Estimation of Philippine Domestic Maritime Transportation Energy Demand

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Abstract: The domestic maritime transportation energy demand in the Philippines in 2016 is estimated using a bottom-up approach and the gaps in the available local data are identified. The transportation energy demand is estimated to be 506.94 kTOE in 2016 using ship calls data provided by the Philippine Ports Authority, and other secondary data such as energy efficiency and fuel consumption factors based on the international fleet, and estimated port-to-port distances. The effect of speed reduction and periodic hull cleaning on the future energy demand is investigated. Establishing a comprehensive data collection system for the information needed in energy demand estimation, updating the database of port distances, and developing local fuel economies to reflect actual local conditions are recommended.

Keywords: Transportation Energy Demand, Maritime Transportation, Bottom-up, Energy Efficiency, Fuel Economy

1. INTRODUCTION

Transportation has the highest energy demand out of all the energy-consuming sectors[1] in the Philippines. According to the Department of Energy (DoE) (2018), the transportation sector accounted for 34.2% of the country's total energy consumption. In 2000-2016, data reveals that the transportation sector consistently held the highest share in energy consumption[2] among all the energy-consuming sectors. Maritime transportation has the second largest energy consumption among the four modes of transport. One of the reasons for its high energy demand is that inter-island maritime transportation is the most economical way of transporting goods, especially for an archipelagic country. According to the Philippine Statistics Authority (2019), seagoing ships transport more than 99% of inter-island domestic cargo shipments.

The total final energy consumption of the transportation sector increased from 4,685 kTOE in 1990 to 11,425 kTOE in 2016. The road transport mode consistently had the largest share ranging from 77.0 to 88.2%, with an average of 83.7%, followed by the water transport mode ranging from 7.2 to 19.7%, with an average share of 12.7%. In terms of fuel, fuel oil was the dominant fuel in 1990-2008 and accounted for 40.5% - 61.2%, averaging at 51.5% of the total fuel consumption of the maritime sector. It was followed by diesel which accounted for 23.6%-37.6%,

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[1] The five sectors are transportation, industry, residential, commercial and agriculture, fishery and forestry (AFF)

[2] Except for the year 2008 where the transportation sector was overtaken by the residential sector. However, the lead of the residential sector was only at 0.4%.

with an average of 29.7%, then by gasoline ranging from 15.1 to 22.6%, with an average of 18.8%, and finally by biodiesel with less than 1% share (0.02%).

This trend had changed in 2008-2016, where diesel had displaced fuel oil as the primary fuel consumed by domestic water transport. Diesel had the largest share ranging from 43.6% to 66.1%, with a higher average of 56.8%, followed by fuel oil ranging from 17.9% to 40.6% with an average share of 29.7%, followed by gasoline ranging from 2.5% to 25.4%, with an average share of 12.9%, and at the bottom, with less than 1% share is biodiesel (0.6%).

Most of the fuel that the transportation sector consumes comprises oil and petroleum products (Department of Energy, 2018) which are vulnerable to supply disruptions, price fluctuations, and other geopolitical dynamics in oil-exporting countries. Crafting policies that ensure a reliable supply of energy for the maritime transportation sector and the transition of the sector into using renewable energy in the future requires identifying cost-effective measures through data-driven analysis. Hence, there is a strong interest in estimating and projecting the country's maritime transportation energy demand, which becomes more urgent and relevant given that the Philippines is an oil-importing and developing country (Bernardo, 2019) with a transportation sector that makes up a significant portion of the energy demand.

In pursuing this need, integrating both top-down macro-economic analyses and a bottom-up activity and technology-based modeling approach should be done. The most effective policies stem from identifying the individual energy consequences of different action plans. The bottom-up approach has the advantage of highlighting the individual effects of different policy paths and focuses attention on the options that provide the most desirable outcome.

This study aims to estimate the maritime sector's baseline energy demand and identify gaps in modeling, including the availability of data at the local, regional and national levels. This study also aims to quantify the effect of a selected policy scenario targeted towards reducing the energy consumption of the maritime transportation sector. This study will follow a methodology parallel to the ASIF approach of carbon emissions estimation from transportation of Schipper *et al*. (2009).

2. REVIEW OF RELATED LITERATURE

2.1 Studies on Related to Maritime Transport Energy Demand

Most of the Philippine maritime transportation energy demand estimates, which the Philippine Department of Energy usually carries out, have been top-down based on fuel sales[3]. A lot of work has been done to account for the energy demand of the maritime sector. However, there are still significant gaps in the available data needed for a comprehensive analysis. Regidor (2019) reported on the current ways transportation data and statistics for the four modes of transportation are produced and published. He found that the data needed for in-depth analyses like estimating transport activity and energy demand in maritime transport are not readily available.

Sigua (1986) produced one of the early estimates on the Philippine transport energy demand, which calculated the energy demand of the different modes of transportation: road, rail, sea, and air transport based on passenger and freight transport demand data in 1980. The study found that, in 1980, the total fuel consumed by domestic transport was approximately 3.6M TOE (tons of oil equivalent), and about 81% of the demand came from road transport. About 16% were

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[3] Internal consultation with DoE. The methodology of DoE is also outlined in the Energy Balance Table primer available at https://www.doe.gov.ph/sites/default/files/pdf/energy_statistics/ebt-primer.pdf

consumed by sea transport, and the remaining percentage were shared by rail and air transport. The inter-island shipping fleet performance and fleet's fuel consumption per unit of traffic from the years 1972 to 1980 were also analyzed. Fleet performance for passenger service in 1980 was about 2,300 million passenger-km. Fleet performance of freight services which consist of breakbulk, dry bulk, liquid bulk, and container services, amounted to approximately 9,300 million ton-km. The total fuel consumption for sea transport in 1980 was about 578.2 thousand TOE (kTOE) with a fuel efficiency of 51.5 GOE per ton-km and 44 GOE per passenger-km for freight and passenger transport respectively. Cargo ships accounted for about 74% of the total fleet fuel consumption, 15% for pure passenger ships, and 11% for combined passenger/cargo liners.

Bayot *et al*. (2006) updated the study of Sigua (1986) in estimating the Philippine transportation energy demand in 1997-2001 using the bottom-up approach. However, only the actual consumption of maritime transport was not evaluated in the study due to the lack of information on the fuel consumption rates of vessels. The data used for energy consumption was obtained from the Department of Energy's computation. Their results, however, were based only on petroleum products sales.

A recent study by Asia Pacific Energy Research Centre, Institute of Energy Economics, (2019) used the top-down approach for maritime transport. The intensity of freight and passenger service by mode were identified and calibrated in the periods when PKM (passenger-kilometers) and TKM (ton-kilometers) were available. The study found that if the current energy demand and supply trends and the energy policies in the Philippines remain, energy demand will double from 13 MTOE in 2016 to 26 MTOE in 2050. Consequently, the maritime sector will increase its energy demand from 0.85 MTOE to 1.9 MTOE from 2016 to 2050.

Mejia *et al*. (2017) conducted a stocktaking report on sustainable transport and climate change and reviewed studies by Japan International Cooperation Agency (JICA), Clean Air Asia, and Gota. The study found that all the available data in the Philippines on transport activity are from independent studies or projects either funded by international organizations or supported by the government. Furthermore, the Philippines neither has a standard methodology for estimating fleet-wide average fuel economy nor has officially adopted one. Mejia *et al*. (2017) added that the energy consumption estimates of the transportation sector are handled by the DoE, which they have derived from fuel sales data. A study by Schipper *et al*. (2007) pointed out that this method may not be accurate on its own due to possible tax evasion, fuel smuggling, and fuel adulteration.

Based on correspondence with the Maritime Industry Authority (MARINA), most data needed for energy demand estimation, including average trips or distance traveled per ship per route, are still in the process of compilation. The availability and completeness of these data sets are still uncertain. The Department of Transportation and Communication (2010) noted in the National Implementation Plan that there were still a lot of inadequate, if not lacking, data needed for the estimation.

2.2 Transportation Activity Data

The MARINA and Philippine Ports Authority (PPA) have been routinely collecting transportation activity data. However, its availability has been limited, and its compilation for use in energy demand estimation has only been done on an ad hoc basis. Furthermore, the data format is not centralized, i.e., data are collected and compiled by different agencies and port authorities all over the country and may not necessarily follow a standard format.

The MARINA collects transportation activity data through forms submitted by shipping companies to the agency. The records contain the total distance traveled and the number of trips made by a particular ship in one year. It also includes the utilization rate of the vessel. The agency has not done a compilation of all the filled-out forms from domestic vessels[4]. The Philippine Statistics Authority (PSA) published the Philippine Statistical Yearbook (PSY) in 2019, which summarizes ship calls, gross tonnage, and ships' lengths grouped into five major port management offices. The data accounts for the shipping activities of the domestic and foreign maritime fleet. However, PSY presents the data in aggregated format with no way to obtain information on the origin and destination of ships and the type of ships considered. A similar data from the Philippine Ports Authority (PPA) statistics report, which can be accessed through their website[5], presents a detailed assignment for shipping traffic based on ship type. The PSA cites these data as the source for the shipping statistics presented in the PSY.

The Survey on Inter-regional Passenger and Freight Flow in the Republic of the Philippines of the Japan International Cooperation Agency (JICA) and the Department of Transportation and Communications (DOTC) in 2005 produced OD tables for commodity flow per transport mode. Meanwhile, the PSA compiles and publishes data on commodities carried through the country's air, rail, and water transport systems (Philippine Statistics Authority, 2018). It gathers information on commodity movement within the Philippines to enable policymakers to monitor domestic trade. In the maritime sector, coasting manifests were collected from 45 major ports and 388 other active seaports, comprising 58.12% of the 745 ports listed by PPA all over the country. The remaining 41.88% are fishing ports which are excluded in the compilation of data.

JICA and MARINA conducted a study on maritime transport entitled, The Study on Domestic Shipping Development Plan in the Republic of the Philippines (Japan International Cooperation Agency and Maritime Industry Authority, 2005). The study used the combination of three data sources: (1) National Statistics Commodity Flow Data (2002); (2) Philippine Ports Authority Port Traffic Statistics (2003); and (3) Cebu Port Authority Port Traffic Statistics (CPA) (2003) to develop OD traffic. According to the study, the NSO (now PSA) data contains port-to-port traffic data derived from ship reports and coasting manifests. This data was used to derive a preliminary OD Matrix. The study reviewed the available information and found that the data from NSO was incomplete and did not match the data from PPA. Furthermore, the study reported that although both the PPA and CPA do not record OD information, they keep accurate records of port traffic.

JICA (2007) also conducted a study on the Development of Road RO-RO Terminal System for Mobility Enhancement in the Republic of the Philippines. The study provides valuable transport activity data of ships based on routes of domestic shipping. By combining the frequency of trips, the type of ships operating for each route, trip frequency, and their corresponding utilization weeks per year, it is possible to estimate the activity data of the domestic maritime sector accurately.

In the case of the Philippine Ports Authority (PPA) and Cebu Ports Authority (CPA), transportation activity may be derived using ship call logs collected from all port offices in the country. The port calls data must be paired with distances of the corresponding port segment pair where the port calls were made. Although the data cannot be used to establish an origin-destination matrix, it gives an insight into the segmented port-to-port trips made by ships when traveling long-distance routes. These port-to-port trips can be combined with a database containing all port-to-

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[4] MARINA internal consultation

[5] A compiled statistics per quarter, as well as the total annual shipping statistics may be accessed through https://www.ppa.com.ph/?q=content/statistics-1

port distances to determine the actual transportation activity of the domestic maritime sector. The National Mapping and Resource Information Authority (NAMRIA) has compiled a list of domestic shipping routes and their corresponding distances. However, not all the port segment pairs in NAMRIA's list match the port call logs from PPA. Finally, the distances compiled from NAMRIA have not been regularly updated, i.e., some distances are manual chart plots and estimations of cartographers[6] and may have a significant difference in the distance compared to plots using modern mapping software. Therefore, although the CPA and PPA's data have been the most complete form of available transportation activity data, it could take a lot of time and effort to process it into something useful for energy demand estimation.

2.3 Fuel Efficiency

Republic Act No. 11285, or the Energy Efficiency and Conservation Act, promotes energy efficiency and the reduction of wastage in energy use, including in the transport sector, to secure energy sufficiency and stability for the Philippines. This is in parallel with the Marine Environment Protection Committee (MEPC) decision to implement a mandatory collection of fuel consumption data for ships[7], one of the energy efficiency measures that the International Maritime Organization (IMO) wants to implement in 2018. The biggest challenge in implementing the provisions of this act is the lack of fuel efficiency data. So far, there has been no public record of any form for ship fuel efficiency, nor have been local studies attempting to measure the fuel economy of ships in the country.

According to the Philippine Department of Transportation (DOTr), the Philippine domestic shipping fleet is primarily composed of aging ships[8] which consists of secondhand vessels imported mostly from Japan. Since the age of a ship dramatically affects its fuel efficiency, the measurement and updating of a fuel efficiency database becomes necessary.

Although there are indications that more attention is given to the collection of fuel consumption and fuel efficiency data[9], records from MARINA only show an individual ship's total annual fuel spending. It would be impossible to accurately translate those records into fuel efficiency, given that the price of fuel fluctuates very frequently in a given year. Furthermore, ship owners and operators may not be totally on board with the idea as it would mean additional costs. There has been no publicly available compilation of data on the fuel efficiency of the Philippine domestic marine vessel fleet. Alternative methodologies for a bottom-up energy demand estimation require information about the installed power of ships. However, this type of data is also not compiled.

The closest fuel economies for ships compiled were from a study conducted in Fiji, an archipelagic country like the Philippines. The study further subdivided the ship types by the length of the hull. When ships were more than 15 m., it is assumed that they used marine diesel oil (MDO) as fuel, while ships less than 15 m. are taken to operate mainly on premix fuel (Prasad and Raturi, 2019).

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[6] NAMRIA correspondence email

[7] https://sdg.iisd.org/news/imo-approves-mandatory-fuel-consumption-data-collection-for-ships/

[8] Department of Transportation and Communication (2010). Philippines National Implementation Plan (NIP) on Environment Improvement in the Transport Sector. Page 35

[9] MARINA Press Release. Obtained from: https://marina.gov.ph/2019/12/19/domestic-shippers-encouraged-to-start-creating-transition-plan-for-imo-2020-global-sulfur-cap-implementation/

2.4 Fleet Characteristics

According to the MARINA[10], the Philippine domestic merchant fleet comprised of 14,336 vessels in 2016; MARINA categorized the fleet as 63% (or 9,056) passenger vessels, 27% (or 3,926) are cargo ships, and 2% (or 290) of which are tankers. A report from MARINA (2018) used a slightly different categorization to disaggregate the fleet data. Passenger vessels are now disaggregated into conventional, RORO, and fast craft. In contrast, cargo ships are disaggregated into solid and liquid cargo, with the tanker category used in 2016 incorporated into those two.

The ship calls data from PPA also uses different ship categories from the ones used by MARINA. Compilation of data collected from different agencies, especially when considering more than one year's worth, can be a challenge when no universal ship categories are in place across all maritime sector agencies. This is also very problematic since transport activity data and fuel efficiency data are also dependent on the ship categories considered.

3. METHODOLOGY OF TRANSPORTATION ENERGY DEMAND ESTIMATION

3.1 Baseline Maritime Transportation Energy Demand Estimation Methodology

The energy demand of domestic maritime transportation is estimated from shipping movement data for individual ships and default values for engine power per ship type, average cruising speed and average duration for maneuvering and hoteling, and available and estimated port-to-port distances. Since data for fuel efficiency per ship is not available, a streamlined power-based calculation is adopted. The energy demand is calculated by summing the energy demand of vessel trips. Three operational phases are considered for each trip: cruising phase, maneuvering phase, and hoteling phase. The energy demand of a trip is computed using equation 1:

$$E_{\mathrm{trip}} = E_{Cruising} + E_{Maneuvering} + E_{Hoteling} \tag{1}$$

The energy consumption for each navigation phase is calculated as:

$$E_i = T_i \sum_{\mathrm{j}} \left(MCR_{ME,j} \times LF_{ME,i}\right) + \left(MCR_{AE,j} \times LF_{AE,i}\right) \tag{2}$$

where:

i : the navigation phase (cruising, maneuvering or hoteling)
j : ship type
E_i : energy consumption for operational phase i (kWh)
T_i : time in phase i (hours)
$MCR_{ME,j}$: main engine nominal power for ship type j (kW)
$LF_{ME,i}$: main engine load factor for the phase i
$MCR_{AE,j}$: auxiliary engine nominal power for ship type j (kW)

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[10] As cited in the preface of the Philippine Coast Pilot Book by National Mapping and Resource Information Authority (NAMRIA) in 2020

$LF_{AE,i}$: auxiliary engine load factor for phase i

The shipping movement data came from the Philippine Ports Authority (PPA) and Cebu Port Authority (CPA). PPA and CPA maintain a database of all domestic and foreign ship calls for ports in the Philippines. The data considered for the study were the domestic ship calls for the year 2016. The domestic ship calls were determined as having their last port of call and current port of call within domestic ports only (European Environmental Agency, 2019; IPCC, 2006).

Ship calls data for small fishing vessels with wooden hulls were limited, and military vessels were not included. Data for pleasure crafts and yachts were limited but included in the calculations. The analysis was done per trip segment, i.e., from the last port of call to the current port of call, and did not distinguish between different types of intermediate stops. For long-distance routes with multiple stops, each stop becomes a single trip segment. For example, if a hypothetical route were to depart from Manila, make a stop at Dumaguete, and finally arrive at Zamboanga, the trip is broken down into two trip segments (Manila – Dumaguete, and Dumaguete – Zamboanga). Only the trip segment from the last port of call and the current port of call was considered to avoid double-counting of ship activity. All trip segments from the current port of call to the next port of call were not counted as they were assumed to be captured in the ship calls made in the next port of call.

Each phase corresponds to different navigation and operation characteristics in a typical vessel trip. The time in the cruising phase can be calculated as in equation 3 with the average cruising speed per ship type presented in Table 1. On the other hand, the maneuvering and hoteling phase time may be derived from the PPA data, including waiting and servicing times for each ship call entry. However, due to missing data entries and concerns on data quality, default average maneuvering and hoteling times for each ship type presented in Table 1 were used.

$$T_{\text{cruising}}(\text{hours}) = \frac{\text{Port to Port Distance (km)}}{\text{Average Cruising Speed (km/hr)}} \tag{3}$$

Table 1. Average cruising speed and average duration of maneuvering and hoteling phases

Ship Categories	Average Cruising Speed (km/hr)	Average Maneuvering Time (hours)	Average Hoteling Time (hours)
Liquid Bulk	26	1	38
Dry Bulk	26	1	52
Container	36	1	14
General Cargo	23	1	39
RoRo Cargo	27	1	15
Passenger	39	0.8	14
Fishing	25	0.7	60
Other	20	1	27
Tugs	23.8	1.7	8

Source: Entec (2002) for Tugs and European Environmental Agency (2019) for others
Note: European Environmental Agency (2019) values were also derived from Entec (2002)

Each phase is associated with a specific engine load related to that phase's typical level of activity. Although there are differences in each vessel's operational characteristics for each phase, the combinations of engine loads for the main engine and auxiliary engine allow for an approximate characterization of the typical vessel activity for each phase (Entec, 2002). The load factors for the main engine, auxiliary engine, and time in phase are presented in Table 2.

Table 2. Estimated % load of MCR (Maximum Continuous Rating) of main and auxiliary engines for different operation phases

Phase	%Load of MCR Main Engine	% Time all Main Engine Operating	% Load of MCR of Auxiliary Engine
Cruise	80	100	30
Maneuvering	20	100	50
Hoteling (except tankers)	20	5	40
Hoteling (tankers)	20	100	60

Source: Entec (2002)

The National Mapping and Resource Information Authority (NAMRIA) has compiled 4,503 port-to-port distances for all ports in the Philippines. The information about the previous port of call and the current port of call for each ship contained inside the ship call logs is matched with a corresponding distance from the port-to-port distance database. This distance is assumed to be the course taken by the ship during the cruising phase. It was also assumed that the distance between any two ports would remain constant regardless of the sailing direction. It was found that although the NAMRIA list includes the majority of the ports, there were segments of the ships' movement data from PPA that were not in the NAMRIA database. To bridge gaps in the data, additional entries for sailing routes not included in the original database were added as each entry was processed, assuming that the ship would sail along the shortest distance between ports.

Using the Measure Distance feature of Google Maps, the assumed route is traced, and careful attention was given so that the route does not directly cross any form of landmass along its path (i.e., the route stays in the water). Once the course has been defined, the distance is noted, and a screenshot is taken to record the path. A sample screenshot is presented in Figure 1. In the figure, the manual sailing route defined using the measure distance feature can be seen as the white line with open circles, while the automatic distance given by Google Maps is seen as the blue line. This process is repeated for all port-to-port distances that were not included in the NAMRIA database. Another challenge encountered during this process was that the data of two government agencies, PPA and NAMRIA, used different codes or port names to identify port-to-port distances.

Measure distance
Click on the map to add to your path
Total distance: 670.36 km (416.54 mi)

Figure 1. Assumed route for El Nido, Palawan to Albuera, Leyte

Source: Google Maps

The gross registered tonnage (GRT) information from the PPA port call log is used to estimate the ship's gross tonnage (GT). The GT is used to calculate the installed main engine power for each ship. The ship type of an individual entry in the ship calls data is crucial. However, since there are more than 100 identified ship types from the PPA data, PPA ship types must be reconciled with the ship categories from the 2010 Lloyd's Registry data elaboration by Trozi (2010). The ships are broken out into the type of cargo they carry, as in Table 3. Representative ships from each identified ship type from the PPA data are used to determine the general category of the PPA ship type.

Installed engine power for the main engine is calculated using the regression functions for each ship type, as presented in Table 3. The installed auxiliary power can then be derived from the installed main engine power using the average vessel ratio of Auxiliary Engine / Main Engine by ship type, as shown in Table 3. These engine ratios were also derived from the 2010 Lloyd's Registry data (European Environmental Agency, 2019; Trozi, 2010).

Table 3. Ship Types Used for Energy Demand Calculations

Ship Type	Description	Installed main engine power (kW) as a function of gross tonnage (GT), 2010 World Fleet	Estimated average vessel ratio of Auxiliary Engine/Main Engine by Ship Type, 2010 World Fleet
Liquid Bulk Ships	Self-propelled liquid-cargo ships, including chemical tankers, oil tankers, and other petroleum tankers	$kW = 14.755*GT^{0.6082}$	0.30
Dry Bulk carriers	Self-propelled dry-cargo ships that carry loose cargo, including bulk carriers, cement and aggregate carriers, etc.	$kW = 35.912*GT^{0.5276}$	0.30
Container	Self-propelled cargo ships that carry containerize cargoes.	$kW = 2.9165*GT^{0.8719}$	0.25
General Cargo	Self-propelled cargo ships that carry a variety of dry cargo	$kW = 5.56482*GT^{0.7425}$	0.23
RoRo Cargo	Self-propelled ships that handle cargo that is rolled on and off the ship	$kW = 164.578*GT^{0.4350}$	0.24
Passenger	Self-propelled ships that transport passengers from one port to the other	$kW = 9.55078*GT^{0.7570}$	0.16
Fishing	Steel hulled, self-propelled ships used for fishing activities	$kW = 9.75891*GT^{0.7527}$	0.39
Tugs	Self-propelled tugboats and towboats that tow/push cargo or barges in the open ocean	$kW = 54.2171*GT^{0.6420}$	0.10
Other	All other ships that do not belong in the previously listed categories. Ships with unidentified ship types are also put in this category	$kW = 59.049*GT^{0.5485}$	0.35

Source: Adopted from European Environmental Agency (2019), US Environmental Protection Agency (2009), IPCC (2006), and Trozzi (2010)
Note: conversion used was 1GT = 1.875 GRT

The fuel type used by each ship is also an essential factor to consider. However, the data on the type of fuel used by the domestic fleet is not available. Available information on engine type for each ship is also not included in the local ship registry. In this case, the energy demand for each ship category in kWh is disaggregated into engine speed and fuel type combinations using default international values in Table 4. The energy estimated for each ship category in kWh is multiplied to the specific fuel consumption (SFC) according to ship engine/fuel type and phase. The SFCs are presented in Table 5.

Table 4. Percentage of installed main engine power by engine type/fuel class (2010 fleet)

Ship Category	SSD MDO/MGO	SSD BFO	MSD MDO/MGO	MSD BFO	HSD MDO/MGO	HSD BFO	GT MDO/MGO	GT BFO
Liquid Bulk	0.87%	74.08%	3.17%	20.47%	0.52%	0.75%	0%	0.14%
Dry Bulk	0.37%	91.63%	0.63%	7.29%	0.06%	0.02%	0%	0%
Container	1.23%	92.98%	0.11%	5.56%	0.03%	0.09%	0%	0%
General Cargo	0.36%	44.59%	8.48%	41.72%	4.30%	0.45%	0%	0.10%
RoRo Cargo	0.17%	20.09%	9.86%	59.81%	5.57%	2.23%	2.27%	0.00%
Passenger	0.00%	3.81%	5.68%	76.99%	3.68%	1.76%	4.79%	3.29%
Fishing	0.00%	0.00%	84.42%	3.82%	11.76%	0.00%	0%	0.00%
Other	0.48%	30.14%	29.54%	19.63%	16.67%	2.96%	0.38%	0.20%
Tugs	0.00%	0.00%	39.99%	6.14%	52.81%	0.78%	0.28%	0.00%

SSD - Slow Speed Diesel, MSD – Medium Speed Diesel, HSD - High-Speed Diesel, GT – Gas Turbine, ST – Steam Turbine; MDO –Marine Diesel Oil, MGO –Marine Gas Oil, BFO –Bunker Fuel Oil
Source: European Environmental Agency (2019) and Trozzi (2010)

Table 5. Specific fuel consumption for different engine types/fuel combinations and vessel trip phases (cruising, maneuvering, hoteling) in g/kWh

Phase	Engine Type	Fuel Type	Specific Fuel Consumption (g fuel/kWh)
Cruise	Gas Turbine	BFO	305
		MDO/MGO	290
	High-speed diesel	BFO	213
		MDO/MGO	203
	Medium-speed diesel	BFO	213
		MDO/MGO	203
	Slow-speed diesel	BFO	195
		MDO/MGO	185
Maneuvering and Hoteling	Gas Turbine	BFO	336
		MDO/MGO	319
	High-speed diesel	BFO	234
		MDO/MGO	223
	Medium-speed diesel	BFO	234
		MDO/MGO	223
	Slow-speed diesel	BFO	215
		MDO/MGO	204

BFO –Bunker Fuel Oil, MDO –Marine Diesel Oil, MGO –Marine Gas Oil
Source: European Environmental Agency (2019)

Finally, the transport activity is the sum of all port-to-port distances (equation 4).

$$A = \sum PPD_{trip} \tag{4}$$

where:

A : total transport activity in ves-km of all trips associated to the port of call

PPD : port to port distance derived from NAMRIA database using the information about last port of call and current port of call on the ship call log

3.2 Policy Scenarios on Maritime Transportation Energy Demand

Policy scenarios are selected from existing policies and developed based on the review of local and international project studies to reduce energy consumption in maritime transportation. The base year of the study of 2016 is chosen because this is the last year in the energy compendium of energy statistics, and data on socio-economic indicators are close to the 2015 census results. Business-as-usual (BAU) and low-fuel consumption scenarios for maritime transport were developed from 2016-2040.

The average GDP growth rate of the Philippines from 2009-2019 was 5.95%[11]. An increase in GDP is invariably accompanied by an increase in transportation activity and, consequently, energy consumption. The growth rates for the economy and energy are also related, such that the energy demand grows rapidly for countries with high economic growth. However, the level of economic activity does not account for all changes in energy consumption.

Trends in maritime transport energy consumption indicate a high correlation between energy growth and economic growth. Based on a report by the United Nations Conference on Trade and Development (UNCTAD) in 2016, the long-term sea trade to GDP elasticity was estimated to be 0.7 in 2008-2013. Combining this elasticity with the average GDP growth rate, maritime transport activity was assumed to grow at 4.16% from 2021-2040.

Many measures can be used to reduce the energy consumption of ships. These can come from the technical, operational, and financial sides (Gusti and Semin, 2018). Technical mitigations could mean more efficient engine and ship design for new ships or modifications and optimizations in the existing engine. Operational mitigations can include speed optimization, route optimization, weather routing optimization, fleet optimization, and other measures that improve energy efficiency or reduce the energy consumption of ships' day-to-day operations. Finally, financial mitigations can include government policies that could give financial incentives to ship owners that operate more energy-efficient ships (RA No. 11285).

A common logistical mitigation is speed reduction in ships. By lowering the vessel's speed, fuel consumption and ship emissions are expected to be reduced. In the rule of thumb, the main engine power output requirements approximate a cubic function between the ship service speed and ship design speed (ICCT, 2011). When a ship reduces its speed by 10%, engine power will be reduced by 27%. When sailing at a lower speed, at the same distance, the sailing time will be longer, and the net effect on emissions is a second-power reduction; hence, a reduction of speed by 10% roughly equates to a decrease in shaft power by 27% and an energy saving of 19% (IMO, 2009).

According to the International Council on Clean Transportation (ICCT) report in 2011, speed reduction has the most considerable reduction potential, with moderate cost among all 15

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[11] https://psa.gov.ph/sites/default/files/Annual-1946-to-2020.xlsx

reviewed mitigations. The study found that a fuel savings of 15%–19% was observed for a 10% speed reduction and 36–39% for a 20% speed reduction. Lindstad et al. (2011) showed that speed reduction results to 19–28% reduction in emissions. Hence, a conservative 15% improvement in fuel economy is used for the cruising phase for modeling this mitigation. Speed reduction was not applied for passenger ships, tugs, and other sea vessels as it may affect their everyday operations and cause port inefficiencies.

An energy mitigation measure related to speed reduction is hull cleaning. The ship's hull becomes fouled (with marine biological growth) after being in operation for some time (ICCT, 2011). This increases the frictional resistance of the ship, and in turn, leads to increased fuel consumption. The easiest method to reduce the effect of surface roughness viscous resistance is to keep the hull clean and free of barnacles and underwater grasses. Periodic hull cleaning removes hull fouling, and as a result, reduces the hull's frictional resistance and increases the ship's fuel efficiency.

Although it is clear that routine hull cleaning improves energy efficiency, it isn't easy to quantify its energy-saving effects due to time-varying factors on fuel consumption like speed, wind direction, and wave and weather conditions during the voyage. ICCT (2011) has assumed a 1-10% fuel savings due to hull cleaning. Another study by Adland et al. (2018) found that hull cleaning performed while the ship is dry-docked can reduce fuel consumption by as much as 17%, while underwater hull cleaning reduced fuel consumption by 9%. The modeling of the policy scenario has adopted a 10% savings in energy demand, applied to all ship types, and only in the cruising phase.

As policies are introduced, it usually takes some time before all operators comply. This policy maturation occurs gradually and must be characterized in the modeling process (ICCT, 2011). The study captured this effect by assuming that policies for energy mitigation would penetrate the maritime fleet at 5% per year, starting in 2021 to 100% in 2040. Table 6 shows the summary of policy scenarios with their corresponding assumptions.

Table 6. Description of policy scenarios

Policy Scenario	Assumptions
BAU	For each type of vessel, the activity ves-km increases annually at an assumed rate of 4.16% until 2040
Vessel Speed Reduction	Optimization of speed for container vessels, Ro-Ro vessels, and general cargo vessels to reduce fuel consumption. Assume 5% of transport activity change in 2021 up to 100% in 2040
Hull Cleaning	Routine hull cleaning is done for all ship types to reduce fuel consumption during the cruising phase. Assume 5% of transport activity change in 2021 up to 100% in 2040

4. BASELINE MARITIME TRANSPORTATION ENERGY DEMAND

4.1 Domestic Maritime Transportation Activity

A breakdown of the 2016 ship calls per port management office clusters is presented in Table 7. Most ship calls were from the Southern Mindanao PMO cluster with 130,118 ship calls (30.89%). This is followed by the South Luzon and Visayas PMO clusters which had 113,859 ship calls (27.01%) and 100,202 ship calls (23.77%), respectively. These areas have a relatively high number of ship calls because most ship calls are from ships that travel short distances and consequently have more frequent trips. The other three areas, NCR/North Luzon, Cebu, and Northern Mindanao, have fewer ship calls because most ships that dock on those ports undertake long-distance trips.

Table 7. Number of ship calls analyzed by Port Management Office, 2016

Port Management Office (PMO)	Number of Ship Calls	Share
NCR/North Luzon	16,917	4.01%
South Luzon	113,859	27.01%
Visayas	100,202	23.77%
Cebu	25,567	6.07%
Northern Mindanao	34,792	8.25%
Southern Mindanao	130,188	30.89%
Total	421,525	100%

In terms of transportation activity, the domestic shipping fleet made 34,899,563 vessel-kilometers (ves-km) in 2016. The breakdown of transportation activity for different ship types is presented in Table 8 and Figure 2. RoRo ships accounted for the largest share of transportation activity at around 9.4 million ves-km (27.15%). A close second is the general cargo type at approximately 9.2 million ves-km (26.47%). The transportation activity in ves-km has not been converted to ton-km/ pass-km due to a lack of occupancy factors for local ships. The majority (more than 80%) of the transport activity came only from 4 types: Container, General Cargo, RoRo Cargo, and Passenger ships.

Table 8. Domestic maritime transportation activity per ship type, 2016

Ship Type	Transportation Activity (ves-km)	Share
Liquid Bulk	1,505,904.48	4.31%
Dry Bulk	2,000,742.85	5.73%
Container	3,694,854.52	10.59%
General Cargo	9,237,063.27	26.47%
RoRo Cargo	9,475,922.28	27.15%
Passenger	6,930,265.23	19.86%
Fishing	313,187.22	0.90%
Other	524,770.30	1.50%
Tugs	1,216,852.58	3.49%
Total	34,899,562.73	100.00%

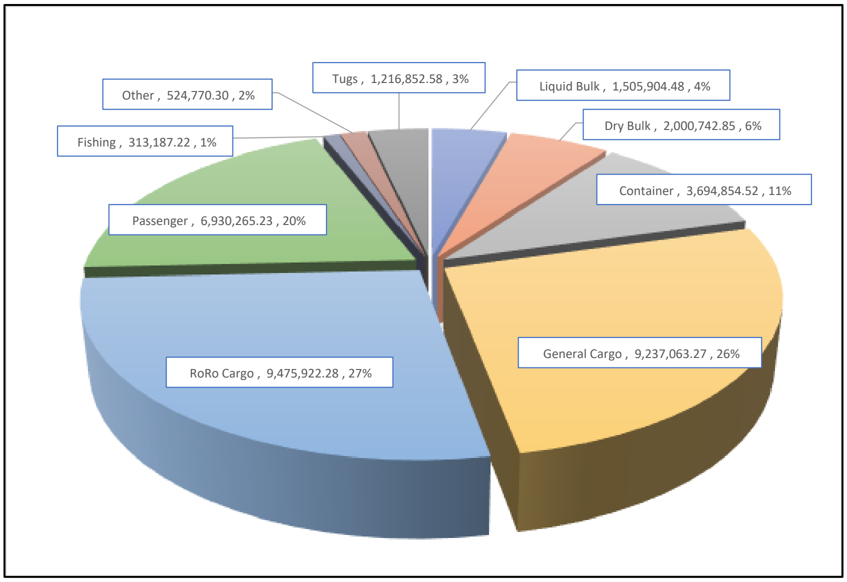

Figure 2. Share of domestic maritime transportation activity by ship type, 2016

4.2 Baseline Maritime Transportation Energy Demand

Domestic maritime transportation consumed 95,780.99 tons of MDO/MGO and 447,890.22 tons of BFO. The primary fuel used was BFO, which accounted for 410.69 kTOE (81.22%) in energy demand. Each ship type's energy demand is presented in Table 9 and Figure 3.

Despite having almost equal transportation activity shares, a significant difference in energy consumption between RoRo and general cargo ships was observed. RoRo ships accounted for the largest share of total energy demand at 283.79 kTOE (56%). Meanwhile, the second-largest consumer, the general cargo ships, only accounted for 71.40 kTOE (14%). It was also observed that 70% of the total energy consumption comes from only two types of ship: General cargo and RoRo Cargo. Since these ship types are generally used to transport cargo, it may be inferred that most of the energy consumed by the maritime sector is used for freight transportation.

Table 9. Domestic maritime energy demand per ship type and fuel type, 2016

Ship Type	MDO/MGO Energy Demand (KTOE)	BFO Energy Demand (KTOE)	Total Energy Demand (kTOE)	Share
Liquid Bulk	0.62	11.82	12.44	2.45%
Dry Bulk	0.28	23.78	24.06	4.75%
Container	0.64	44.22	44.86	8.85%
General Cargo	10.09	61.31	71.40	14.09%
RoRo Cargo	55.74	228.05	283.79	55.98%
Passenger	6.67	34.25	40.91	8.07%
Fishing	0.92	0.04	0.96	0.19%
Other	5.98	6.14	12.12	2.39%
Tugs	15.30	1.09	16.39	3.23%
Total	96.25	410.69	506.94	100.00%

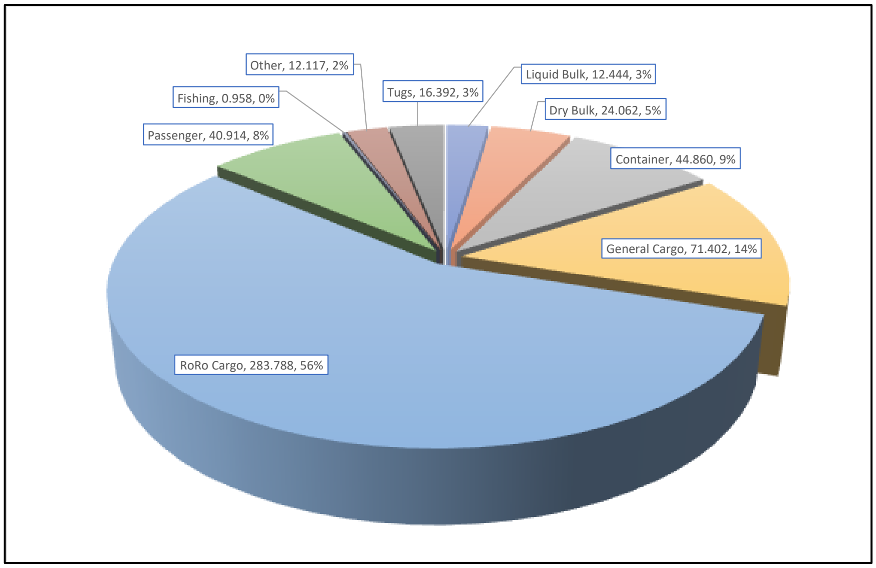

Figure 3. Share of maritime transportation energy demand by ship type, 2016

In terms of the navigation phase, the cruising phase accounted for the largest share of energy demand, at 327.14 kTOE (64.53%), the maneuvering phase accounted for 26.25 kTOE (5.18%), and the hoteling phase accounted for 153.55 kTOE (30.29%), as shown in Table 10. It is also evident that most fuel consumption is sourced from bunker fuel oils, accounting for 81.33% for the cruising phase, 77.99% for the maneuvering phase, and 80.85% for the hoteling phase.

Table 11 shows the comparison of the estimated and the official maritime transportation energy demand by fuel type. The difference is due to the use of fuel use distribution from the 2010 international fleet. The global shipping fleet relies mainly on bunker fuel oil, as presented in the EEA/EMEP guidebook distribution factors. The difference may also be attributed to the energy estimation not covering pleasure crafts, military vessels, and wooden-hulled motorboats that do not rely on BFO. The disaggregation of the energy demand into fuel type may only be indicative due to the lack of local data; however, it does not significantly affect the calculation results for total energy demand.

Table 10. Energy demand according to ship type, fuel type and operation phase (kTOE)

Ship Type	Cruising Phase		Maneuvering Phase		Hoteling Phase		Total	
	MDO/ MGO	BFO	MDO/ MGO	BFO	MDO/ MGO	BFO	MDO/ MGO	BFO
Liquid Bulk	0.39	7.40	0.02	0.29	0.22	4.14	0.62	11.82
Dry Bulk	0.15	12.86	0.01	0.54	0.12	10.39	0.28	23.78
Container	0.57	39.34	0.01	0.85	0.06	4.03	0.64	44.22
General Cargo	6.99	42.46	0.23	1.38	2.87	17.47	10.09	61.31
RoRo Cargo	34.36	140.54	3.58	14.66	17.80	72.85	55.74	228.05
Passenger	4.22	21.69	0.43	2.23	2.01	10.33	6.67	34.25
Fishing	0.26	0.01	0.02	0.00	0.64	0.02	0.92	0.04
Other	0.82	0.84	0.44	0.45	4.72	4.84	5.98	6.14
Tugs	13.30	0.95	1.03	0.07	0.97	0.07	15.30	1.09
TOTAL	61.07	266.07	5.77	20.48	29.41	124.14	96.25	410.69
Share (Total)	12.05%	52.49%	1.14%	4.04%	5.80%	24.49%	18.99%	81.01%

Ship Type	Cruising Phase		Maneuvering Phase		Hoteling Phase		Total	
	MDO/ MGO	BFO	MDO/ MGO	BFO	MDO/ MGO	BFO	MDO/ MGO	BFO
Share per phase	18.67%	81.33%	22.01%	77.99%	19.15%	80.85%		

Overall, it was found that RORO cargo ships consume the most fuel out of all the ship types in the analysis, despite the trends in transportation activity discussed previously. The RORO consumes more energy per vessel-km compared to other ship types. For example, while the RORO and General Cargo ships have very close transport activity values, the RORO Cargo ships consumed significantly greater energy than the General Cargo ships.

Table 11. Comparison of baseline maritime transportation energy demand estimate and the Department of Energy's water transportation energy consumption, 2016

Fuel	Baseline Energy Demand Estimate		Total Final Energy Consumption (DOE)	
	kTOE	Share	kTOE	Share
Gasoline	-		157.0	18.5%
Diesel	96.247	19.0%	482.0	56.9%
Fuel Oil	410.688	81.0%	203.0	24.0%
Biodiesel	-		5.0	0.6%
Total	506.935	100%	847.0	100%

5. ASSESSMENT OF ENERGY IMPACTS OF POLICY SCENARIOS

From the results of the bottom-up calculations in 2016, the maritime transportation energy demand would increase to more than double its amount, from 506.93 kTOE in 2016 to 1,250.95 kTOE in 2040 in the BAU scenario. In terms of fuel consumption, demand for marine distillates[12] would grow from 96.25 kTOE in 2016 to 237.5 kTOE in 2040, while demand for bunker fuel oil would grow from 410.69 kTOE in 2016 to 1,013.44 kTOE in 2040 in the BAU scenario. The growth in energy demand per ship type is presented in Figure 4.

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[12] Marine gas oil and marine diesel oil (MGO/MDO)

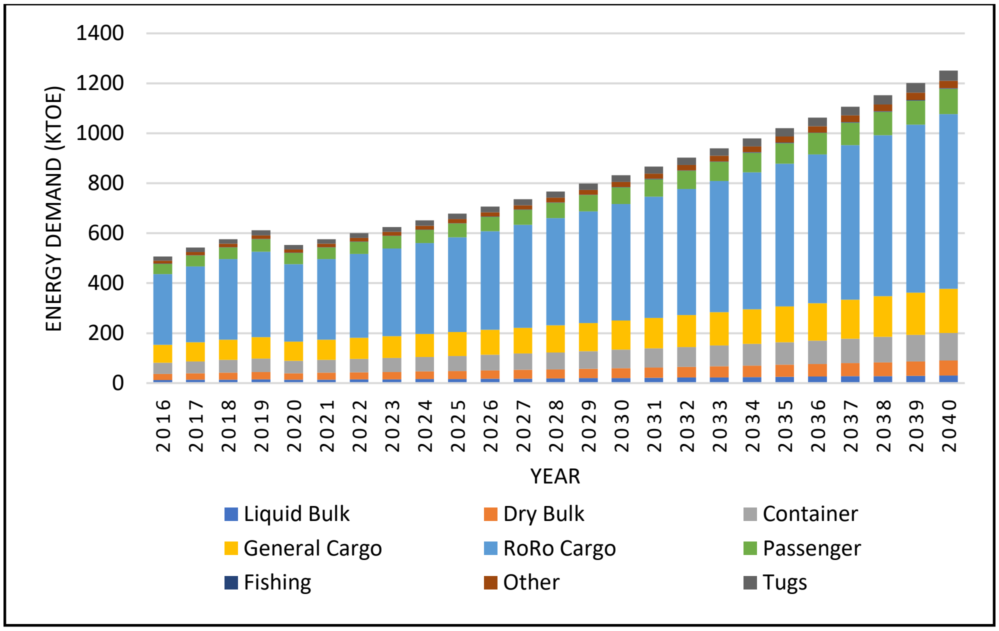

Figure 4. Maritime transportation energy demand for 2016-2040 for the BAU Scenario

Ship speed reduction can reduce energy demand by 97.81 kTOE (7.82%) by 2040 without additional costs to ship operators. Figure 5 shows the maritime transportation energy demand for the BAU and policy scenarios. The main concern is the disruption of the supply chain. People may complain about longer times for goods in transit. Research is needed to model the relationships between speed and fuel consumption, journey time, distance traveled, and loads carried in the local setting. This could take into account the effects of weather and schedule as well.

On the other hand, routine hull cleaning can reduce energy demand by 43.60 kTOE (3.49%) by 2040. Although periodic hull cleaning entails additional costs, it usually becomes a net negative cost for the shipowner due to the fuel savings. Based on the ICCT (2011), the cost of saving 1 ton of fuel by hull cleaning is close to $250. With a projected fuel price of $700 per ton (actual fuel prices range from around $600 - $650)[13], it still makes sense to apply hull cleaning.

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[13] Obtained from https://shipandbunker.com/prices on November 4, 2021

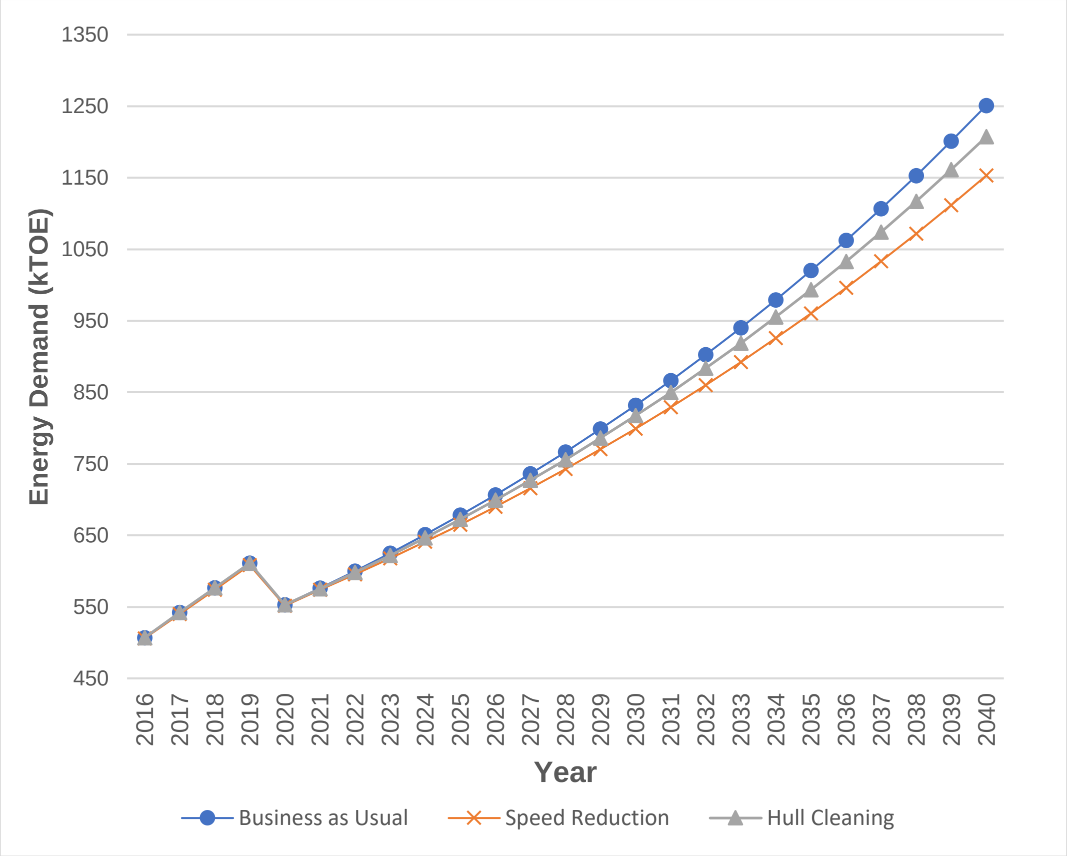

Figure 5. Policy scenarios vs. BAU scenario

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The Philippines' baseline transportation energy demand of domestic maritime transportation is estimated to be 506.94 kTOE in 2016 using the bottom-up approach, available local transportation activity, and international fuel/energy efficiency from secondary data sources. The primary fuel used was BFO, which accounted for 410.69 kTOE (81.22%) in energy demand. RORO cargo ships consumed the most fuel out of all the ship types in the analysis. They accounted for 283.79 kTOE of energy demand or a 55.98% share in the total maritime transportation energy demand, despite only accounting for 27.15% of the transportation activity. In terms of the navigation phase, the cruising phase accounted for the largest share of energy demand, at 327.14 kTOE (64.53%) of the total, the maneuvering phase accounted for 26.25 kTOE (5.18%), and the hoteling phase accounted for 153.55 kTOE (30.29%).

In the baseline scenario, the maritime transport sector's energy demand would increase to more than double its amount, from 506.93 kTOE in 2016 to 1,250.95 kTOE in 2040. Policies like speed optimization can reduce the energy demand by 97.81 kTOE (7.82%) by 2040 without additional costs to ship operators, while periodic hull cleaning can reduce energy demand by 43.60 kTOE (3.49%) by 2040. However, the determination of effective policies is still highly dependent on the availability of maritime transportation data, which could significantly enhance the accuracy of energy demand estimations and policy assessment.

5.2 Recommendations

The local data needed to perform a holistic, bottom-up estimation of the baseline maritime energy demand remains incomplete, if not unavailable. For MARINA, it is recommended that ship categories, ship engine type, engine size, and fuel type for each ship's main and auxiliary engine are maintained in a database or incorporated in a local ship registry that is regularly updated. Furthermore, the average cruising speed, fuel economy per unit of activity (kWh, ton-km, etc.) for each ship type and local emission factors need to be measured. For the PPA and CPA, quantifying average maneuvering time and hoteling time for seagoing vessels could lead to more accurate estimates. Additionally, the encoding ship calls data using codes instead of names for ships (such as IMO number) and ports that would be used across all concerned agencies will help eliminate uncertainties in processing. For NAMRIA, additional port-to-port distances also need to be added, and existing entries need to be updated in a GIS database.

Finally, the data on wooden-hulled *motorbancas* are incomplete and difficult to characterize (i.e., they can be used for various activities such as fishing, private use, and tourism). To bridge this gap, the MARINA, PPA, and CPA can collect and archive additional information on the transportation activity and fuel economy of *motorbancas.*

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