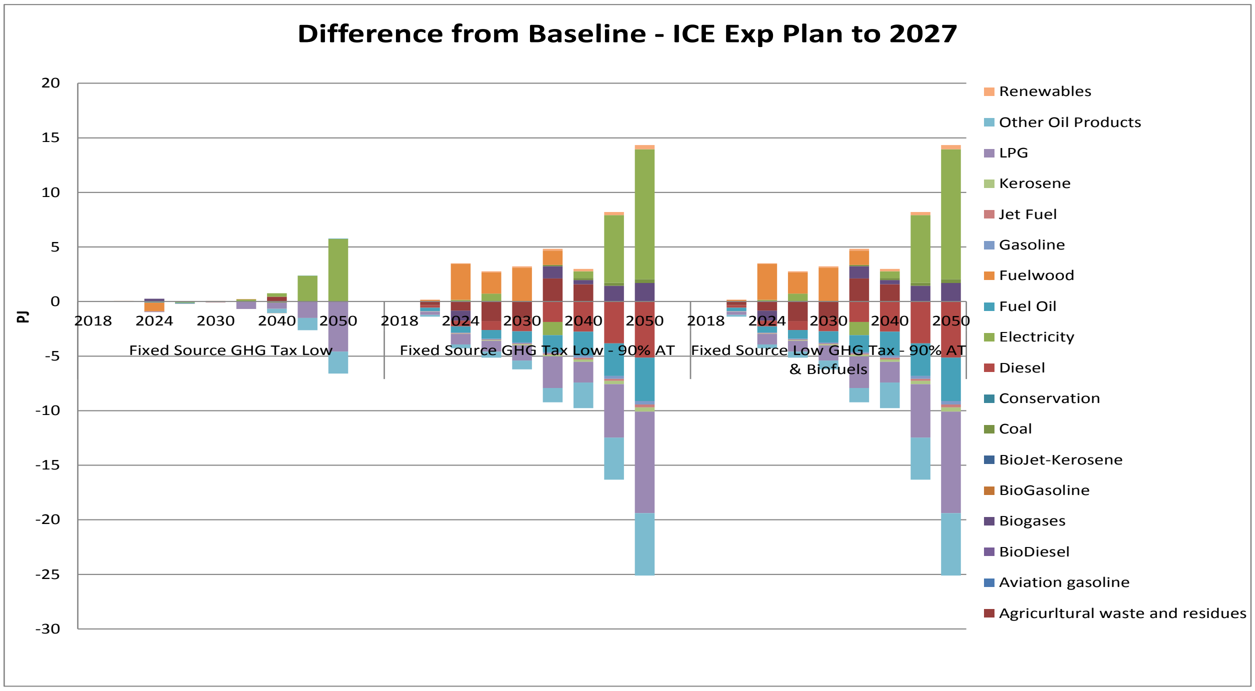


Figure 90: Change in Final Energy Consumption compared to Baseline

As shown in Table 53, the High GHG levy measure on stationary sources produces only slightly more reduction in cumulative GHG emissions (4.8 Mt) compared to the Low levy level, but more than doubles the increase in energy system costs to $US4.75 B). Combined with the 90% AdvTechs measure, the High levy on stationary sources produces an 8.2% reduction in emissions. Interestingly, at the high levy level, the emission reductions occur almost primarily from the Industry sector, as illustrated in Figure 91. As with the Low levy case, adding the option to use biofuels has no impact on stationary emissions. The High levy raises US$3.4 to 4.7 billion in revenue to the government that could be applied to mitigation measures and improved infrastructure. However, the potential impact of re-investing funds from the levy was not included.

Figure 92 shows the change in final energy use by fuel for the High Levy cases compared to the Baseline scenario. The figure shows that final energy shifts from LPG, fuel oil and other petroleum products to electricity, fuelwood and agricultural residues.

Table 53: Stationary Source GHG Emission Levy- High

Metrics / Scenario	Baseline - ICE 2027	Fixed Source GHG Levy High		Fixed Source GHG Levy High - 90% AT		Fixed Source High GHG Levy - 90% AT & Biofuels	
	Value	Difference	% Change	Difference	% Change	Difference	% Change
System Cost (2015$M)	228,212	4,775	2.09%	1,356	0.59%	1,355	0.59%
Primary Energy (PJ)	9,975	-7	-0.07%	-138	-1.39%	-138	-1.39%

Electricity Generation (GWh)	642,439	17,136	2.67%	36,612	5.70%	36,612	5.70%
Final Energy Consumption (PJ)	8,212.05	-8.07	-0.10%	-175.33	-2.14%	-175.33	-2.14%
PP Builds (GW)	3.92	0.53	13.48%	1.25	31.94%	1.25	31.94%
Electricity Investment (2015$M)	14,546	2,518	17.31%	4,635	31.86%	4,635	31.86%
Demand Device Purchases (2015$M)	290,920	19	0.01%	-1,585	-0.54%	-1,585	-0.54%
Fuel Expenditures (2015$M)	184,668	-1,024	-0.55%	-8,104	-4.39%	-8,059	-4.36%
GHG Emissions (kt CO2 eq.)	324,823	-4,780	-1.47%	-26,708	-8.22%	-26,871	-8.27%

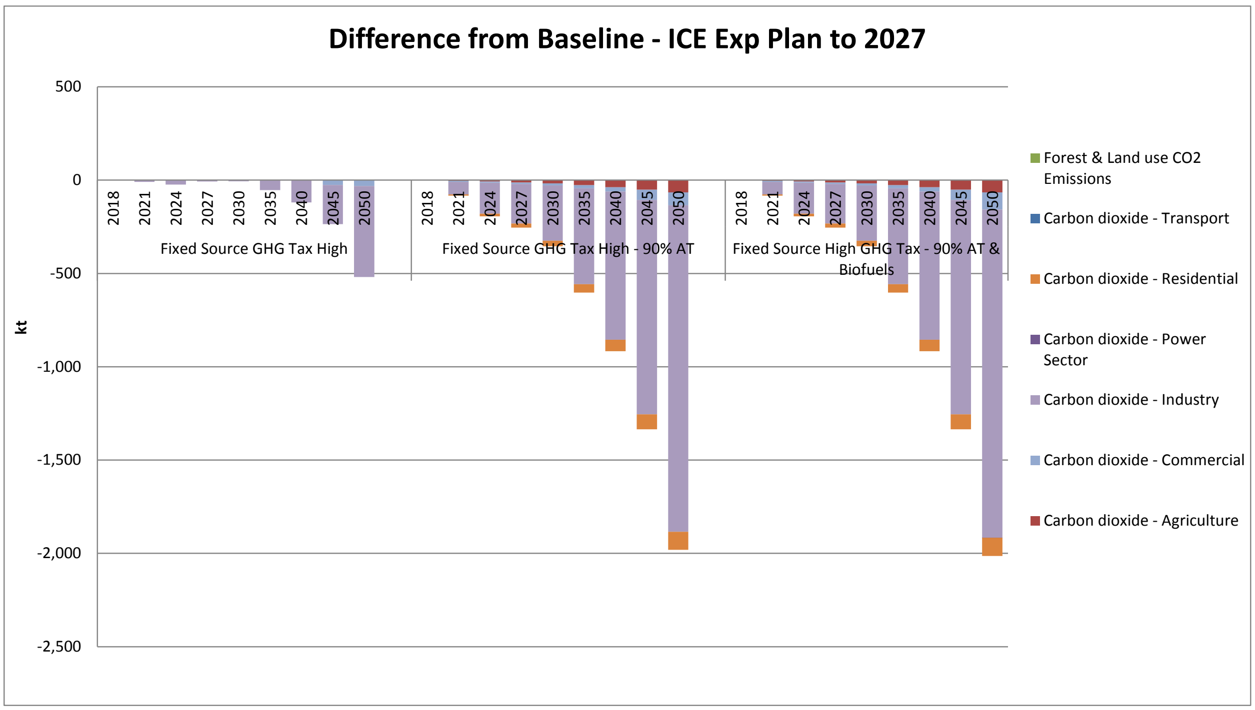


Figure 91: Change in GHG Emissions by Sector compared to Baseline

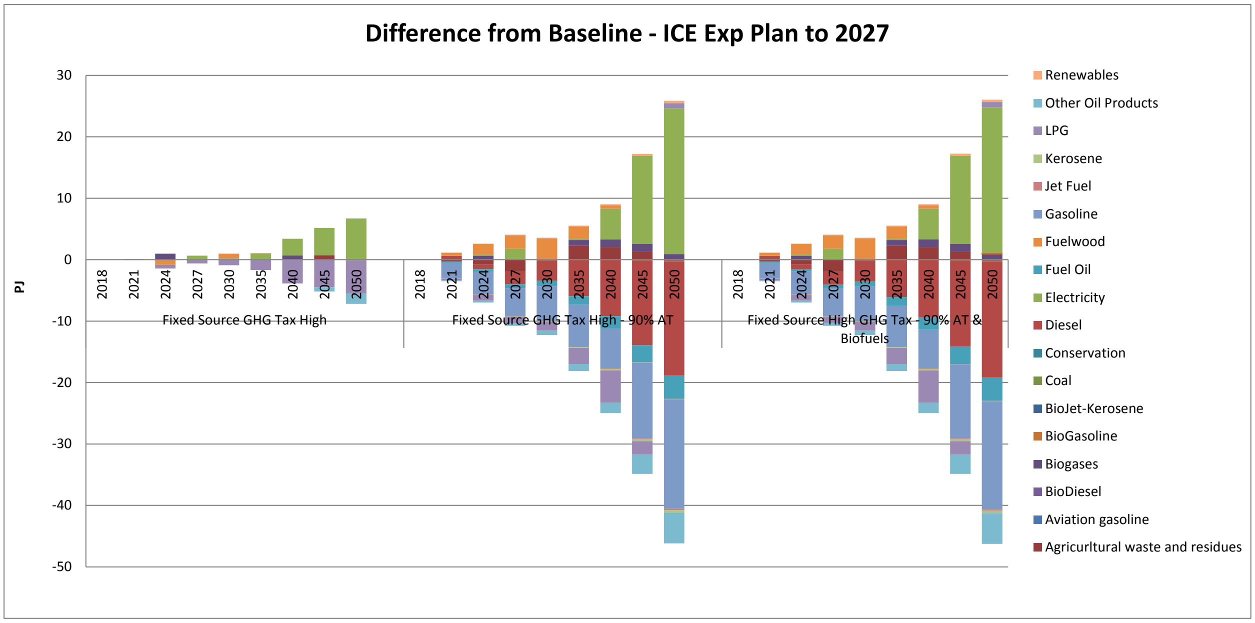


Figure 92: Change in Final Energy Consumption compared to Baseline

E.3 Transportation Sector

The Transport sector consists of 19 measures that cover vehicle technology improvement, mode-shifting for both passenger and freight transport, as well as cap and levy measures.

E.3.1 Transport Technology Measures

The following three measures examine ways to improve the efficiency of the transport fleet by retiring older less efficient Light Duty Vehicles (LDVs) before the end of their useful life; by allowing the share of new hybrid and electric LDVs to increase up to 50% in 2050 (with a 25% share by 2030), and by increasing the share of Advanced Taxis, Buses and Mini-buses to 100% of new vehicles by 2030.

The measure to retire older less efficient vehicles (clunkers) achieves a small reduction in emissions while increasing system cost through the added cost of buying new vehicles sooner than in the Baseline. The GHG reduction is small (820 kt) due to the fact that the measure affects only 20% of the existing vehicles. Increasing the share of hybrid and electric vehicle in the new vehicles purchased reduces the overall system cost by 0.44% because over the long run, the savings in fuel expenditures outweighs the increased cost of the hybrid and electric vehicles and the cost of increasing electricity generation and investments in new power plants. The cumulative GHG emission reductions are 4% (13 Mt). Increasing the share of Advanced Taxis, Buses and Mini-buses reduces 5.4 Mt in cumulative GHG emissions. The change is energy system cost is minimal because the savings in fuel expenditures, balance out the increased investment in demand devices and added power plants.

Figure 93 shows the change in final energy consumed in the transport sector compared to the Baseline and illustrates that increasing the share of hybrid and electric vehicle primary reduces gasoline and increases electricity use, while the public vehicle measure decreases diesel use while increasing gasoline (for hybrids) and electricity use.

Table 54: Incentives for Advanced Transport Technologies

Metrics / Scenario	Baseline - ICE 2027	Retire Oldest 20% of Existing LDV stock		25% share of HY&ELC in new LDV stock		100% share of Advanced Techs in Public Vehicles	
	Value	Difference	% Change	Difference	% Change	Difference	% Change
System Cost (2015$M)	228,212	2,537	1.11%	-1,006	-0.44%	134	0.06%
Primary Energy (PJ)	9,975	-11	-0.11%	-112	-1.13%	-44	-0.45%
Electricity Generation (GWh)	642,439	219	0.03%	19,274	3.00%	7,705	1.20%
Final Energy Consumption (PJ)	8,212.05	-10.81	-0.13%	-119.70	-1.46%	-46.26	-0.56%
PP Builds (GW)	3.92	0.00	0.10%	0.41	10.57%	0.13	3.43%
Electricity Investment (2015$M)	14,546	-14	-0.10%	529	3.64%	76	0.52%
Demand Device Purchases (2015$M)	290,920	3,945	1.36%	4,334	1.49%	2,199	0.76%
Fuel Expenditures (2015$M)	184,668	-426	-0.23%	-8,028	-4.35%	-3,089	-1.67%
GHG Emissions (kt CO2 eq.)	324,823	-822	-0.25%	-13,072	-4.02%	-5,383	-1.66%

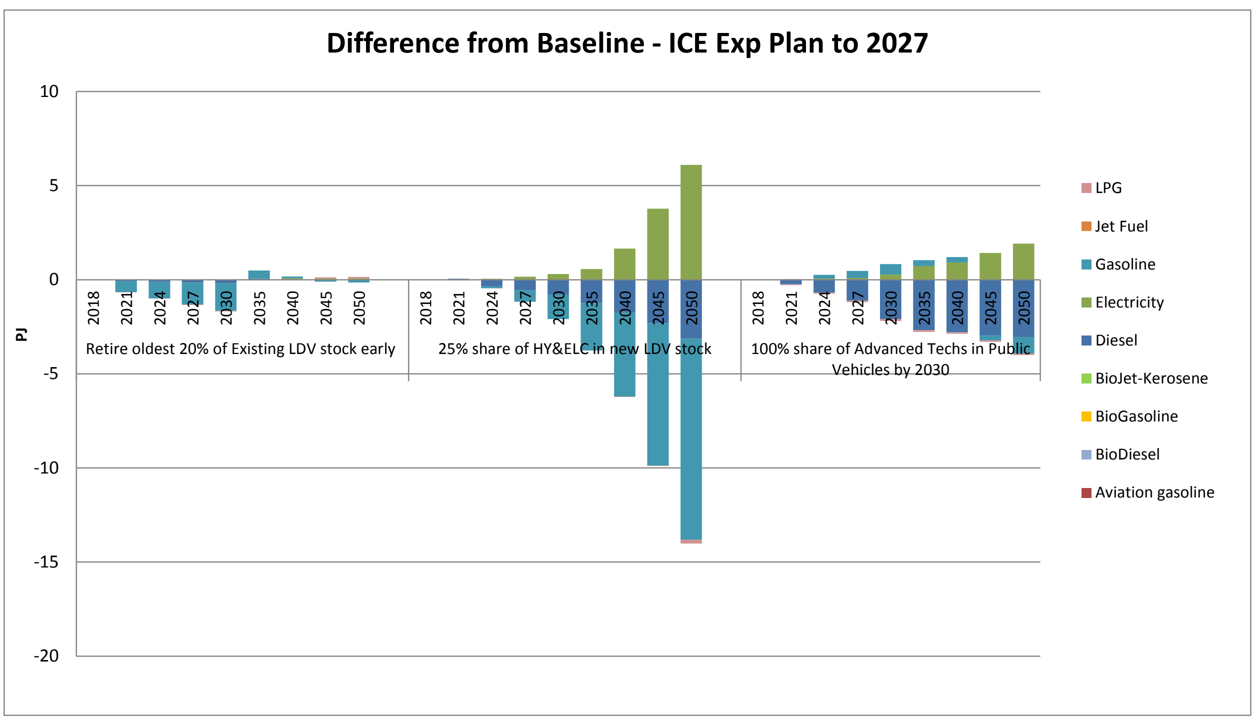


Figure 93: Change in Final Energy to Transport compared to the Baseline

To examine the details of the hybrid and electric LDV measure, three additional scenarios were run. The first only allows hybrid LDVs, the second only allows electric LDVs, and the third allows the combination of hybrid and electric vehicles to go up to 40% by 2050. These measures were modelled at upper bounds, so the model only implements cost-effective vehicle options.

A comparison of Table 54 and Table 55 shows that almost all of the reductions from the combined hybrid and electric measure are achieved by the electric vehicles. This implies that there is little economic incentive for the hybrid options. Table 55 also shows that increasing the allowed new vehicle share to 40% significantly increases the cumulative emission reductions to 20 Mt, indicating that the electric vehicles appear to be very cost-effective, especially after 2030. Although the devices are more expensive to purchase, and require additional investments in the power sector, the savings in fuel expenditures (mostly imported) out-weigh these.

Table 55: Comparison of Incentives for Hybrid and Electric LDVs

Metrics / Scenario	Baseline - ICE 2027	25% share of HYB in new LDV stock		25% share of ELC in new LDV stock		40% share of HY&ELC in new LDV stock	
	Value	Difference	% Change	Difference	% Change	Difference	% Change
System Cost (2015$M)	228,212	-269	-0.12%	-928	-0.41%	-1,416	-0.62%
Primary Energy (PJ)	9,975	-6	-0.06%	-119	-1.19%	-171	-1.71%
Electricity Generation (GWh)	642,439	-2,934	-0.46%	19,562	3.04%	30,392	4.73%
Final Energy Consumption (PJ)	8,212.05	-5.64	-0.07%	-125.91	-1.53%	-182.93	-2.23%
PP Builds (GW)	3.92	-0.08	-1.99%	0.41	10.57%	0.63	16.19%
Electricity Investment (2015$M)	14,546	246	1.69%	530	3.64%	887	6.10%
Demand Device Purchases (2015$M)	290,920	-611	-0.21%	4,819	1.66%	7,075	2.43%
Fuel Expenditures (2015$M)	184,668	204	0.11%	-8,341	-4.52%	-12,397	-6.71%
GHG Emissions (kt CO2 eq.)	324,823	286	0.09%	-13,693	-4.22%	-20,252	-6.23%

The next two measures allow more advanced technologies in all transport modes. The first allows up to 50% advanced technology penetration by 2050 for all transport vehicles, and the second scenario increases the allowed advanced technology penetration to 90%.

As shown in Table 56, both measures show significant GHG emission reductions, savings in fuel expenditures, increased investment in power plants, and lower total system cost. The measure to promote 50% uptake of advanced transport techs produces 18.4 Mt of reductions, while the 90% advanced transport technology measure produces 32.9 Mt. These emission reductions are driven by changes in fuel use, with electricity and LPG displacing gasoline and diesel, as shown in

Figure 94. The increased shift to electric vehicles in the 90% advanced technology measure generating capacity needs by 21% and power plant investment needs by 8%.

Table 56: Promote Advanced Technology for All Transport Modes

Metrics / Scenario	Baseline - ICE 2027	50% Uptake of ADV Techs for all TRN		Reference with TRN UC90	
	Value	Difference	% Change	Difference	% Change
System Cost (2015$M)	228,212	-1,737	-0.76%	-2,547	-1.12%
Primary Energy (PJ)	9,975	-191	-1.92%	-306.1	-3.07%
Electricity Generation (GWh)	642,439	18,005	2.80%	41,770	6.50%
Final Energy Consumption (PJ)	8,212.05	-197	-2.40%	-324.8	-3.95%
PP Builds (GW)	3.92	0.35	8.85%	0.84	21.36%
Electricity Investment (2015$M)	14,546	411	2.83%	1,188	8.17%
Demand Device Purchases (2015$M)	290,920	4,975	1.71%	10,371	3.57%
Fuel Expenditures (2015$M)	184,668	-10,955	-5.93%	-19,812	-10.73%
GHG Emissions (kt CO2 eq.)	324,823	-18,396	-5.66%	-32,886	-10.12%

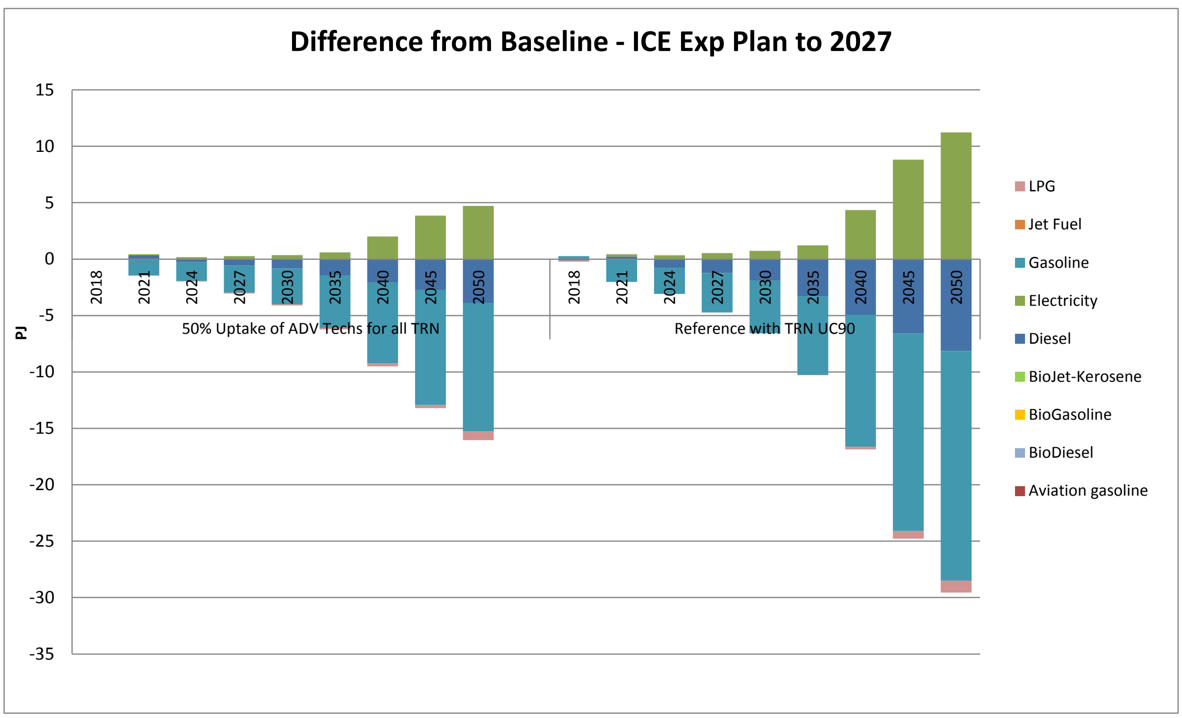


Figure 94: Change in Transport Final Energy Use compared to Baseline

E.3.2 Transport Mode Shift Measures

A total of seven mode shift measures were examined. First, two variations of the Improved public transport measures were examined. In these measures, the use of larger buses compared to the existing buses increases the overall pkm efficiency by 20% through a combination of increased bus load factor and decreased efficiency. The measure impacts 34% of all bus demand. The total distance driven by buses is also reduced by 33%. Two levels of increased bus demand were modelled. The initial study predicted an 8% increase in bus demand, and another indicated a 35% shift in demand from LDVs to buses. As shown in Table 57, both variations of this measure lower the total system cost, and reduce GHG emissions by 2.0 and 2.5 Mt respectively.

As shown in Table 57, both variations of this measure lower the total system cost, and reduce GHG emissions by 2.0 and 2.5 Mt respectively. Figure 95 shows that this measure reduces diesel and gasoline consumption due to the introduction of the larger buses capable of carrying more people, but that the diesel fuel savings decreases as the bus demand increases. In the 35% demand increase variation, more diesel fuel is needed to meet the greater bus demand, and that offsets much of the additional fuel savings, so the incremental improvement in emissions reductions is small.

Table 57: Comparison of Integrated PublicTtransport Measures

Metrics / Scenario	Baseline - ICE 2027	Integrated Public Transport System - 8% MS by 2030		Integrated Public Transport System - 35% MS by 2030	
	Value	Difference	% Change	Difference	% Change
System Cost (2015$M)	228,212	-1,528	-0.67%	-2,525	-1.11%
Primary Energy (PJ)	9,975	-29	-0.29%	-38	-0.38%
Electricity Generation (GWh)	642,439	-160	-0.02%	-410	-0.06%
Final Energy Consumption (PJ)	8,212.05	-29.07	-0.35%	-37.58	-0.46%
PP Builds (GW)	3.92	0.00	-0.10%	-0.01	-0.25%
Electricity Investment (2015$M)	14,546	4	0.03%	10	0.07%
Demand Device Purchases (2015$M)	290,920	-2,966	-1.02%	-6,172	-2.12%
Fuel Expenditures (2015$M)	184,668	-1,167	-0.63%	-1,434	-0.78%
GHG Emissions (kt CO2 eq.)	324,823	-2,075	-0.64%	-2,491	-0.77%

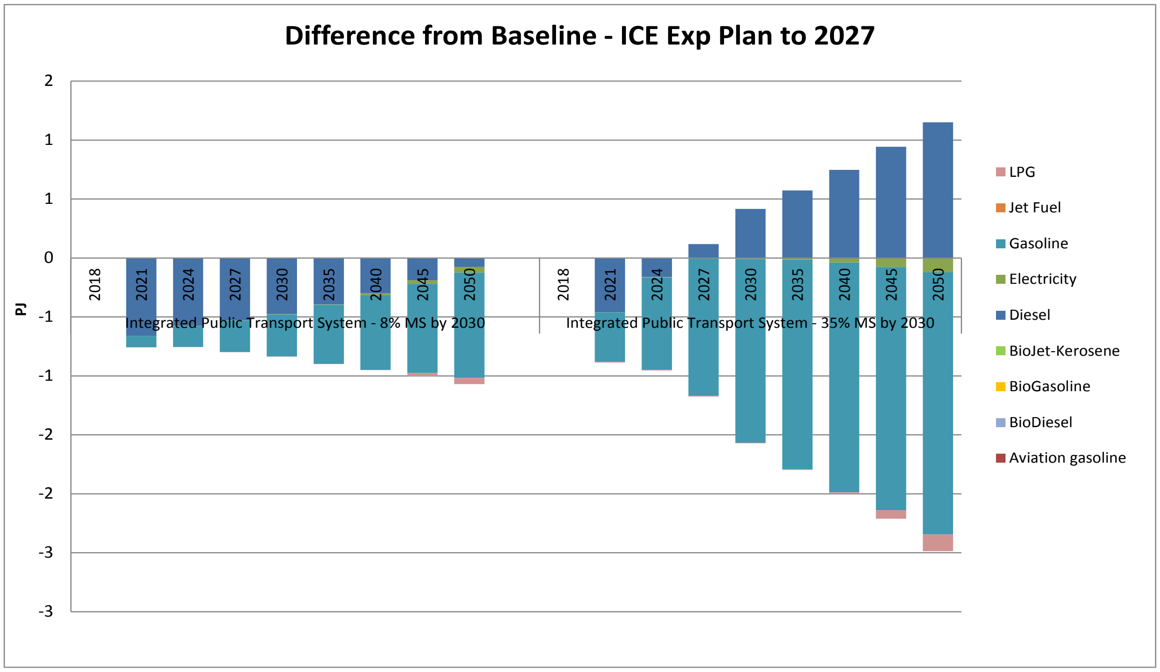


Figure 95: Change in Final Energy to Transport compared to the Baseline

The next three mode-shift measures include: An urban Tram measure that captures 5.4% of LDV demand; An Intercity train connecting the four main cities in the greater metropolitan area and shifts 57 Mpkm annually from LDVs; and an Improved rail freight measure that shifts 25% of heavy truck demand to rail by 2050.

The urban Tram measure reduces GHG emissions by 3.5 Mt and reduces the total system cost by $3 B between 2015 and 2050, which is well within the $1 B very preliminary estimate of the infrastructure cost to implement this measure. The intercity rail measure produces very little impact because the demand shift is quite small (less than 0.2% of total LDV demand). The estimated infrastructure cost of $1.6 B was not included in the system cost calculation. The improved rail freight measure produces 7.8 Mt of GHG emission reductions and reduces the energy system cost by 1.9% as the savings in fuel expenditures outweigh the cost of increased electricity generation. Figure 96 shows that the Tram measure reduces gasoline consumption while the freight mode shift reduces diesel consumption.

Table 58: Transport Mode Shift Measures - 1

Metrics / Scenario	Baseline - ICE 2027	5.4% shift from LDV to tram		Intercity rail - shift 57 Mpkm from cars		25% shift from trucks to rail	
	Value	Difference	% Change	Difference	% Change	Difference	% Change
System Cost (2015$M)	228,212	-3,052	-1.34%	-108	-0.05%	-4,250	-1.86%
Primary Energy (PJ)	9,975	-26	-0.26%	1	0.01%	-79	-0.79%
Electricity Generation (GWh)	642,439	5,208	0.81%	653	0.10%	6,037	0.94%

Final Energy Consumption (PJ)	8,212.05	-25	-0.31%	1	0.01%	-80	-0.97%
PP Builds (GW)	3.92	0.08	1.96%	0.01	0.19%	0.12	2.93%
Electricity Investment (2015$M)	14,546	404	2.78%	37	0.25%	546	3.75%
Demand Device Purchases (2015$M)	290,920	-6,467	-2.22%	-251	-0.09%	-7,238	-2.49%
Fuel Expenditures (2015$M)	184,668	-1,951	-1.06%	-63	-0.03%	-4,461	-2.42%
GHG Emissions (kt CO2 eq.)	324,823	-3,490	-1.07%	-134	-0.04%	-7,810	-2.40%

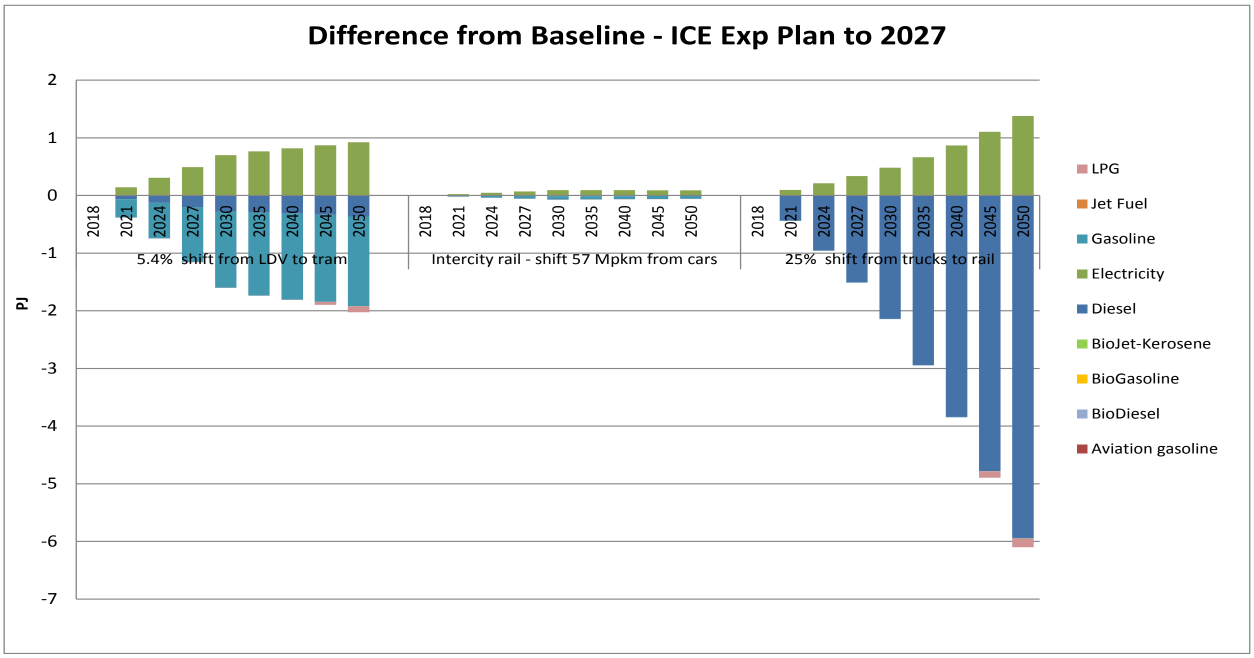


Figure 96: Change in Transport Final Energy Use compared to Baseline

The next three transport measures are: Green driving, which affects 50% of vehicles and increases LDV and taxi efficiency by 5%, and bus, mini-bus and light truck efficiency by 2%; administrative Demand control measures, which limit congestion and affect around 10% of LDVs only; and promoting Non-motorized transport modes, such as walking and cycling, to shift 5% of passenger demand to non-motorized transport by 2030 with 60% coming from bus demand and 40% from LDV demand.

As shown in Table 59, Green driving reduces GHG emissions by 2 Mt and lowers the total system cost by 0.2%. The administrative Demand control measure produces a small impact but lowers the energy system cost slightly. The promotion of non-motorized modes reduces the system cost by 2.7% because it reduces both energy and investment expenditures, although investment in bikes, bike lines and pedestrian infrastructure is not considered. Cumulative GHG emission reductions are 6.2 Mt.

Table 59: Transport Mode Shift Measures - 2

Metrics / Scenario	Baseline - ICE 2027	Green Driving		Demand Control Measures		5% passenger shift to Non-motorized modes	
	Value	Difference	% Change	Difference	% Change	Difference	% Change
System Cost (2015$M)	227,431	-6,176	-2.72%	-98	-0.04%	-2,834	-1.25%
Primary Energy (PJ)	9,770	-84	-0.86%	-1	-0.01%	-22	-0.22%
Electricity Generation (GWh)	56,018	6	0.01%	-21	0.00%	160	0.28%
Final Energy Consumption (PJ)	8,105.32	-83.63	-1.03%	-1	-0.01%	-22	-0.27%
PP Builds (GW)	3.76	0.00	-0.05%	0.00	-0.01%	0.01	0.23%
Electricity Investment (2015$M)	14,311	-9	-0.06%	1	0.00%	44	0.31%
Demand Device Purchases (2015$M)	290,320	-10,424	-3.59%	-288	-0.10%	-6,393	-2.20%
Fuel Expenditures (2015$M)	183,576	-3,528	-1.92%	-35	-0.02%	-1,418	-0.77%
GHG Emissions (kt CO2 eq.)	353,398	-6,161	-1.74%	-57	-0.02%	-1,875	-0.53%

E.3.3 Transport Cap and GHG Levy Measures

The following scenario examines a cap on GHG emission for the transport sector 25% below the Baseline in 2030 and 50% in 2050 with 90% allowed penetration of improved, better and advanced technologies. The measure achieves the target GHG emission reduction because of strong access to advanced technologies through use of biofuels and electricity, which is illustrated in Figure 97.

Table 60: Transport Cap and Measures

Metrics / Scenario	Baseline - ICE 2027	25%-50%CO2TRN cap in 2030/50	
	Value	Difference	% Change
System Cost (2015$M)	228,212	89	0.04%
Primary Energy (PJ)	9,975	-383	-3.84%
Electricity Generation (GWh)	642,439	47,398	7.38%
Final Energy Consumption (PJ)	8,212.05	-402	-4.90%

PP Builds (GW)	3.92	0.91	23.10%
Electricity Investment (2015$M)	14,546	1,290	8.87%
Demand Device Purchases (2015$M)	290,920	15,367	5.28%
Fuel Expenditures (2015$M)	184,668	-17,218	-9.32%
GHG Emissions (kt CO2 eq.)	324,823	-65,921	-20.29%

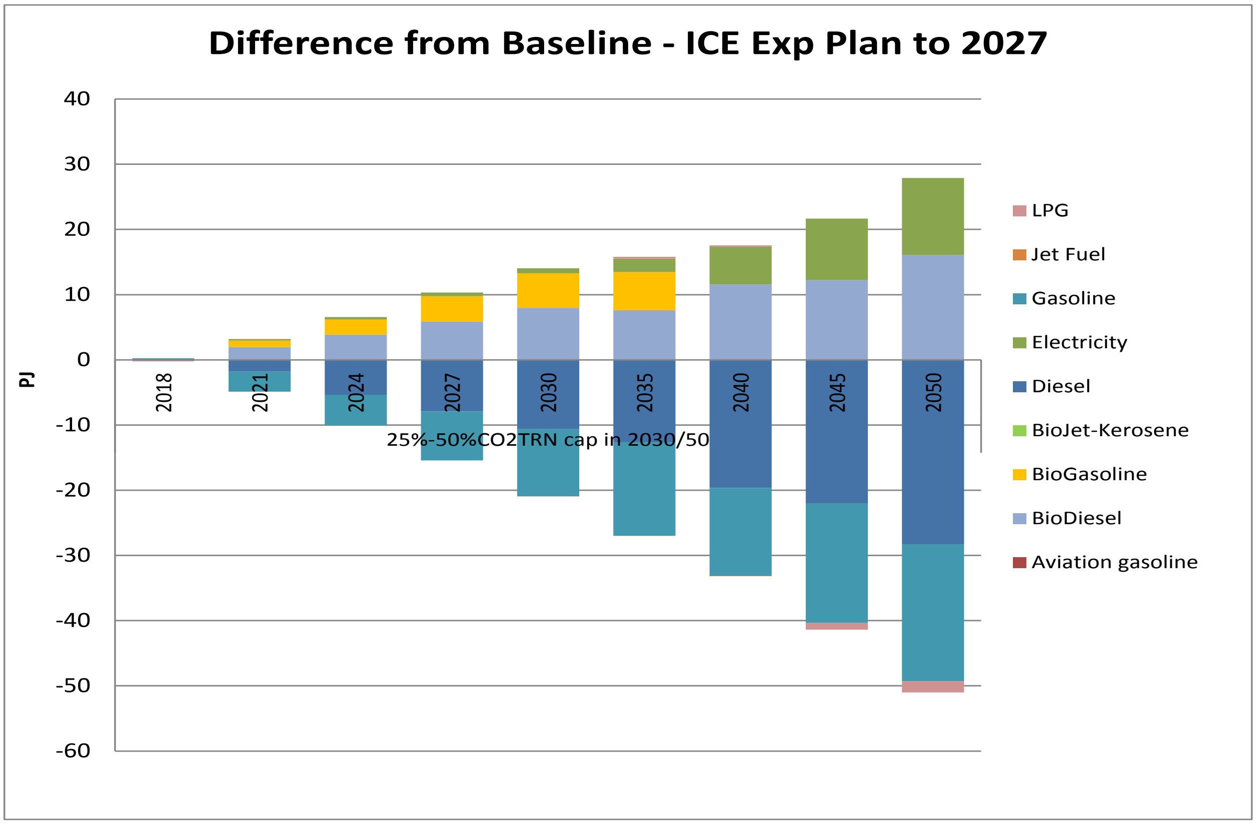


Figure 97: Change in Transport Final Energy Use compared to Baseline

The following three scenarios examine GHG levy options for the transport sector. The first applies a levy that starts at $10/t in 2021 and increases to $300/t in 2050, but maintains the Baseline limits on advanced technology penetration – which is not really a viable policy scenario as seen in the results below. The next two scenarios allow 90% AdvTech penetration, at two levy levels: one going to $150/t in 2050 and the other going to $300/t. As shown in Table 61, the GHG levy without advanced technology access achieves relatively little GHG emission reductions compared to the two cases where 90% AdvTech penetration is allowed. The $150/t levy in 2050 achieves over 10% reduction in cumulative emissions (34 Mt), while the $300/t levy achieves over 11% (38 Mt), which indicates that there are diminishing returns for going much beyond $150/t. Figure 98 shows that going from the $150/t to the $300/t levy produces only small changes in final energy use, which indicates there are limits to how much certain fuels can be reduced given current system constraints.

Table 61: Transport GHG Levy Measures

Metrics / Scenario	Baseline - ICE 2027	TRN GHG Levy - $300/t in 2050		TRN GHG Levy +UC90 - $150/t in 2050		TRN GHG Levy +UC90 - $300/t in 2050	
	Value	Difference	% Change	Difference	% Change	Difference	% Change
System Cost (2015$M)	228,212	11,779	5.16%	2,741	1.20%	7,286	3.19%
Primary Energy (PJ)	9,975	-5	-0.05%	-312	-3.13%	-360	-3.61%
Electricity Generation (GWh)	642,439	4,096	0.64%	43,149	6.72%	44,870	6.98%
Final Energy Consumption (PJ)	8,212.05	-6	-0.07%	-332	-4.04%	-382	-4.65%
PP Builds (GW)	3.92	0.08	1.98%	0.86	21.96%	0.88	22.55%
Electricity Investment (2015$M)	14,546	-17	-0.12%	1,223	8.41%	1,258	8.65%
Demand Device Purchases (2015$M)	290,920	1,390	0.48%	10,958	3.77%	13,823	4.75%
Fuel Expenditures (2015$M)	184,668	-1,391	-0.75%	-20,398	-11.05%	-22,693	-12.29%
GHG Emissions (kt CO2 eq.)	324,823	-1,483	-0.46%	-33,710	-10.38%	-37,806	-11.64%

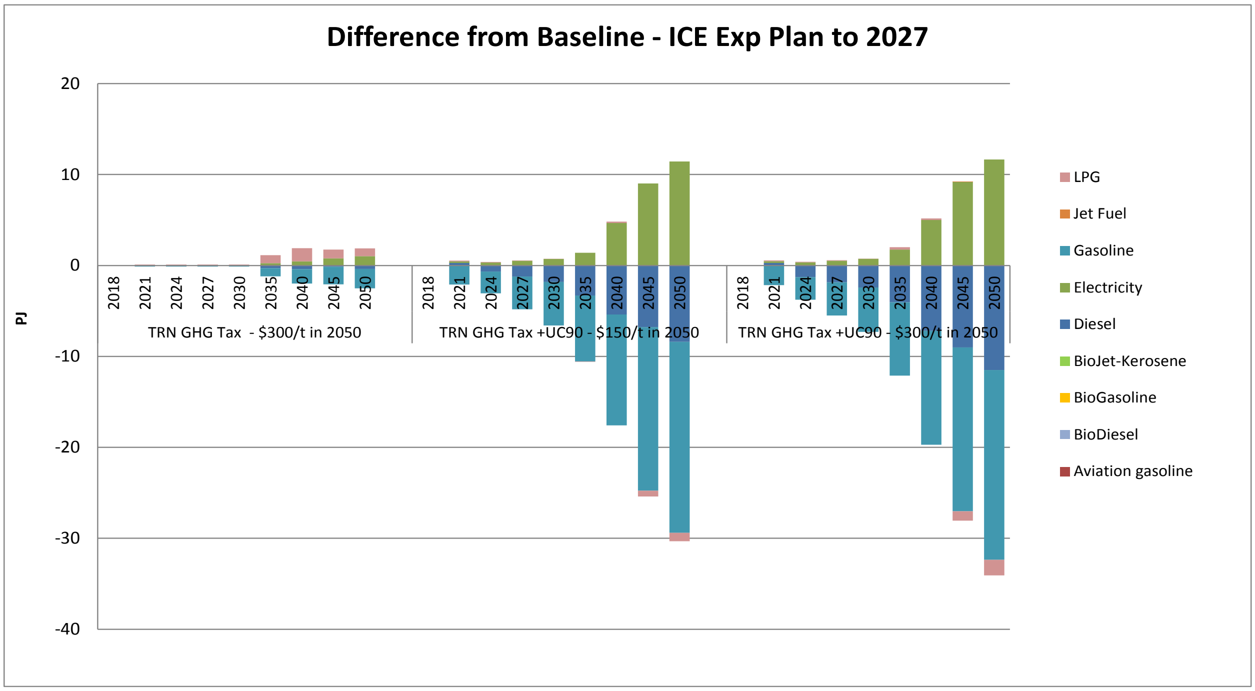


Figure 98: Change in Transport Final Energy Use compared to Baseline

E.3.4 Combined Transport Measures

Three combination scenarios for transportation are examined below. The first combines the advanced technology and mode shift measures, the second measure adds biofuels to the allowed mix of fuels, and the third adds the transport GHG levy going to $300/t in 2050. As shown in Table 62, the TRN combination run achieves almost 13% reduction in GHG emissions (42 Mt) through the implementation of advanced technology, such as hybrid and electric vehicles, and promotion of public transport measures. Interestingly, the addition of biofuels to the allowed fuel mix does not impact the results, as there is no driver to overcome their assumed 10% higher cost over traditional fuels. When the GHG levy is added in the third scenario, GHG emission reduction increase to 46Mt, but this is due to more advanced technology penetration and not due to biofuels, as can be seen in Figure 99.

Table 62: Combined Transport Measures

Metrics / Scenario	Baseline - ICE 2027	TRN Combination		TRN & Biofuels Combination		TRN, Biofuels & Levy Combination	
	Value	Difference	% Change	Difference	% Change	Difference	% Change
System Cost (2015$M)	228,212	-13,832	-6.06%	-13,832	-6.06%	-8,898	-3.90%
Primary Energy (PJ)	9,975	-452	-4.53%	-452	-4.53%	-473	-4.74%
Electricity Generation (GWh)	642,439	34,815	5.42%	34,815	5.42%	44,102	6.86%
Final Energy Consumption (PJ)	8,212.05	-456	-5.55%	-456	-5.55%	-487	-5.94%
PP Builds (GW)	3.92	0.69	17.67%	0.69	17.67%	0.81	20.61%
Electricity Investment (2015$M)	14,546	946	6.50%	946	6.50%	1,139	7.83%
Demand Device Purchases (2015$M)	290,920	-17,326	-5.96%	-17,326	-5.96%	-14,373	-4.94%
Fuel Expenditures (2015$M)	184,668	-24,177	-13.09%	-24,177	-13.09%	-27,168	-14.71%
GHG Emissions (kt CO2 eq.)	324,823	-42,045	-12.94%	-42,045	-12.94%	-46,228	-14.23%

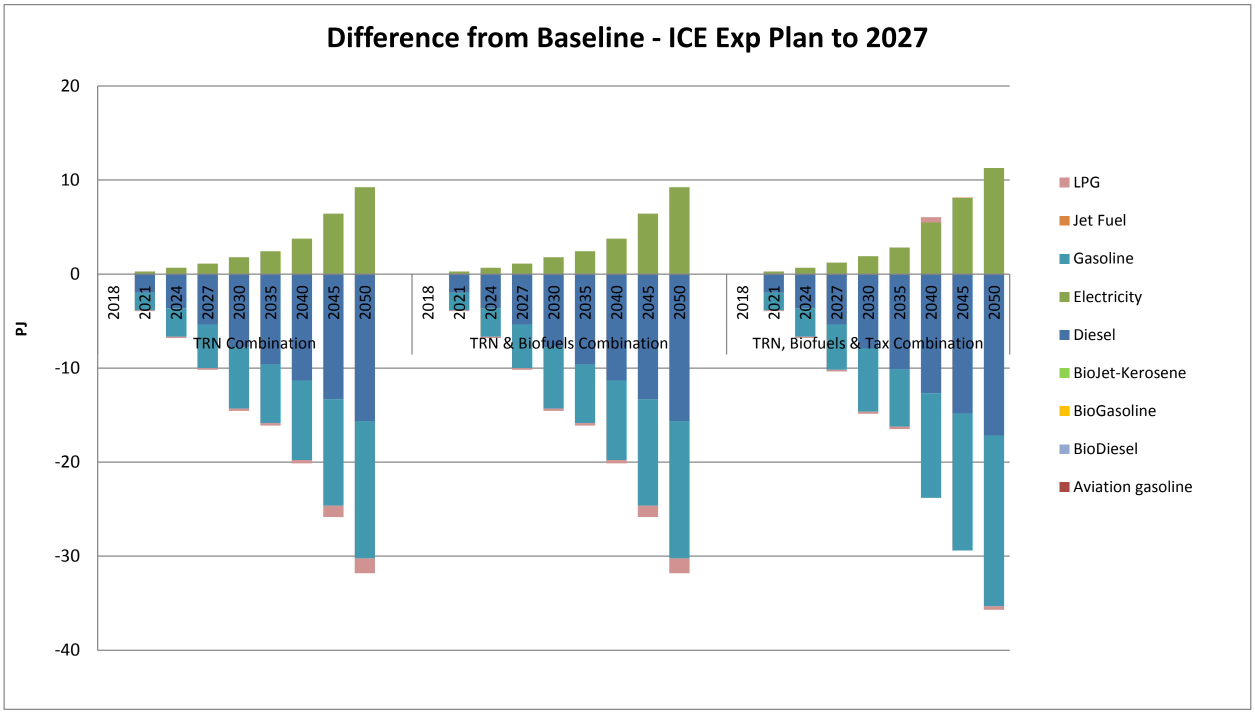


Figure 99: Change in Transport Final Energy Consumption compared to Baseline

E.4 GHG Taxes

This section examines measures to apply a GHG to the entire energy system. Two levels of levy were run. The Low GHG Levy starts at \$10 in 2021 and increases linearly to 150/t CO2 eq. in 2050, and the High GHG Levy starts \$10 in 2021 and increases linearly to 300/t CO2 eq. in 2050.

Table 63 shows the results of applying the Low levy alone, with 90% AdvTech allowed, and with 90% AdvTech and biofuels allowed. Without incentives to promote advanced demand devices, the Low GHG levy achieves modest emission reductions (4.6 Mt) but with a 3.7% increase in the energy system cost – but as noted this is not really a logical policy scenario. With advanced demand devices incentives the emission reduction increases to 59 Mt, and the energy system cost increases only 1% because of the savings inherent in the advanced technologies. As we saw previously with the buildings and industry sectors, the Low levy level does not significantly increase the use of biofuels, which is illustrated in Figure 101.

Table 63: Low GHG Levy Measures

Metrics / Scenario	Baseline - ICE 2027	Low GHG Levy (\$10-150) on All Sectors		Low GHG Levy (\$10-150) on All Sectors - 90% NT		Low GHG Levy (\$10-150) on All Sectors - 90% NT & Biofuels	
	Value	Difference	% Change	Difference	% Change	Difference	% Change
System Cost (2015\$M)	228,212	8,485	3.72%	2,200	0.96%	2,200	0.96%

Primary Energy (PJ)	9,975	-9	-0.09%	-458	-4.59%	-458	-4.59%
Electricity Generation (GWh)	642,439	14,465	2.25%	74,337	11.57%	74,337	11.57%
Final Energy Consumption (PJ)	8,212.05	-13	-0.16%	-502	-6.11%	-502	-6.11%
PP Builds (GW)	3.92	0.51	12.90%	2.01	51.36%	2.01	51.36%
Electricity Investment (2015$M)	14,546	2,251	15.48%	5,284	36.33%	5,284	36.33%
Demand Device Purchases (2015$M)	290,920	521	0.18%	9,359	3.22%	9,359	3.22%
Fuel Expenditures (2015$M)	184,668	-1,420	-0.77%	-28,218	-15.28%	-28,218	-15.28%
GHG Emissions (kt CO2 eq.)	324,823	-4,571	-1.41%	-58,966	-18.15%	-58,966	-18.15%

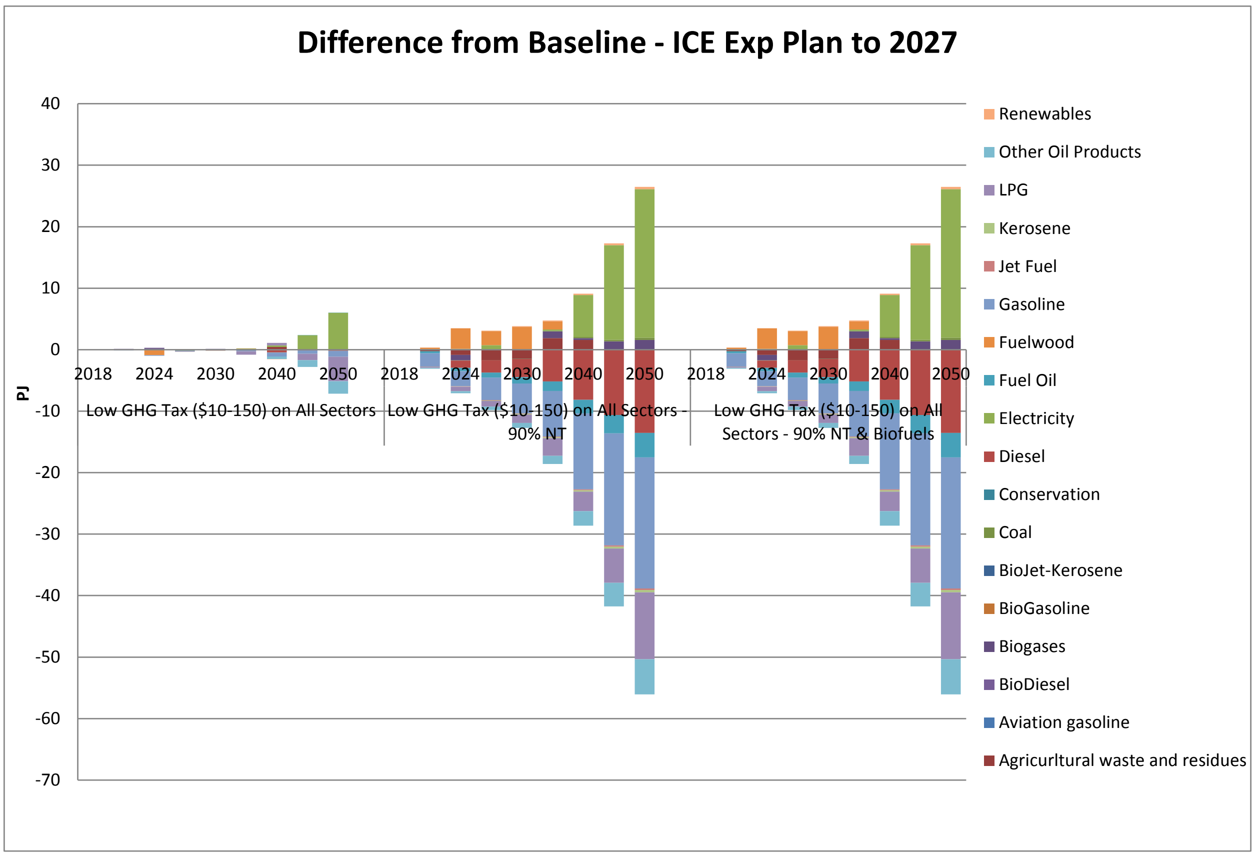


Figure 100: Change in Final Energy compared to Baseline

Table 64 shows the results of applying the High levy alone, with 90% AdvTech allowed, and with 90% AdvTech and biofuels allowed. Without incentives to promote advanced demand devices, the High GHG levy produces only 6.3 Mt of emission reductions, which is not much more than the Low levy achieved, and the energy system cost increases by 8.1%. With advanced demand devices incentives the emission reduction increases to almost 65 Mt, but the energy system cost increases by 4.5%, as the cost of emission reductions at the High levy level out-weigh the savings from cost-effective advanced demand devices. However, in this case, allowing biofuels increases the GHG emission reductions to over 72 Mt. The result is illustrated in Figure 101, and Figure 102 shows that the additi0onal emission reductions come from the Transport sector.

Table 64:High GHG TaxMeasures

Metrics / Scenario	Baseline - ICE 2027	High GHG Levy ($10-300) on All Sectors		High GHG Levy ($10-300) on All Sectors - 90% NT		High GHG Levy ($10-300) on All Sectors - 90% NT & Biofuels	
	Value	Difference	% Change	Difference	% Change	Difference	% Change
System Cost (2015$M)	228,212	18,427	8.07%	10,276	4.50%	10,265	4.50%
Primary Energy (PJ)	9,975	-12	-0.12%	-509	-5.10%	-509	-5.10%
Electricity Generation (GWh)	642,439	21,064	3.28%	82,482	12.84%	82,482	12.84%
Final Energy Consumption (PJ)	8,212.05	-14	-0.17%	-557	-6.78%	-557	-6.78%
PP Builds (GW)	3.92	0.61	15.53%	2.11	53.82%	2.11	53.82%
Electricity Investment (2015$M)	14,546	2,384	16.39%	5,738	39.44%	5,738	39.44%
Demand Device Purchases (2015$M)	290,920	1,417	0.49%	12,309	4.23%	12,309	4.23%
Fuel Expenditures (2015$M)	184,668	-2,411	-1.31%	-30,893	-16.73%	-28,697	-15.54%
GHG Emissions (kt CO2 eq.)	324,823	-6,251	-1.92%	-64,616	-19.89%	-72,253	-22.24%

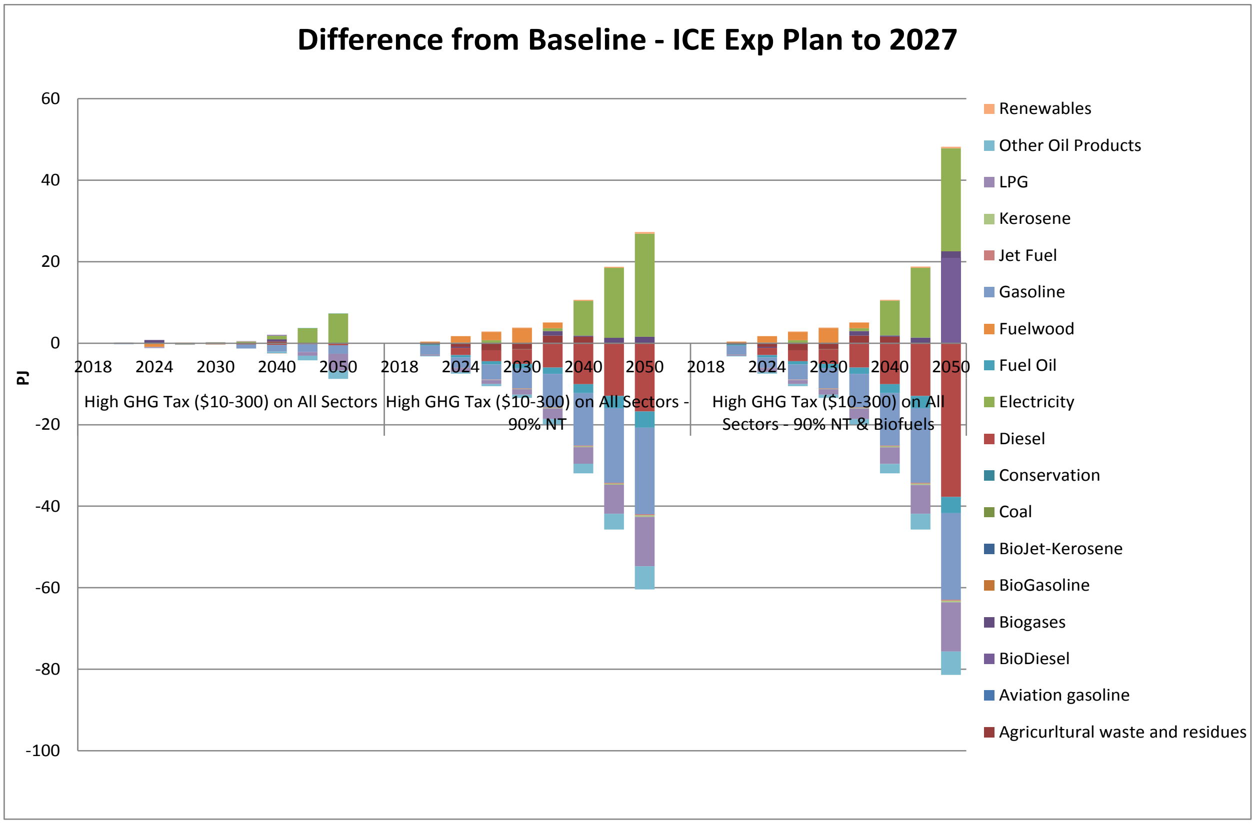


Figure 101: Change in Final Energy use compared to Baseline

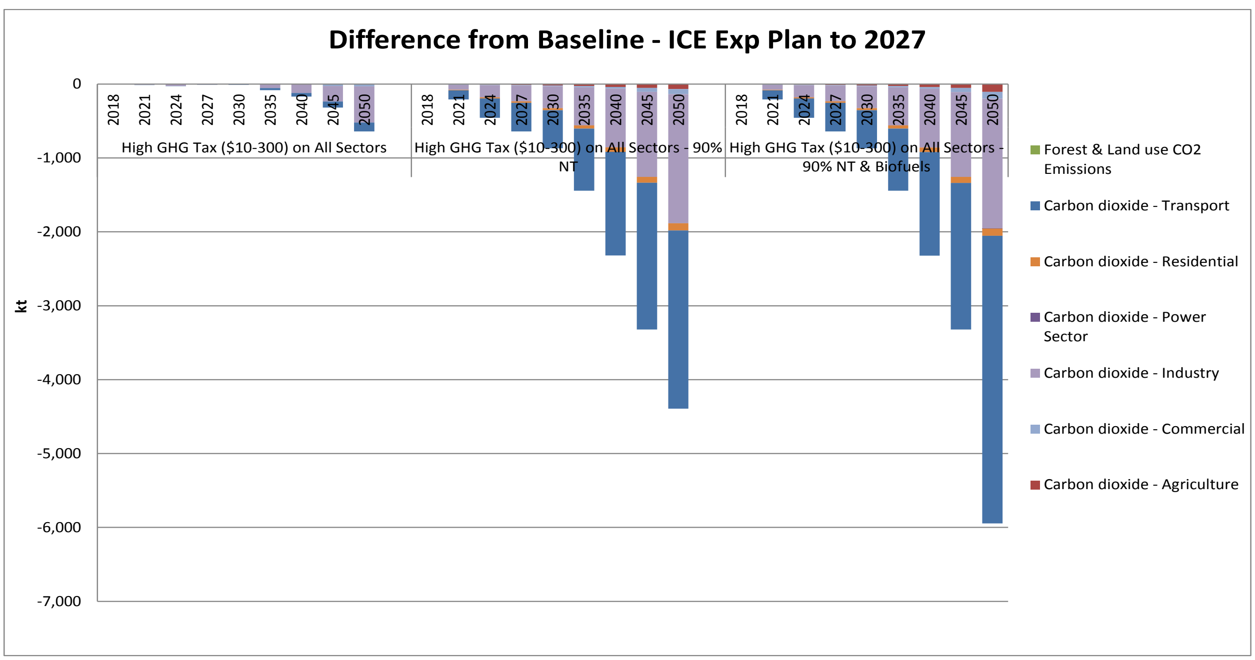


Figure 102: Change in GHG emissions compared to Baseline

E.5 GHG Targets

Three system-wide GHG emission target measures were examined – 40%, 50% and 60% below the Baseline in 2050. The 60% case represents the energy systems share of the NDC target for 2050, and the 40% and 50% cases are sensitivity analyses to understand how the energy system responds to the GHG cap. Table 65 shows the results for the 40% case without and with biofuels and 50% case with Biofuels. The 50% case without biofuels and both 60% reduction scenarios are not feasible, and are not shown, but the run results are informative. The 50% case without biofuels cannot achieve enough reductions for agriculture tractors (diesel), as well as coal and petroleum coke in industry. The 60% case without biofuels also cannot make enough reductions in conventional use for transportation. In the 60% case with biofuels, the model still lacks the ability to sufficiently reduce fuel use in 2030 for agriculture tractors (diesel), as well as coal and petroleum coke in industry.

The two 40% target cases both generate over 88 Mt in cumulative emission reductions between 2015 and 2050. However, without biofuels, the energy system cost increases almost 13% compared to a 1.5% reduction for the case with biofuels. The 50% target case with biofuels achieves over 107 Mt in emission reductions, but with an increase in the energy system cost of 5.4%.

Table 65: GHG Emission Reduction Measures

Metrics / Scenario	Baseline - ICE 2027	40% GHG Emission Reduction		40% GHG Emission Reduction -Biofuels		50% GHG Emission Reduction-Biofuels	
	Value	Difference	% Change	Difference	% Change	Difference	% Change
System Cost (2015$M)	228,212	28,621	12.54%	7,352	3.22%	12,294	5.39%
Primary Energy (PJ)	9,975	-924	-9.26%	-648	-6.50%	-757	-7.59%
Electricity Generation (GWh)	642,439	110,136	17.14%	85,968	13.38%	86,395	13.45%
Final Energy Consumption (PJ)	8,212.05	-824	-10.03%	-651	-7.93%	-719	-8.75%
PP Builds (GW)	3.92	2.48	63.17%	2.12	53.93%	2.22	56.66%
Electricity Investment (2015$M)	14,546	5,983	41.13%	5,441	37.41%	5,355	36.82%
Demand Device Purchases (2015$M)	290,920	72,512	24.93%	29,416	10.11%	38,863	13.36%
Fuel Expenditures (2015$M)	184,668	-42,968	-23.27%	-31,137	-16.86%	-30,098	-16.30%
GHG Emissions (kt CO2 eq.)	324,823	-88,159	-27.14%	-88,512	-27.25%	-107,251	-33.02%

Figure 103 shows the GHG emissions by sector and gas for these scenarios. The transport sector accounts for almost two-thirds of the reductions in 2050, and the industry sector accounts for almost one-third. The fact that the power and buildings sectors are not significant contributors to

GHG emissions results from the fact that the current power sector is primarily renewable based, and the buildings sectors primarily uses electricity.

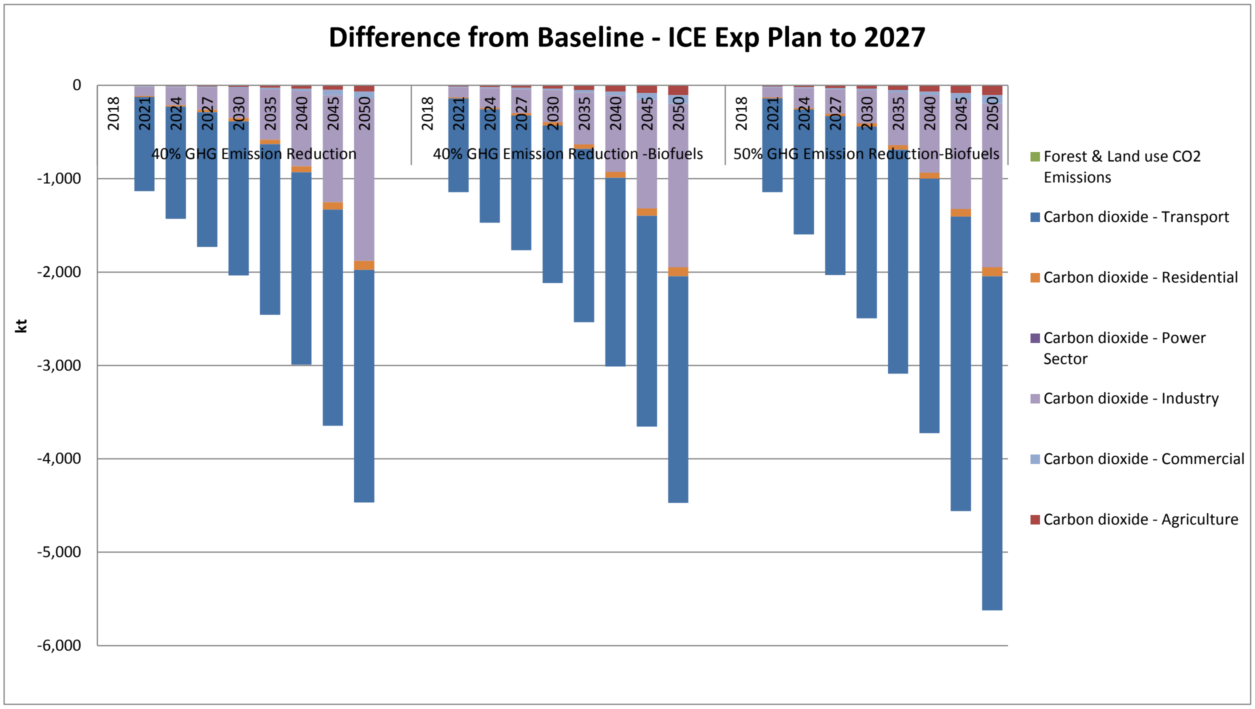


Figure 103: GHG Emissions by Sector and Change compared to Baseline

E.6 Planned and Enhanced Mitigation Measures

While it is important to analyze how individual measures affect the energy system, the individual measures interact with each other so they cannot necessarily be summed to determine the aggregate reduction that might be achieved. The TIMES-CR model properly accounts for these interactions, and in this section, we examine the combined impact of the Planned measures in the three demand sectors discussed above, and then the NDC target, biofuels option and GHG taxes are added to this combined scenario to begin the process of examining what insights the TIMES-CR model provides regarding areas where enhanced policies may be needed

Table 66 compares the results of the combined Planned policies run (All Planned Power, Efficiency & Transport Measures) with the Planned and known Enhanced measures and the combination of these measures and the 60% GHG target. The Planned policy run achieves over 103 Mt of cumulative GHG emission reductions, and reduces the energy system cost by 5.2% compared to the Baseline. The Planned and known Enhanced policies run achieves over 109 Mt in GHG emission reductions, and decreases energy system cost by 5.4%. These measures along with the 60% GHG target achieve over 139 Mt in GHG emission reductions, but increases energy system cost by 6.9%. In this case, the 60% GHG target is quite feasible, as the contributions from all the other measures make achieving the target easier. Interestingly, adding the biofuel target does not change the result for either scenario, as biofuels are already use up to their allowed limits.

Table 66: Planned and Enhanced Mitigation Measures

Metrics / Scenario	Baseline - ICE 2027	All Planned Power, Efficiency and Transport Measures		Planned & Enhanced Measures		Planned & Enhanced Measures with GHG 60%	
	Value	Difference	% Change	Difference	% Change	Difference	% Change
System Cost (2015$M)	228,212	-11,827	-5.18%	-12,392	-5.43%	15,812	6.93%
Primary Energy (PJ)	9,975	-690	-6.92%	-733	-7.35%	-1,131	-11.34%
Electricity Generation (GWh)	642,439	9,000	1.40%	17,931	2.79%	101,682	15.83%
Final Energy Consumption (PJ)	8,212.05	-702	-8.55%	-783	-9.54%	-1,040	-12.66%
PP Builds (GW)	3.92	0.66	16.84%	1.04	26.41%	2.10	53.64%
Electricity Investment (2015$M)	14,546	933	6.42%	3,878	26.66%	7,611	52.32%
Demand Device Purchases (2015$M)	290,920	-14,180	-4.87%	-12,067	-4.15%	45,938	15.79%
Fuel Expenditures (2015$M)	184,668	-19,190	-10.39%	-24,113	-13.06%	-45,575	-24.68%
GHG Emissions (kt CO2 eq.)	324,823	-103,303	-31.80%	-109,062	-33.58%	-139,344	-42.90%

The changes needed to move from the Planned policy scenario to the NDC target are examined in the next few charts in which highlight the changes between the target scenario and the Planned Policy scenario (not the Baseline scenario.)

Figure 104 shows that most of the additional GHG emission reductions must come from the transport and industry sectors. The additional needed transport sector reductions start early and the industry sector additional reductions mostly come after 2030.

Figure 105 shows the changes in final energy use that need to be achieved to reach the NDC target. The figure clearly shows that increased electricity use is needed by the demand sectors, displacing a variety of conventional fuels.

Figure 106 shows that additional electricity generation is needed from wind, biofuels and run-of-river hydropower, in addition to electric energy storage for wind and solar to meet the increased demand for electricity. The figures also show that using biofuels up to the target levels does produce incremental emission reductions.

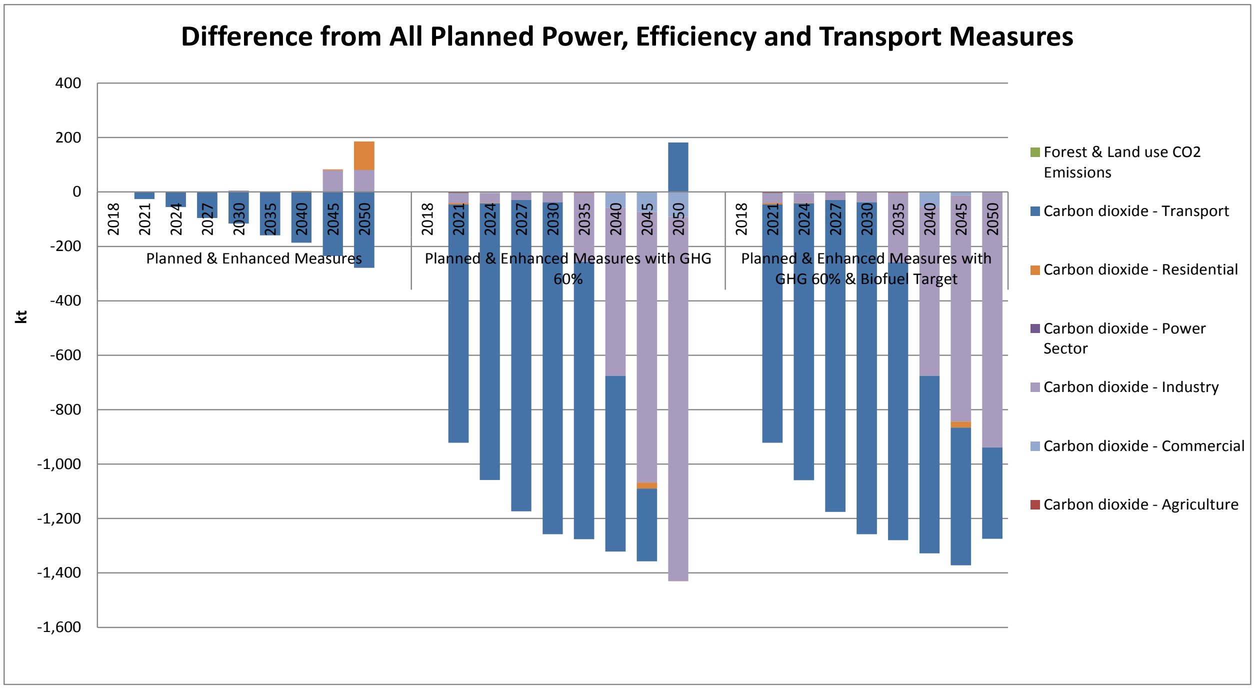


Figure 104: Change in GHG Emissions by Sector compared to Planned Policy Scenario

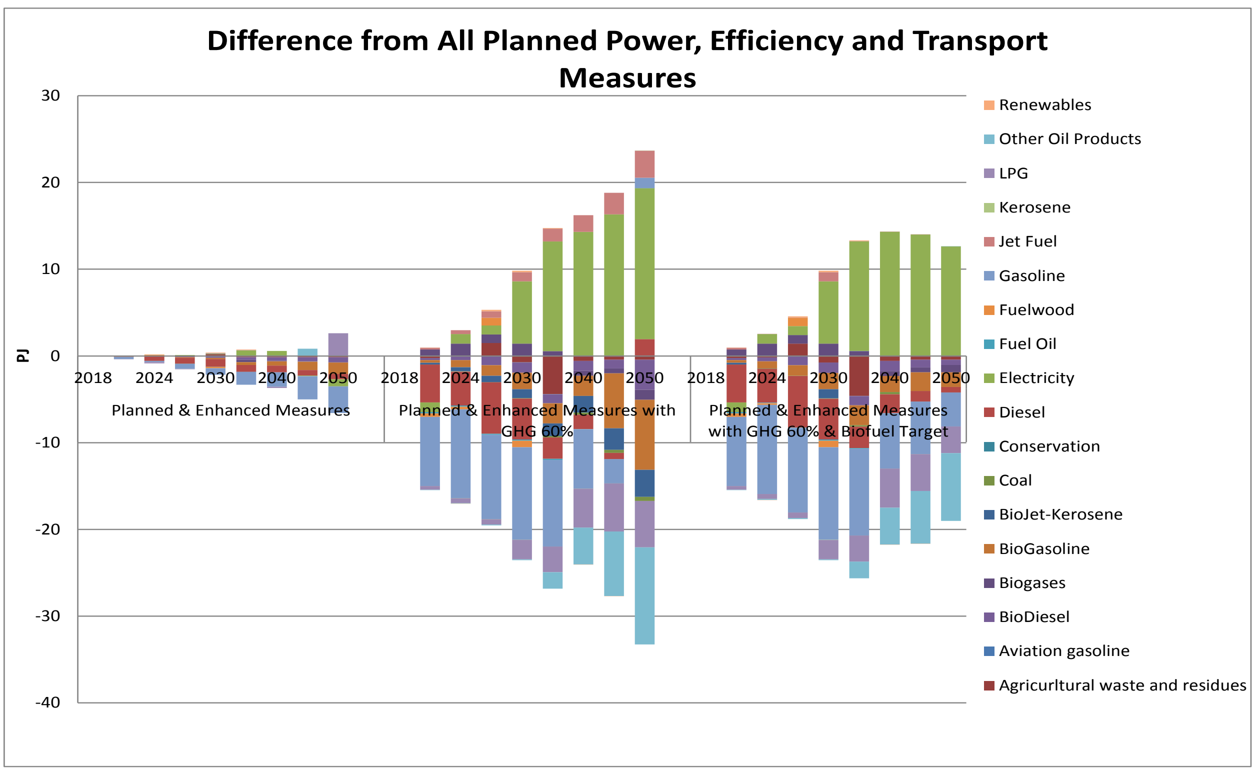


Figure 105: Change in FEC by Fuel compared to Planned Policy Scenario

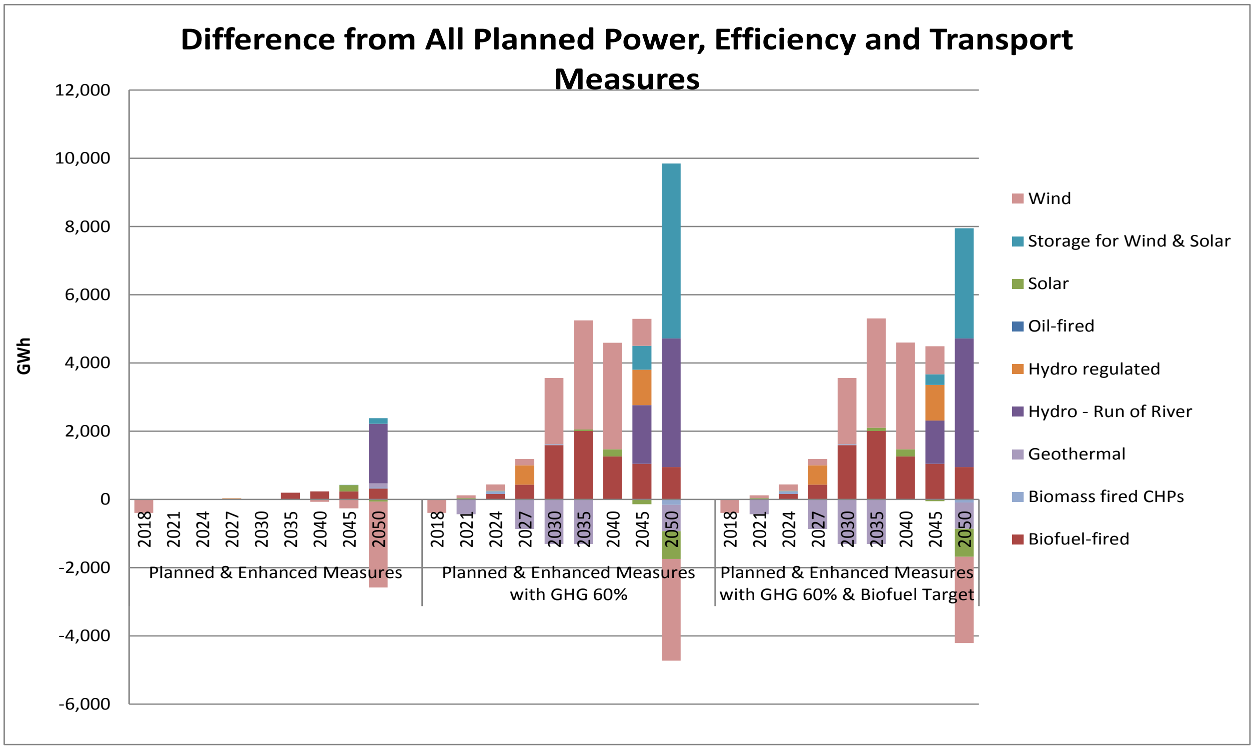


Figure 106: Change in Electricity Generation compared to Planned Policy Scenario

E.7 Example Non-Energy Mitigation Action

As the non-energy emission sectors were a secondary priority, and because data from all the sectors was not available, an example was performed using a REDD+ strategic mitigation measure that reduces deforestation and forest degradation, and fosters conservation, sustainable management of forests, and enhancement of forest carbon stocks. The annual potential reductions were estimated at 2,053,323 tCO_2 per year, with a cost of $15/t, based on the recent REDD+ Strategy, which projected 28.75 million tons of emission reductions up to 2025 based on current policy, with the possibility of additional emission reductions being achieved in the future. As there are currently no estimates after 2025, for this example, the maximum REDD+ reduction was limited to 28.75 million tons.

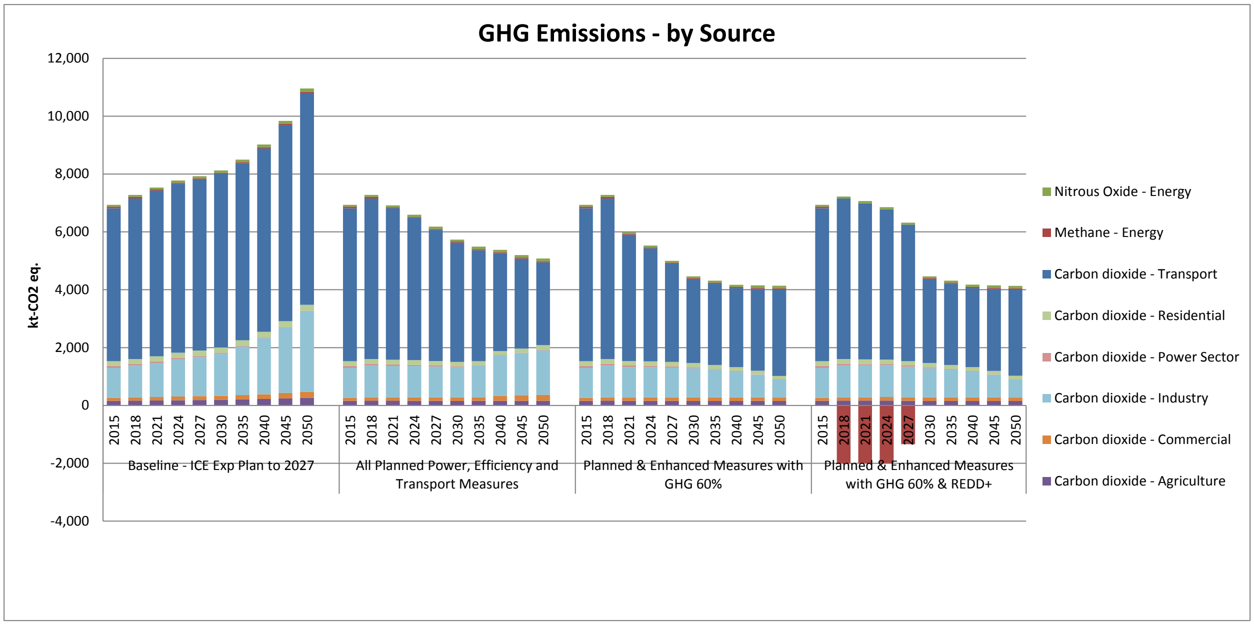
To illustrate the potential impact of this REDD+ mitigation measure, it was assumed that all the REDD+ emission reductions would offset the energy sector emissions. Given that the Forestry and Land Use sector is a net absorber of CO_2, this assumption is seen as reasonable. Table 67 contains the results metrics for the Planned & Enhanced Measures and the NDC target runs with and without the REDD+ Measure. Comparing the latter two scenarios, the addition of the REDD+ measure to the NDC target lowers the impact on the energy system cost by over $US20 B between 2015 and 2050, because net energy sector emission reductions are offset by 22.5 Mt (2018 thru 2027) of REDD+ reductions. The increases in electricity generation are similar to the NDC target case without REDD+, but the purchases for advanced end-use technologies (mostly advanced vehicles) is reduced by approximately $US30 B.

Table 67: Example Non-energy (REDD+) Mitigation Measure Impacts

Metrics / Scenario	Baseline - ICE 2027	Planned & Enhanced Measures		Planned & Enhanced Measures with GHG 60% & REDD+		Planned & Enhanced Measures with GHG 60%	
	Value	Difference	% Change	Difference	% Change	Difference	% Change
System Cost (2015$M)	228,212	-12,392	-5.43%	-4,274	-1.87%	15,812	6.93%
Primary Energy (PJ)	9,975	-733	-7.35%	-972	-9.75%	-1,131	-11.34%
Electricity Generation (GWh)	642,439	17,931	2.79%	97,143	15.12%	101,682	15.83%
Final Energy Consumption (PJ)	8,212.05	-783	-9.54%	-917	-11.17%	-1,040	-12.66%
PP Builds (GW)	3.92	1.04	26.41%	2.05	52.36%	2.10	53.64%
Electricity Investment (2015$M)	14,546	3,878	26.66%	7,709	53.00%	7,611	52.32%
Demand Device Purchases (2015$M)	290,920	-12,067	-4.15%	15,441	5.31%	45,938	15.79%
Fuel Expenditures (2015$M)	184,668	-24,113	-13.06%	-42,338	-22.93%	-45,575	-24.68%
GHG Emissions (kt CO2 eq.)	324,823	-109,062	-33.58%	-150,305	-46.27%	-139,344	-42.90%

Figure 107 shows that if these REDD+ strategic measures were fully implemented, the impact on the mitigation requirements of the energy sector would be significant between 2018 and 2027, which delays energy sector reductions that would otherwise occur, especially in the transport sector. Figure 108 shows that the REDD+ scenario implements a rather abrupt shift from gasoline to electricity in the 2030 period. This transition, primarily in the transport sector, happens more gradually in the NDC target run, as shown in Figure 109.

This transition has a relatively small impact on electricity generation requirements, as shown in Figure 110, primarily because power plant builds thru 2027 are fixed to the ICE expansion plan.



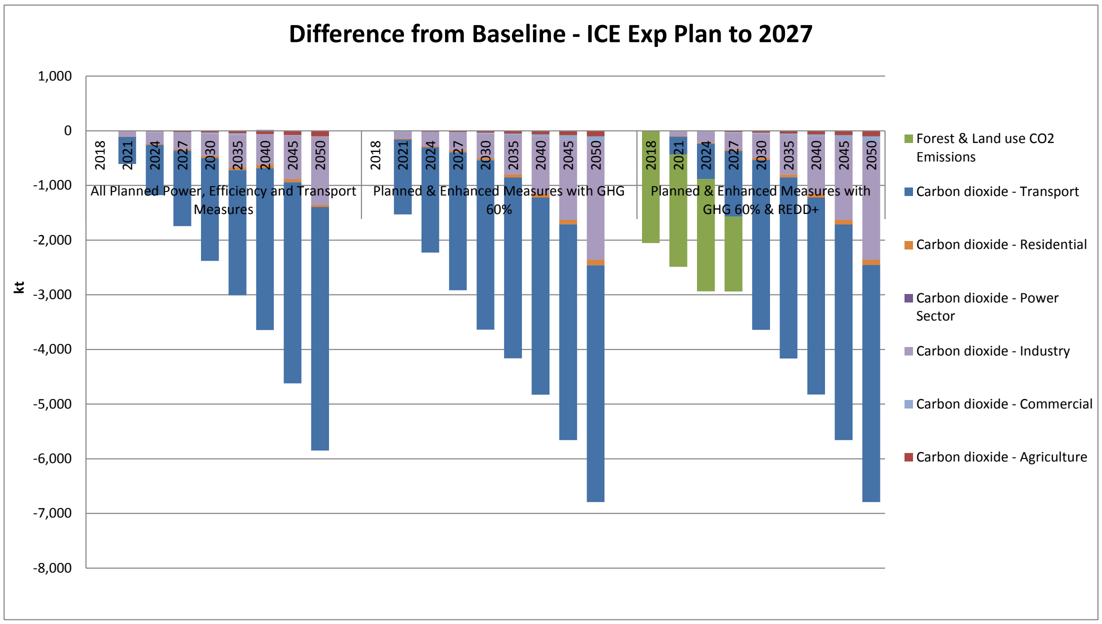


Figure 107: GHG Emissions and Change compared to Baseline Scenario

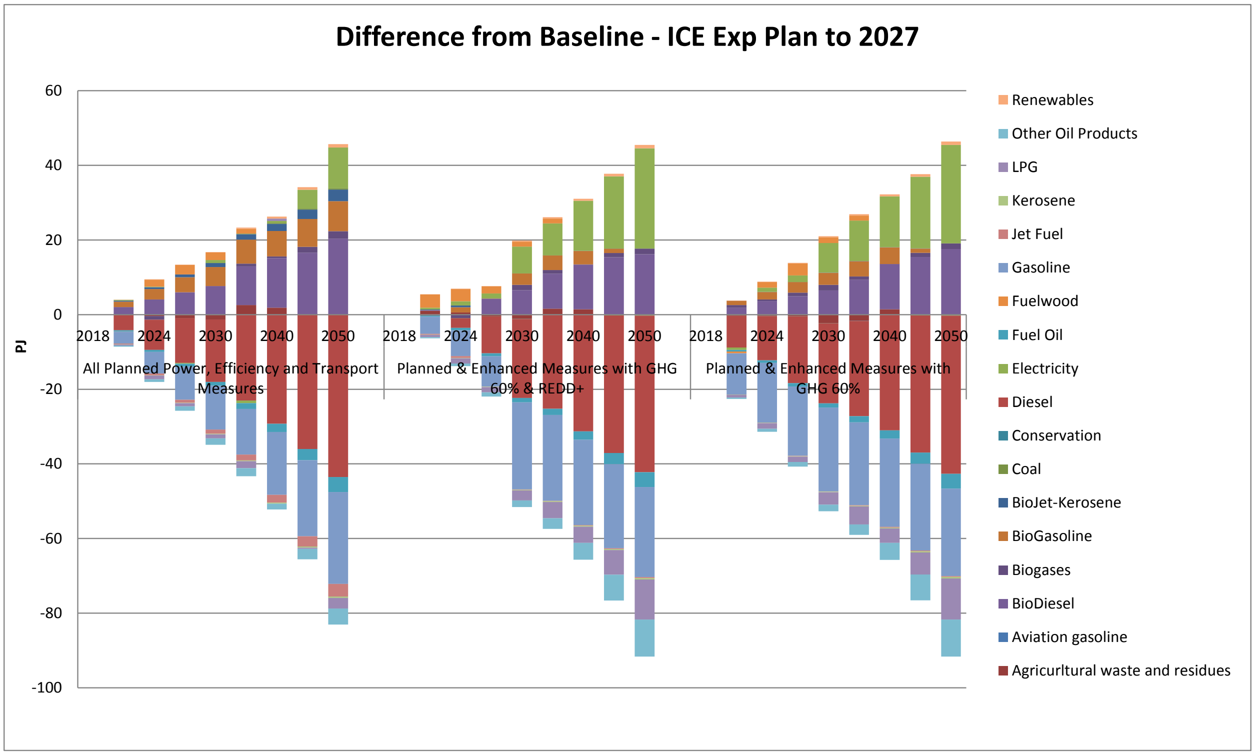


Figure 108: Change in Final Energy Consumption compared to Baseline Scenario

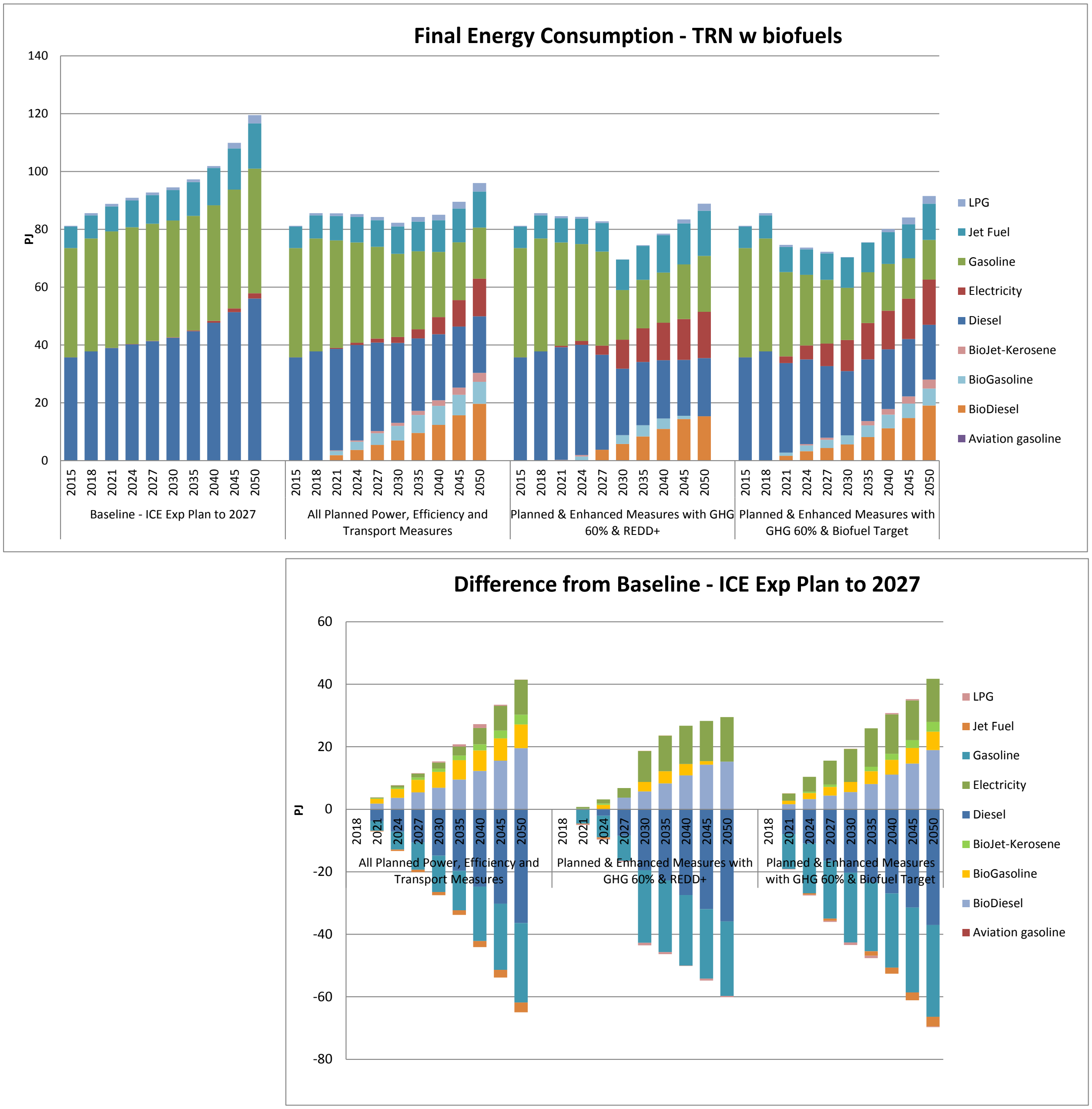


Figure 109: Change in Transport Final Energy Use compared to Baseline Scenario

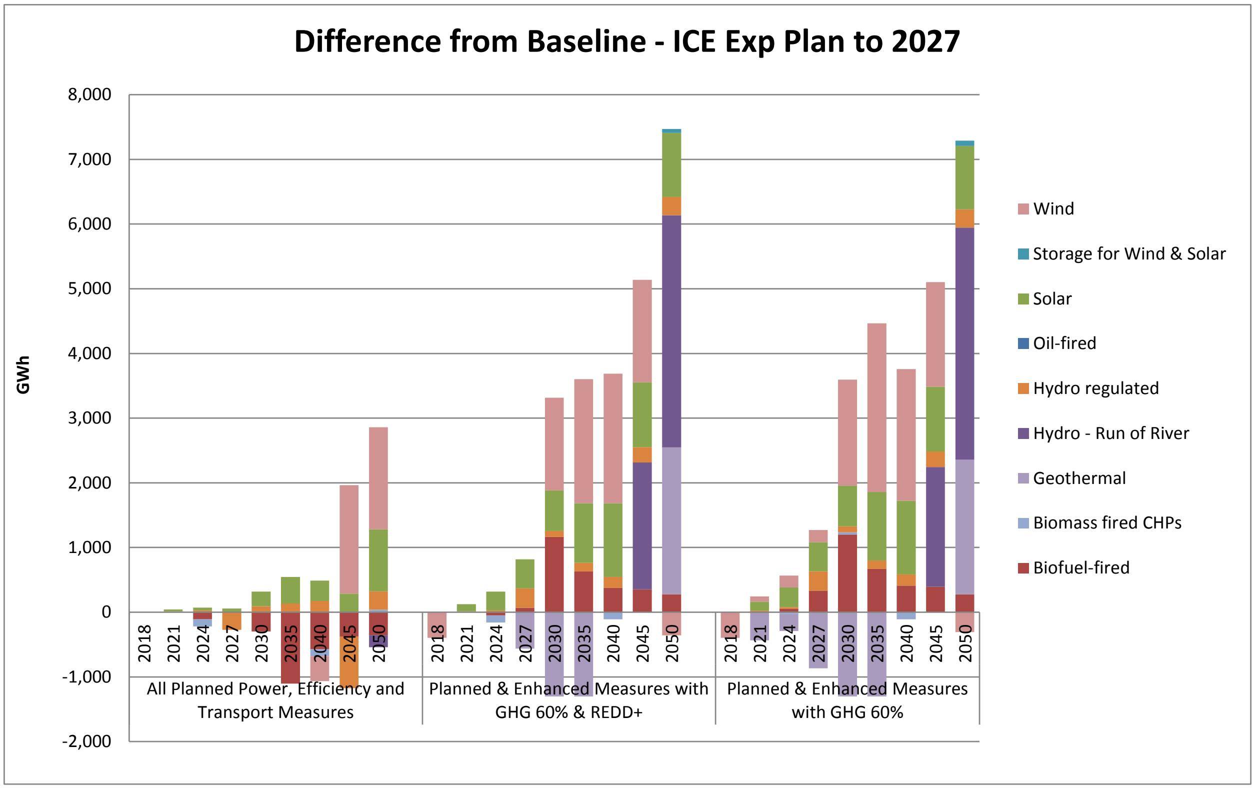


Figure 110: Change in Electricity Generation compared to Baseline Scenario