icct

BRIEFING

Adapting the Vehicle Energy Consumption Calculation Tool (VECTO) for use in India and other countries

INTRODUCTION

On-road commercial trucks and buses are among the fastest-growing transportation sectors worldwide, and many nations and regions have developed programs and policies to improve the environmental performance of their heavy-duty vehicle (HDV) fleets. Japan, China, the United States, Canada, India, and, most recently, the European Union are among those that have implemented fuel-efficiency and greenhouse gas (GHG) regulations for new HDVs.

Still, the heavy-duty industry presents regulatory challenges. First, there is tremendous diversity in the vehicle configurations and operating patterns found in commercial trucks and buses. Additionally, measuring the fuel consumption of HDVs can be quite complicated because a single engine model can be paired with a large number of chassis types and transmissions, with each combination having different fuel-consumption characteristics. The fuel efficiency of a given HDV may vary dramatically based upon the duty cycle and payload and, unlike passenger cars and light-duty trucks, HDV manufacturing is often a fragmented and highly customized process.

Given the challenges inherent in measuring HDV fuel efficiency in a regulatory context, a combination of component testing and vehicle simulation has emerged as the state-of-the-art alternative for evaluating vehicle performance. Via this process, the physical testing of a relatively small number of components produces input values for vehicle simulation software that is, in turn, used to predict fuel consumption and CO_2 emissions

from HDVs under various operating conditions. The primary advantage of this approach is the ability to model a large number of vehicle variants over a large number of cycles and payloads without time-intensive and costly full-vehicle testing like chassis dynamometer testing or on-road testing.

INTEREST IN INDIA

India's initial regulation for HDVs greater than 12 tonnes, currently in effect, requires that vehicles be evaluated on a test track while operating at constant speeds. Nonetheless, government officials have indicated a desire to move to fuel-efficiency standards based on simulation modeling. Specifically, there has been considerable interest in exploring the feasibility of using the Vehicle Energy Consumption Calculation Tool (VECTO) developed by the European Commission.

The government of India has created a technical committee to guide the development of a VECTO-based certification process. The vision is for manufacturers to be able to use an India-specific version of VECTO to determine the fuel consumption and CO_2 levels that will be used for evaluating compliance with efficiency standards. Also, policymakers in other jurisdictions, including Brazil and Argentina, have taken an interest in VECTO and are exploring the feasibility of modifying it for their own HDV markets.[1]

Based on India's interest in using VECTO, the ICCT undertook a project to develop a proof-of-concept (PoC) adaptation of the VECTO model that represents vehicles and operating conditions in India. Over roughly a three-month period in early 2019, the ICCT worked with EMISIA SA, a consultancy in Europe with extensive knowledge of the VECTO software, to develop this adaptation. PoC VECTO-India has some simplifications by design. This is because the primary objectives of the model are to (1) use it as a learning exercise to guide more comprehensive VECTO development for India in the near future and (2) provide relevant best practices for other interested governments.

More details about VECTO can be found in several ICCT publications.[2] The primary objective of this paper is to summarize the key software modifications made in the PoC VECTO-India model and detail the lessons for India and other countries considering adapting VECTO. After a brief overview of the VECTO model, we describe the PoC VECTO-India model in detail. Following that, we discuss the recommendations for India in moving beyond a basic PoC tool and toward a fully functional VECTO-India that can be used for the second phase of HDV fuel efficiency standards.

VECTO OVERVIEW

VECTO is an open-source, publicly available software program that was developed by the European Commission and its Joint Research Centre to be the centerpiece of the European Union's CO_2 certification process for HDVs.[3] Since January 1, 2019, manufacturers in the European Union have been required to use VECTO to certify

1   "Heavy-duty vehicle efficiency," International Council on Clean Transportation, accessed August 20, 2019, https://theicct.org/heavy-duty-vehicle-efficiency

2   Vicente Franco, Oscar Delgado, and Rachel Muncrief, *Heavy-duty vehicle fuel-efficiency simulation: A comparison of US and EU tools*, (ICCT: Washington, DC, 2015), https://theicct.org/publications/heavy-duty-vehicle-fuel-efficiency-simulation-comparison-us-and-eu-tools
    Felipe Rodríguez, *Certification of CO₂ emissions and fuel consumption of on-road heavy-duty vehicles in the European Union*, (ICCT: Washington, DC, 2017), https://theicct.org/publications/certification-co2-emissions-and-fuel-consumption-road-heavy-duty-vehicles-european
    Felipe Rodríguez, *Fuel consumption simulation of HDVs in the EU: Comparisons and limitations*, (ICCT: Washington, DC, 2018), https://theicct.org/publications/fuel-consumption-simulation-hdvs-eu-comparisons-and-limitations

3   Felipe Rodríguez, *Certification of CO2 emissions and fuel consumption of on-road heavy-duty vehicles in the European Union*, (ICCT: Washington, DC, 2017), https://theicct.org/publications/certification-co2-emissions-and-fuel-consumption-road-heavy-duty-vehicles-european

HDV fuel consumption and CO_2 emission levels. In addition, the European Commission recently finalized the European Union's first CO_2 regulation for new HDVs, and the Commission will use certified CO_2 values from VECTO in determining compliance.[4]

For a given driving cycle and payload, VECTO uses the results of component testing and vehicle characteristics to simulate the fuel consumption and CO_2 emissions of a given vehicle. As shown in Figure 1, data from standardized testing of five vehicle subsystems—engine, transmission, axle, aerodynamic drag, and tires—constitutes the majority of the user inputs into VECTO. In addition, users need to input data about the vehicle's auxiliary systems. However, no testing is required for the inputs about equipment such as the cooling fan and steering system—users must simply input basic information about these technologies. Finally, vehicle curb weight (empty weight), gross vehicle weight (GVW; maximum weight), and axle configuration are required inputs. Using the weight and axle configuration data, the VECTO software automatically assigns the vehicle's segment and the corresponding cycles, payloads, and other default parameters, as pre-determined by regulators. At the end of the process, VECTO outputs the results in three forms: by distance, in grams of CO_2 per kilometer (km) and liters of fuel consumed/km; by payload, in grams of CO_2/tonne-km and liters/tonne-km; and by volume, in grams of CO_2/m³-km and liters/m³-km.
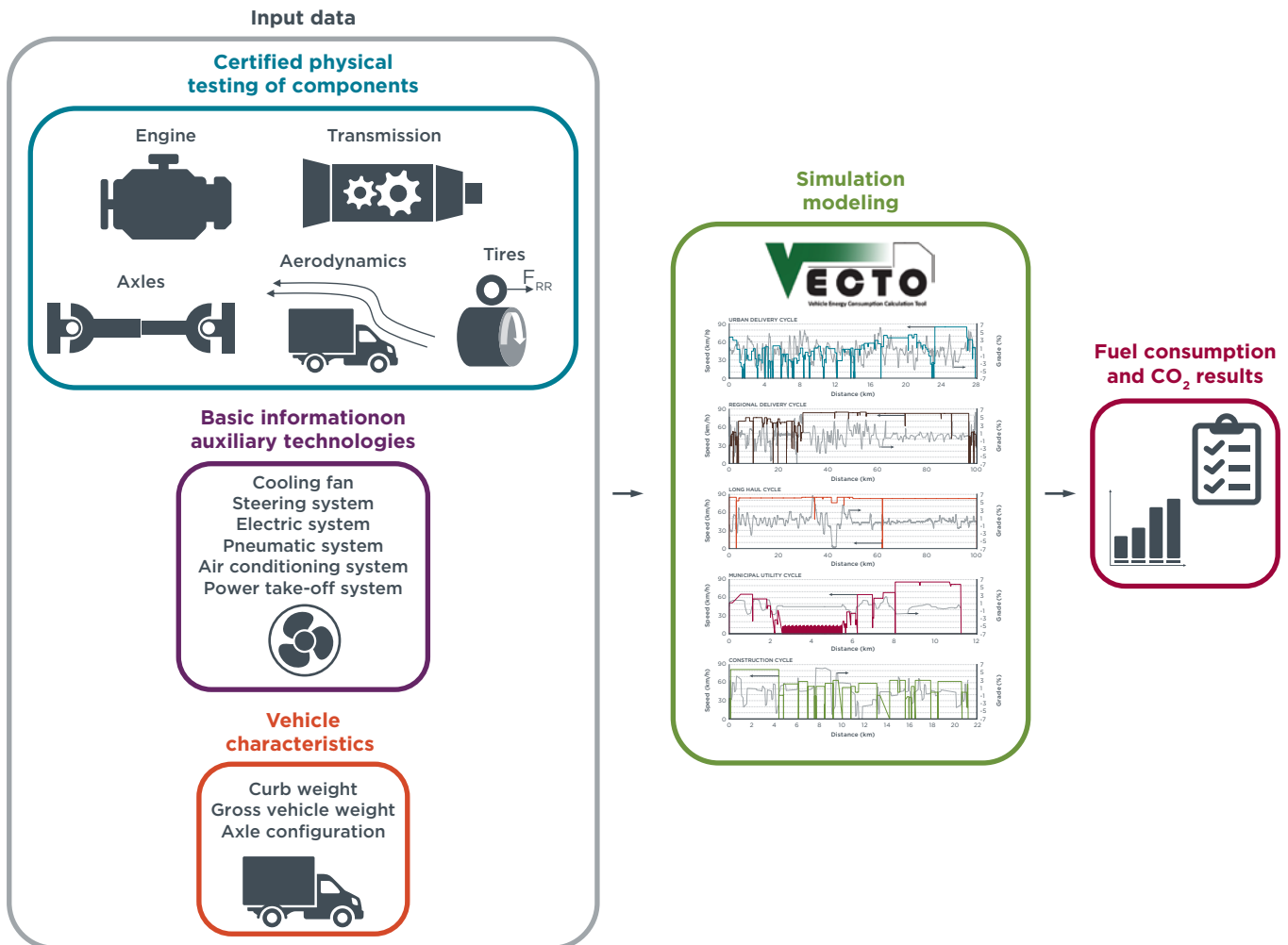
Figure 1: Schematic of the VECTO-based certification process for HDV fuel consumption and CO_2 emissions

4   Regulation (EU) 2019/1242 of the European Parliament and of the Council of 20 June 2019 setting CO_2 emission performance standards for new heavy-duty vehicles and amending Regulations (EC) No 595/2009 and (EU) 2018/956 of the European Parliament and of the Council and Council Directive 96/53/EC, https://eur-lex.europa.eu/eli/reg/2019/1242/oj

At present, there are 17 groups for trucks and six groups for buses in the VECTO-based certification process in the European Union. To complement this vehicle categorization scheme, there are five different driving cycles defined in VECTO: urban delivery; regional delivery; long haul; municipal utility; and construction. In VECTO's declaration mode, each vehicle group is assigned a default payload and drive cycle(s) based on typical HDV operating conditions in the European Union.[5]

PROOF-OF-CONCEPT (POC) VECTO-INDIA MODEL

The primary motivation behind the development a PoC VECTO-India model is to assess the level of resources needed to adapt the software for use in another country. The scope of this project was to reparametrize VECTO for the Indian context by modifying the datasets relevant for VECTO's declaration mode—i.e., data about vehicle segments, payloads, generic component data, and test cycles. Figure 2 summarizes the three main areas in VECTO that were modified to create the PoC VECTO-India model: (1) vehicle types; (2) user input data; and (3) drive cycles. We discuss each in the following subsections.

---

5   VECTO also has an engineering mode in which the user can select and change all input data to allow recalculation of test results.
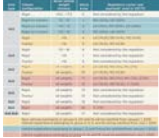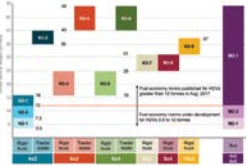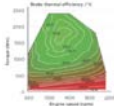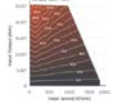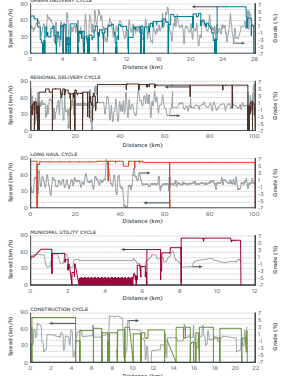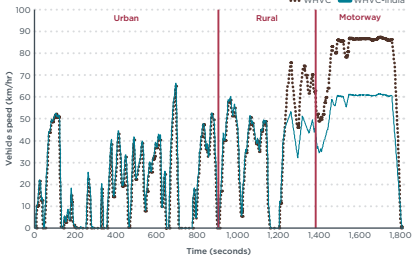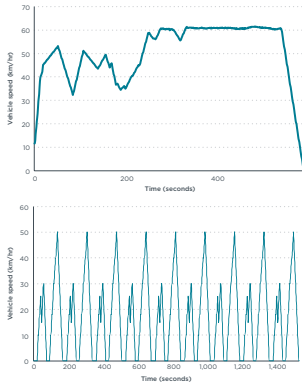
	European version	**Proof-of-concept India version**	**Proposed India regulatory version**
Vehicle types	17 truck segments are included in VECTO. Segmentation is based on vehicle type (rigid truck, tractor truck, or bus), gross vehicle weight, and axle configuration.	Users can select from these 3 truck types 6x4 25-tonne rigid truck 8x2 31-tonne rigid truck 4x2 40-tonne tractor truck	India creates 11 truck and 3 bus categories to match the segmentation approach in the existing fuel consumption regulations. See Sathiamoorthy and Sharpe (2019) for further discussion.
Input data	**Physical testing-based data** Dynamometer-based engine fuel consumption maps Testing-based torque loss maps for transmissions, axles, and auxiliaries Aerodynamic drag area (C_DA) → track testing Coeff. of rolling resistance (C_{RR}) → lab testing	**Combination of user inputs and default values** User has the ability to input an engine fuel consumption map Default values auto-populate for transmission, axle, and auxiliary data. Users can modify the number of gear and/or the gear ratio values. Aerodynamic drag area (C_D) → default value Vehicle frontal area → modifiable input C_{RR} → modifiable input	**Physical testing-based data** We propose that VECTO-India be identical to VECTO in terms of component testing and input data requirements. India should aim to require physical testing for all component inputs for which a certified test procedure already exists in the CO_2 certification process in the European Union. If this arrangement proves too burdensome, then certain technology modules in VECTO can be modified to be based on default values.
Drive cycles	Unique drive cycles are assigned based on vehicle group	WHVC-India cycle is used for all 3 vehicle types. Weighting factors are used for each of the 3 'mini cycles' in the WHVC to account for different mission profiles of the 3 vehicles.	India creates an appropriate number of new truck and bus driving cycles that is based on real-world operations data.

Figure 2: Overview of the modifications made in the VECTO-India model

VEHICLE TYPES

For the PoC VECTO-India, we chose three vehicle types based on popular truck size and axle configurations for HDVs greater than 12 tonnes in India—a 4x2 40-tonne tractor-trailer, an 8x2 31-tonne rigid truck, and a 6x4 25-tonne rigid truck. We focus on these heavier truck categories because India already has fuel-efficiency standards in place for commercial trucks and buses greater than 12 tonnes. These three trucks have identical engines and transmissions, and for simplicity, we assume they have the same coefficients of aerodynamic drag and tire-rolling resistance values. The remaining parameters come from information available in online vehicle specification sheets.

As discussed further below, a fully functional VECTO-India that can be used in a regulatory context should eventually cover all major HDV sizes and axle configurations. For components, engine, transmission, axle, aerodynamics, and tire inputs should be determined through standardized test procedures, as is currently the case with the European Union's CO_2 certification process.

USER INPUT DATA

PoC VECTO-India has several updates that are designed to simplify the user-input requirements. The default values and user-input controls for the seven main technology areas are summarized in Table 1. For the three vehicle types chosen for the model, we used publicly available information about top-selling trucks to develop representative vehicle models in each segment. Rather than requiring users to input detailed energy-consumption maps for transmissions, axles, and auxiliaries, PoC VECTO-India uses default maps and values based on previous research.[6] In the engine module, users have the ability to input a fuel-consumption map, but the transient correction factors are non-modifiable. Default values are used for transmission gear ratios and number of gears, but users can opt to edit these files. In the aerodynamics module, rather than inputting the total drag area (C_DA), PoC VECTO-India sets C_D value as a non-modifiable default, and users are required to input a value for vehicle frontal area. Tire size is fixed for all three vehicle types, but the coefficient of rolling resistance (C_{RR}) input can be modified. Finally, GVW and the default payload values for all three vehicle types are auto-populated and cannot be edited, whereas vehicle curb weight is a modifiable input.

Table 1: Default data and user inputs in PoC VECTO-India

Parameter	Default parameter	Editable user input
Engine	Transient correction factors	Fuel consumption map
Transmission	Energy loss map	Number of gears and gear ratios
Axles	Torque loss map[a]	N/A
Aerodynamics	Aerodynamic drag coefficient[b]	Frontal area
Tires	Tire loaded radius[b]	Tire coefficient of rolling resistance
Auxiliaries	Constant electric system load[a]	N/A
Vehicle mass	GVW and payload	Vehicle curb weight

a. Based on Delgado et al. (2016)
b. Based on Karali et al. (2017) and the study team's best judgment

6   Oscar Delgado, Josh Miller, Ben Sharpe, and Rachel Muncrief, *Estimating the fuel efficiency technology potential of heavy-duty trucks in major markets around the world*, (GFEI Working paper 14: London, UK, 2016), https://theicct.org/publications/estimating-fuel-efficiency-technology-potential-heavy-duty-trucks-major-markets-around
Nihan Karali, Anand Gopal, Ben Sharpe, Oscar Delgado, Anup Bandivadekar, and Mehul Garg, *Improved heavy-duty vehicle efficiency in India: Benefits, costs, and environmental impacts*, (Lawrence Berkeley National Laboratory: Berkeley, CA, 2017), https://energyanalysis.lbl.gov/publications/improved-heavy-duty-vehicle-fuel

DRIVE CYCLES

In PoC VECTO-India, each of the three vehicle types is evaluated over the World
Harmonized Vehicle Cycle (WHVC)-India drive cycle, which was created for previous
analyses to account for the fact that HDV speeds in India are typically much slower
than in other major markets like China, the United States, and the European Union.[7] The
WHVC itself was the basis for the World Harmonized Transient Cycle (WHTC), an engine
dynamometer cycle used as a certification test for criteria pollutant emissions.[8] The
main purpose of the WHVC is to cover a wide range of driving situations for commercial
vehicles. As such, the cycle contains distinct urban, rural, and motorway 'mini cycles,'
as shown in Figure 3. The WHVC-India cycle is identical to the WHVC for roughly the
first 20 minutes, and then afterward the speeds of the WHVC are multiplied by 0.7 to
produce the speeds for the WHVC-India. As depicted in Figure 3, during the highway
portion, which is approximately the final seven minutes of the cycle, the maximum
speed of WHVC-India is approximately 60 kilometers per hour (kph), as compared to
roughly 87 kph in the WHVC. This maximum cruising speed of 60 kph is reasonably
representative of commercial vehicle behavior in India.[9]
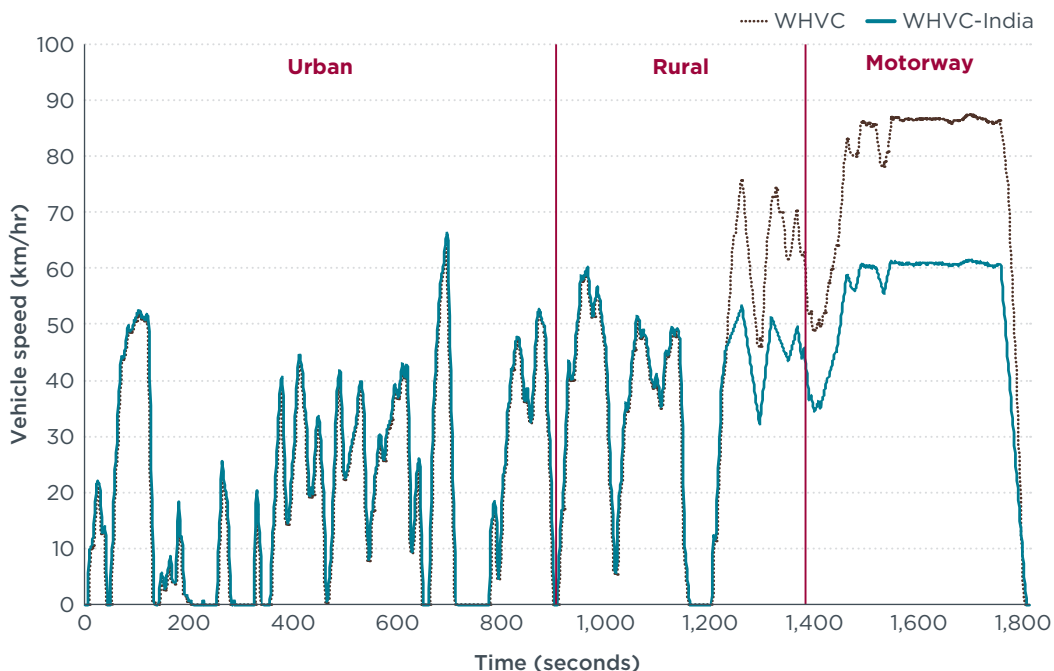
Figure 3: Vehicle speed-time trace for the World Harmonized Vehicle Cycle (WHVC) and WHVC-India cycle

To more closely account for the different in-use driving behaviors of the three
representative vehicle types, we used weighting factors for the urban, rural, and
motorway portions of the cycle. These weighting factors, shown in Table 2, are based

---

7   ibid.
     Nihan Karali, Nikit Abhyankar, Ben Sharpe, Oscar Delgado, and Anup Bandivadekar, *Improving fuel efficiency for heavy-duty vehicles efficiency of 3.5 to 12 tonnes in India: Benefits, costs, and environmental impacts*, (Lawrence Berkeley National Laboratory: Berkeley, CA, 2019), https://energyanalysis.lbl.gov/publications/improving-fuel-efficiency-heavy-duty

8   "World Harmonized Vehicle Cycle (WHVC)," DieselNet, accessed August 5, 2019, https://www.dieselnet.com/standards/cycles/whvc.php

9   ibid.

on cycle breakdowns in the regulatory programs of the United States and China and the study team's best judgment.[10]

Table 2: Weighting factors used for the mini cycles in the WHVC-India cycle

Vehicle type	Urban	Rural	Motorway
40-tonne tractor-trailer	0.1	0.1	0.8
25-tonne rigid truck	0.4	0.3	0.3
31-tonne rigid truck			

LESSONS FOR VECTO ADAPTATION IN INDIA AND OTHER COUNTRIES

The resource requirements for modifying VECTO's source code are relatively modest, assuming VECTO experts are available.[11] Component testing and drive-cycle development are the two major critical path activities in a VECTO adaptation effort.[12] As India and other countries embark on the process of developing regulation-ready VECTO models that are appropriate for local conditions, the following are our key recommendations.

1. Prioritize component and full-vehicle testing based on existing standardized methodologies

Standardized test methodologies for vehicle components have already been designed as part of fuel-efficiency and CO_2 standards in the United States and European Union. Regions interested in developing similar policies would ideally leverage these efforts.[13] Focus should be placed on procuring the necessary technical knowledge and infrastructure to conduct standardized component testing. Harmonized component testing would allow vehicle manufacturers and technology suppliers to certify in one country and sell in others. This would increase the opportunities for scale and reduce compliance costs.

Depending on specific region and vehicle segment needs, test methodologies for certain components could be prioritized. While engine fuel-consumption maps and tires' rolling-resistance coefficients should be a requirement for all vehicle types, aerodynamic drag coefficients are more relevant to vehicle segments that operate at relatively high speeds like long-haul tractor-trailers.[14] Remaining vehicle input parameters related to the transmission, axle, and vehicle accessories have less

---

10 Oscar Delgado, *Stage 3 China fuel consumption standard for commercial heavy-duty vehicles*, (ICCT: Washington, DC, 2016), https://theicct.org/publications/stage-3-china-fuel-consumption-standard-commercial-heavy-duty-vehicles
Rachel Muncrief, Ben Sharpe, *Overview of the heavy-duty vehicle market and CO_2 emissions in the European Union*, (ICCT: Washington, DC, 2015), https://theicct.org/publications/overview-heavy-duty-vehicle-market-and-co2-emissions-european-union
U.S. Environmental Protection Agency and Department of Transportation, "Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles – Phase 2: Regulatory Impact Analysis" (2016), https://nepis.epa.gov/Exe/ZyPDF.cgi/P100EG9C.PDF?Dockey=P100EG9C.PDF

11 The PoC VECTO-India project took toughly 20 person-days to complete.

12 This assumes that the vehicle segmentation is already set.

13 Oscar Delgado, Felipe Rodriguez, Nikiforos Zacharof, *Comparison of aerodynamic drag determination procedures for HDV CO_2 certification*, (ICCT: Washington, DC, 2019), https://theicct.org/publications/aerodynamic-drag-HDV-EU

14 Ben Sharpe, Oscar Delgado, *Engines and tires as technology areas for efficiency improvements for trucks and buses in India*, (ICCT: Washington, DC, 2016), https://theicct.org/publications/engines-and-tires-technology-areas-efficiency-improvements-trucks-and-buses-india

influence on the overall fuel demand. Therefore, these could initially be defined with default values, but the methodology could include the option for manufacturers to overwrite if they decide to perform such tests.

Testing full vehicles and component systems from the local market is necessary for generating updated default vehicle parameters and validating the modified VECTO model. Physical testing of HDVs is typically time-consuming and expensive, so it is important that the project team create a detailed testing plan with input from all relevant stakeholders. As an example of the level of testing needed to validate a locally adapted version of VECTO, Table 3, below, is a proposed testing plan for VECTO-India. We believe this testing campaign would be sufficient to generate default vehicle parameters for each vehicle segment—i.e., pre-populate a given vehicle segment with a corresponding payload or vehicle curb weight—and provide enough component and vehicle test results to validate that VECTO-India simulations are close to what the actual vehicles consume in-use.

Table 3: Recommended minimum testing program for VECTO-India validation

	Segment	Number of unique models tested	Methods
Complete vehicles (or rolling chassis)			
Rigid truck	< 12 tonnes	1	• Chassis dynamometer and/or portable emissions measurement system (PEMS)
Tractor truck	> 12 tonnes	1	• Aerodynamic drag testing[a]
Engines			
Test the engines from both of the trucks		2	Engine mapping procedure[b]
Test the components from both of the two trucks			
Transmission		2	Transmission torque loss mapping procedure[b]
Axles		2	Axle torque loss mapping procedure[b]
Tires		2	Tire rolling resistance (ISO 28580)[b]
Auxiliaries demand		2	See the LOT 3 study for the methodology for determining auxiliary load values and defaults.[c]

a. See Delgado et al. (2019) for a detailed description of the aerodynamic drag test procedures that are required for HDVs in the European Union and United States. Based on our research, we believe that India can use either the constant speed test (European Union) or the coastdown test (United States) for determining aerodynamic drag performance.
b. See Rodríguez (2017) for more information about these component test procedures.
c. Raphael Luz, Martin Rexeis, Stefan Hausberger, Dalibor Jajcevic, Wolfgang Lang, Leif-Erik Schulte, Jan Hammer, et al. "Development and Validation of a Methodology for Monitoring and Certification of Greenhouse Gas Emissions from Heavy Duty Vehicles through Vehicle Simulation. Draft Final Report," (European Commission Report No. I 07/14/Rex EM-I 2012/08 699, June 25, 2014), https://ec.europa.eu/clima/sites/clima/files/transport/vehicles/heavy/docs/final_report_co2_hdv_en.pdf

2. Collect real-world operations data

As described above, testing data from vehicles and components is needed to reparametrize the model. Additionally, real-world operations data is necessary to create and/or modify a set of regulatory drive cycles and weighting factors in VECTO, and to update the default vehicle market segmentation scheme and auto-populated payload values.

Developing a robust database of HDV operations data should ideally include real-world data from truck and bus fleets of various types and mission profiles. Using a cross-section of speed and payload profiles for each vehicle segment, the set of

regulatory drive cycles and weighting factors in VECTO can be adapted to represent local conditions as closely as possible.

3. Build up local VECTO software and source code expertise

At present, VECTO expertise is primarily concentrated within the European Commission and the various European universities, consultants, and HDV manufacturers that have been involved in its development and validation. Ideally, government officials in India and elsewhere can coordinate closely with the European Commission throughout the process of adapting VECTO. But, in parallel, we recommend that countries also invest in strengthening internal VECTO source code expertise so they can take ownership of their country-specific VECTO models. This would allow each country to have an autonomous VECTO model and vehicle-certification process that is not dependent on interventions from outside VECTO experts. For example, the Automotive Research Association of India has been developing proficiency with VECTO and will be taking the lead role in creating a VECTO-India that can be used in the next round of HDV fuel-efficiency standards.

4. Bring industry stakeholders into the process as early as possible

Developing a country-specific VECTO model will require governments to collaborate with a range of stakeholders, including vehicle manufacturers, component manufacturers, truck and bus fleets of various types and sizes, and testing facilities. It may be advantageous to create multi-stakeholder technical working groups and/or steering committees that are responsible for the various tasks related to VECTO adaptation. These tasks include vehicle and component testing, drive cycle development, and source code editing. Recall from above that the government of India has established such a steering committee and it is guiding the VECTO adaptation process; the Automotive Research Association of India has been assigned as the technical lead for the project. We recommend that government officials in other interested countries start building these coalitions early in the process, so that as many stakeholders as possible acquire familiarity with VECTO and feel invested in the overall regulatory-development effort.

5. Ensure transparency with VECTO inputs and the overall vehicle CO_2 certification process

Ideally, the VECTO-based HDV certification process should be transparent and include requirements for public reporting of certain component testing results. Such is the case in the European Union, where engine, aerodynamic, and tire testing data are made public, and information about vehicle auxiliary systems must also be disclosed. Because manufacturers have so much responsibility for testing their own vehicles and components, it is essential that governments create mechanisms to audit VECTO input data at their discretion. Public reporting of key VECTO inputs from vehicle subsystems will also help to ensure a more fair and robust certification process, and give stakeholders increased confidence that the CO_2 reductions expected from regulation are actually achieved in the real world.

FUTURE OUTLOOK

Several countries around the world have embraced simulation modeling in developing
fuel-efficiency and GHG standards for commercial trucks and buses. With the ability
to adapt the European Union's VECTO model for country-specific vehicle types and
operations, policymakers in India and other countries could avoid the arduous process
of developing a completely new simulation tool. By demonstrating the relatively minor
resource requirements for creating a PoC VECTO-India model here, we have helped
illuminate the path ahead for India in developing a VECTO-India model that can be used
for future fuel-consumption regulations. Additionally, other countries are now in an
advantageous position to learn from India's example.