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# Determinar huella de carbono mediante la aplicación de Eco-Driving para distintos vehículos desde el año 2010.

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Álvaro Remache

# DEDICATORIA

Dedico la presente investigación a mi madre quien siempre me ha brindado su apoyo incondicional a lo largo de mi vida, a mi hermano que ha sido mi inspiración para lograr todo lo que me he propuesto, a mi familia y amigos que han estado junto a mí y han aportado en mi desarrollo personal.

***Esteban Addrian Ortega Villagómez.***

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***Esteban Addrian Ortega Villagómez.***

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# DETERMINAR HUELLA DE CARBONO MEDIANTE LA APLICACIÓN DE ECO-DRIVING PARA DISTINTOS VEHÍCULOS DESDE EL AÑO 2010.

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## RESUMEN

**Introducción:** La presente investigación analiza la diferencia de kg de Co2/kg de combustible emitido por vehículos bajo parámetros de la normativa vigente en el país y mediante conducción eficiente, debido a que el sector automotor es el que más incidencia tiene con alrededor de 3 millones de toneladas de CO2 **Metodología:** se realizaron pruebas siguiendo los parámetros FTP-75 a 3500 y 2500 Rpm y mediante la automatización de un modelo matemático basado en la ecuación estequiométrica para detectar la cantidad de huella de carbono emitido por el vehículo **Resultados:** se determinó que los valores de emisiones de Co2 aplicando la conducción eficiente Eco-Driving muestran una reducción del 3.31% **Conclusión:** aplicar este tipo de conducción eficiente permitirá reducir los kilogramos de dióxido de carbono en un total aproximado de 236 mil kilogramos junto con la herramienta automatizada que determinará los valores de manera sencilla para el operador.

**Palabras clave:** kg de Co2/kg de combustible, Co2, FTP-75, Automatización, huella de carbono, Eco-Driving.

## ABSTRACT

**Introduction:** The present investigation analyzes the difference of kg of Co2/kg of fuel emitted by vehicles under parameters of the regulations in force in the country and through efficient driving, the automotive sector is the one with the most incidence with around 3 million tons of CO2 **Methodology:** tests were carried out following FTP-75 parameters at 3500 and 2500 RPM and through the automation of a mathematical model based on the stoichiometric equation to detect the amount of carbon footprint emitted by the vehicle **Results:** it was determined that the values of Co2 emissions applying efficient driving Eco-driving show a reduction of 3.31% **Conclusion:** applying this type of efficient driving will reduce the kilograms of carbon dioxide by a total of approximately 236 thousand kilograms together with the automated tool that will determine the values in a simple way for the operator.

**Keywords:** kg of Co2/kg of fuel, Co2, FTP-75, Automation, carbon footprint, Eco-driving.

## 1. INTRODUCCION

Los gases de efecto invernadero son una de las principales problemáticas a nivel mundial debido a que es una de las causas primordiales de contaminación ambiental, por lo que el desarrollo de diferentes métodos de medida han sido elaboradas para determinar su grado de impacto. [1]

El aumento de la concentración de gases de efecto invernadero en la atmósfera altera la estabilidad del medio ambiente causando grave calentamiento global y consecuencias asociadas. Siguiendo la regla de que sólo lo medible es manejable, la graduación de la intensidad de gases de efecto invernadero de diferentes productos, cuerpos y procesos está ocurriendo en todo el mundo, expresadas como sus huellas de carbono. [2]

La huella de carbono es una medida de la cantidad de dióxido de carbono emitido a través de la combustión de combustibles fósiles, representando una cantidad de emisiones gaseosas que son relevantes para el cambio climático, asociado con la producción humana y actividades de consumo. Reflejando también la energía fósil representada en un producto o mercancía que alcanza el mercado. [3],[4]

Debido a que el problema es generado por sobrepoblación, es indispensable analizar y buscar nuevas alternativas que permitan la disminución de gases emitidos por la alteración del equilibrio natural. A medida que la población crece, incrementan a su vez las industrias, entre ellas, la de transportes por motores de combustión interna, lo que converge en la búsqueda de alternativas amigables al medio ambiente. [5]

En el distrito metropolitano de Quito la huella de carbono es de 5.164,946 ton Co2, estás emisiones equivalen en magnitud a las emisiones de CO2 generadas por el uso de energía eléctrica en más de 15 millones de hogares urbanos en Ecuador en un año, o el carbono secuestrado por 125 millones de árboles en 10 años. Para el año 2032 las emisiones de GEI proyectadas en un escenario BAU (escenario sin cambios) ascienden a 11.517.106 ton Co2. [6]

El sector automotor es el que más incidencia presenta, generando alrededor de 3.004,296 toneladas de Co2 equivalente al 66% de éstas corresponde al consumo de gasolina, mientras que el 33% corresponde a diésel. [7] Siendo el principal objetivo reducir esta cantidad de emisiones de Co2 emitidas al ambiente.

Las metodologías para el cálculo de la huella Co2 continúan evolucionando y se perfila como una herramienta importante para la gestión de gases de efecto invernadero. [2]

Una alternativa para reducir la cantidad de huella de carbono en el área automotor es el uso de programas eficientes llamados Eco-Driving.

Eco-Driving es una forma modificada de conducción cuyos principios básicos incluyen anticipar cambios en el tráfico, mantener el vehículo en buen estado y minimizar el uso de frenos; entre sus beneficios están el ahorro de costos y consumo de combustible como a su vez la reducción de gases de efecto invernadero al igual que la reducción de contaminación auditiva. [8]

El control por medio de la huella de carbono es un tema indispensable debido a que sirve como indicador de la sostenibilidad y del impacto hacia el cambio climático, aportando información sobre la cantidad de gases contaminantes emitidos a la atmosfera, por lo que el presente estudio está enfocado en realizar una comparativa de la huella de carbono expresada por la cantidad de kg de Co2/ kg de combustible generada por los ciclos de conducción establecidos por entes regulatorios INEN y mediante la conducción eficiente Eco-Driving, con el fin de analizar la variación de emisiones de Co2, Co, O2.

## 2. FUNDAMENTACION TEORICA

### 2.1 Antecedentes

Debido a que en Ecuador las entidades de control de emisiones no poseen información sobre la huella de carbono que emiten los vehículos es crucial determinar estos datos para una mejora en las normativas de emisiones.

Las normativas ecuatorianas se basan en una serie de normas extranjeras para determinar los valores y llevar un control de emisiones estándar.

Un aporte fundamental es brindar la herramienta de automatización de cálculo de huella de carbono para de esta manera determinar el valor que los vehículos emiten por kilogramo de combustible, de igual manera la aplicación de técnicas de conducción eficientes permitirá analizar si el valor de huella de carbono disminuye frente a los ciclos establecidos por entes regulatorios.

### 2.2 Huella de carbono

La huella de carbono se refiere a la cantidad (específicamente de dióxido de carbono) liberada en la atmósfera por una actividad en particular del ser humano.

Actualmente, el término huella de carbono se utiliza como abreviatura de la cantidad de carbono, normalmente en toneladas que emite una organización o actividad. Las emisiones de carbono producidas por la quema de combustibles fósiles se acumulan en la atmosfera si no hay suficiente biocapacidad dedicada a absorber estás emisiones. Es por eso por lo que cuándo la huella de carbono se reporta dentro del contexto de la huella ecológica, las toneladas de las emisiones de dióxido de carbono son expresadas como la cantidad de área productiva requerida para embargar las emisiones de dióxido de carbono así, determinando la cantidad de biocapacidad necesaria para neutralizar las emisiones de la quema de combustibles fósiles. Un estilo de conducción con exceso de velocidad, y aceleración excesiva reduce la autonomía en un 33% gastando combustible, dinero, e incrementa la huella de carbono. [9]

### 2.3 Ciclos de conducción para determinar emisiones contaminantes (INEN 2204)

En Ecuador las entidades de regulación de emisiones contaminantes en su normativa (INEN 2204) sobre los límites permitidos de emisiones producidas por fuentes móviles que emplean gasolina establecen que, utilizan dos tipos de ciclos de conducción para determinar los valores de emisiones contaminantes estas siendo el Ciclo ECE + EUDC la cual es un ciclo europeo para vehículos livianos que utilizan gasolina, y el ciclo FTP-75 establecida por la asociación de protección de medio ambiente de Estados Unidos para vehículos livianos a gasolina.

### 2.3.1 Ciclo ECE + EUDC

El ciclo ECE+EUDC, también llamado ciclo MVEG-A fue utilizado por la unión europea para aprobar las emisiones y consumo de combustible por parte de vehículos livianos. Las pruebas son realizadas mediante un dinamómetro de chasis, el ciclo completo se compone por 4 segmentos del ciclo ECE mostrados en la figura 1, estas pruebas se repiten sin interrupciones seguida por un segmento UEDC (figura 2), cabe recalcar que antes de la prueba el vehículo puede mantenerse por al menos 6 horas en temperatura apta para la prueba siendo 20°-30° grados centígrados, para luego ponerlo en marcha y dejarlo en ralentí por 40 segundos.

La prueba inicia con 4 segmentos de ECE, este ciclo se caracteriza por una velocidad baja del vehículo, baja carga del motor, y baja temperatura de los gases de escape. [10]

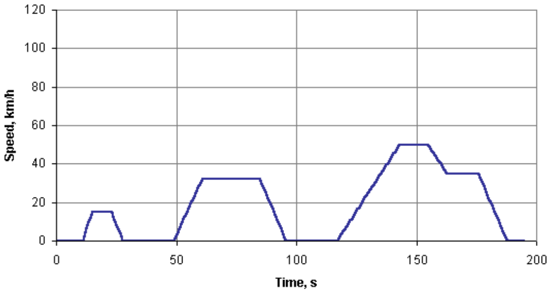

**Figura 1.** Ciclo ECE

**Fuente.** EEC Directive [10]

el segmento EUDC (ciclo extraurbano de conducción) se añade después del cuarto segmento ECE para simular un manejo más agresivo, o modos de conducción de alta velocidad. La velocidad máxima establecida para EUDC es de 120 km/h, o en su defecto para vehículos de menor potencia se estableció una velocidad máxima de 90 km/h mostrada en la figura 3. [10]

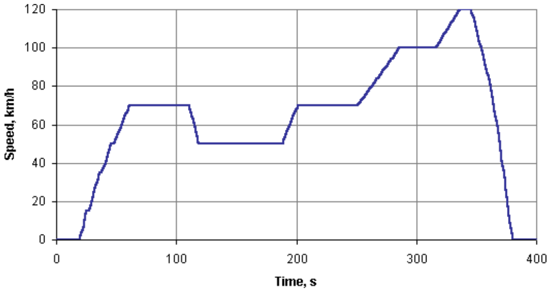

**Figura 2.** Ciclo EUDC

**Fuente.** EEC Directive [10]

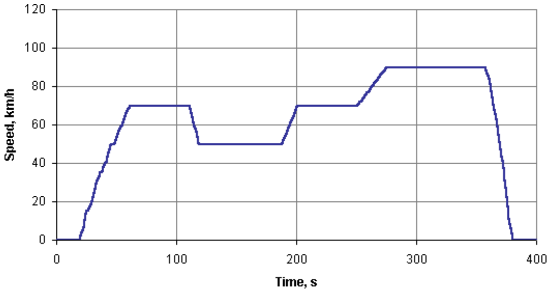

**Figura 3.** Ciclo UEDC para vehículos de baja potencia

**Fuente.** EEC Directive [10]

### 2.3.2 Ciclo FTP-75

El ciclo FTP-75 es una de las dos variantes del programa de conducción dinamométrica urbana de EPA (UDDS). FTP-75 es derivado del ciclo FTP-72 el cual añade una tercera fase que consta de 505 segundos idéntica a la primera fase de FTP-72 pero con un inicio en caliente, la tercera fase inicia una vez el motor se ha parado por 10 minutos. [11] Así el ciclo FTP-75 consta de los siguientes segmentos:

- Fase transitoria de arranque en frío (temperatura ambiente 20-30°C), 0-505 s,
- Fase estabilizada, 506-1372 s,
- calentamiento (mín. 540 s, máx. 660 s),
- Fase transitoria de arranque en caliente, 0-505 s.

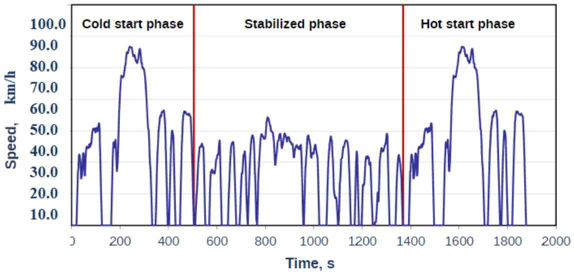

**Figura 4.** Programa de conducción dinamométrica urbana (FTP-75)

**Fuente.** EPA [11]

Los siguientes son parámetros básicos para la medición del ciclo:

- Duración: 1877 segundos
- Distancia: 17.77 Km
- Velocidad promedio 34.12 km/h
- Velocidad máxima: 91.25 km/h. [11]

## 2.4 Eco-Driving

La teoría sobre Eco-Driving se refiere al comportamiento de conducción de ahorro de energía basado en la experiencia de conducción, pruebas de ruta, y cognición teórica. El proceso de conducción incluye principalmente cuatro modos de conducción los cuales son aceleración, desaceleración, velocidad crucero, y ralentí. [12],[13]

Según investigaciones relacionadas se muestra que, en condiciones urbanas, el consumo de energía producido en los cuatro modos de conducción da un resultado de 38%, 8%, 35%, y 19% respectivamente. [12]

**Tabla 1.** Teoría de Eco-Driving.

| **Modo de conducción** | | |
|---|---|---|
| Velocidad crucero (35%) | velocidad crucero económica | Para vehículos convencionales: 50 km/h – 90km/h |
| | | Para vehículos eléctricos 40 km/h – 60 km/h |

| | | |
|---|---|---|
| | Realizando cambios lo antes posible | Manejo utilizando la marcha más alta posible |
| Aceleración (38%) | Aceleración suave | Reducir la apertura del pedal, evitar arranques bruscos |
| | Escoger el punto correcto de cambio de velocidad | Cambio óptimo de marcha: 2000 – 2500 rpm |
| Desaceleración (8%) | Desaceleración suave | Inercia y reducción de numero de frenadas |
| Ralentí (19%) | Reducción de tiempo en ralentí | Apagar el motor durante largas paradas |

**Fuente:** On-road motor vehicle emissions and fuel consumption in urban driving conditions.[12]

### 2.4.1 Cambios de velocidad eficientes

El realizar cambios de marcha los más antes posible aumenta la tasa de carga en el motor y ayuda a controlar la velocidad del motor en la zona económica. [14] Beusen [15],[16] explica mediante la obtención de información por parte de conductores los cuales han obtenido una reducción significativa de consumo de combustible luego de aplicar Eco-Driving que el punto promedio de cambio de velocidad cerca de las 2000 rpm. Escoger el punto correcto de cambio (2000 – 2500 rpm) y manejar el vehículo con la marcha más alta posible son métodos efectivos para reducir el consumo de combustible al igual que las emisiones contaminantes.

### 2.4.2 Reducción de tiempo en ralentí

Ralentí es una condición de trabajo en dónde el motor se encuentra inactivo, pero no produce ningún tipo de potencia, resultando así en consumo de combustible. Si el vehículo se encuentra en ralentí por más de minuto y medio, es recomendable para el conductor apagar el motor ya qué, el combustible requerido para reiniciar el motor es menor al consumido durante ralentí. El evitar las acciones explicadas anteriormente, combinadas con otros factores se puede obtener hasta un 20% en ahorros en cuestión de combustible y una reducción de emisiones al tener el motor apagado. [17]

### 2.4.3 Principios de Eco-Driving

Eco-Driving emplea una serie de reglas para maximizar la economía de combustible mientras minimiza las emisiones de carbono.

Estas reglas son:

- Conducir al límite de velocidad.
- Mantener la presión correcta de neumáticos.

- Evitar el uso de aire acondicionado a bajas velocidades.
- Cambiar el filtro de aire según lo recomendado por el fabricante.
- Aceleración suave y deslizándose hacia paradas y parqueaderos.
- No mantener ralentí por más de 30 segundos.
- Evitar pesos innecesarios. [8]

## 3. MATERIALES Y METODOS

### 3.1 Métodos

El método utilizado en el presente artículo es cuantitativo comparativo el cuál es un procedimiento que permite comparar de manera sistemática los objetos de estudio aplicado para obtener la comprobación de hipótesis. En el presente estudio se compara el porcentaje de huella de carbono obtenido en vehículos desde el año 2010 generadas a partir de la automatización de un cálculo estequiométrico a partir de Eco-Driving y los ciclos de conducción establecidos por entes regulatorios INEN, CORPAIRE.

Debido a que Eco-Driving brinda mejores resultados en condiciones lo más ideales posibles ambas pruebas basadas en el ciclo de conducción FTP-75 se realizan sin ningún tipo de carga, justificado en la guía aproximada para conducción a velocidad constante (en camino plano no en pendientes) el cambio óptimo de velocidad para cada auto debe ser identificado individualmente.[18] Mientras menos peso tenga el vehículo con el uso de Eco-Driving menores serán las emisiones emitidas por el vehículo.

A través de automatización del cálculo para la obtención de kilogramos de Co2 emitidos por cada tipo de ciclo de conducción mediante el programa Microsoft Excel el cual permitió realizar un cálculo matemático de una serie de ecuaciones en dónde se determinaron los valores Co2.
Los resultados se encuentran expuestos en tablas dónde se detalla cada una de las emisiones contaminantes recopiladas. Es así como el cálculo se encuentra automatizado para cada una de las tablas, determinando los valores finales únicamente reemplazando los valores de emisiones en cada uno de los apartados de la tabla principal, a través de esta herramienta complementaria se determinará el valor de huella de carbono que cada uno de los vehículos está produciendo, como resultado se obtienen valores en kilogramos de Co2 con los diferentes ciclos de conducción.

Todas las pruebas realizadas en los vehículos se llevaron a cabo en la ciudad de quito con la ayuda de los equipos proporcionados por dinamómetro Redin.

### 3.1.1 Características del combustible

El combustible es clave para determinar la huella de carbono ya que es necesario conocer la composición química del mismo.

**Tabla 7.** Composición química del combustible.

| **Composición química del combustible** | |
|---|---|
| Extra | $C_7H_{16}$ |

**Fuente:** Revista Infociencia. [19]

### 3.1.2 Ecuación estequiométrica

Ecuación general para la obtención de la relación estequiométrica de combustible que se requiere trabajar.

$$(x)C7h16\ + (y)O_2 = 13.68\, CO_2 + 0.27\, CO + 0.18\, O_2 + (a)H_2O \text{ [20]}$$

### 3.1.3 Automatización de cálculo

Para determinar los valores de las incógnitas de la ecuación estequiométrica es necesario igualar los carbonos, hidrógenos, y oxígenos de la ecuación al igual que determinar los valores de emisiones Co2, Co, O2 los cuales se obtienen a partir de una medición al escape del vehículo.

**Tabla 8.** Emisiones y composición química para resolución de ecuación estequiométrica.

| (x) | C | H | O+ | (y)O2= | Co2+ | Co+ | O2+ | (a)H2O |
|---|---|---|---|---|---|---|---|---|
| ? | ? | ? | ? | ? | ? | ? | ? | ? |

**Fuente:** Autor.

Para determinar los valores de (x), (y), y (a) se debe realizar un despeje de ecuaciones entre los valores de emisiones con su respectivo combustible, las variantes a introducir en la tabla automatizada son los valores de combustible (composición química), Co2, Co, y O2.

En la tabla 9 la sección marcada como "Value" y en tablas posteriores son los resultados que arrojará el modelo matemático al aplicar las variantes en la tabla 8.

**Tabla 9.** Ecuación automatizada para determinación de variables.

| | | |
|---|---|---|
| **Igualación de carbonos** | | |
| ? | x= | Value! |
| Ecuación= | Value! | |
| **Igualación de oxígenos** | | |
| ? 2 y = | Value! + ? + | Value! + a |
| **Igualación de hidrógenos** | | |
| Value! = | 2 | a |
| Ecuación = | Value! | |
| y = | Value! | |

**Fuente:** Autor.

Una vez determinadas las variantes los valores son reemplazados en la tabla de ecuación estequiométrica con el fin de obtener los Kg de Co2 mediante la detección de la masa molecular del combustible y del Co2.

**Tabla 10.** Reemplazo de variantes en ecuación estequiométrica.

| (x) | C | H | O+ | (y)O2 | Co2+ | Co+ | O2+ | (a)H2O |
|---|---|---|---|---|---|---|---|---|
| Value! | ? | ? | 0 | Value! | ? | ? | ? | Value! |
| **Calculo dividido para (x)** | | | | | | | | |
| (x) | C | H | O+ | (y)O2 | Co2+ | Co+ | O2+ | (a)H2O |
| Value! | ? | ? | 0 | Value! | Value! | Value! | Value! | Value! |

**Fuente:** Autor.

**Tabla 11.** Masa molecular elementos.

| Masa molecular carbono, hidrogeno, oxigeno | | | | | |
|---|---|---|---|---|---|
| C= | 12 | H= | 1 | O= | 16 |

**Fuente:** Autor.

**Tabla 12.** Cálculo de masa molecular y Kg de Co2/ Kg combustible.

| Masa molecular combustible | |
|---|---|
| Value! | Kg/mol |
| **Masa molecular Co2** | |
| 44 | Kg/mol |
| | |
| **Cálculo de kg de Co2** | |
| Value! | Kg Co2/kg combustible |

**Fuente.** Autor.

## 3.2 Materiales

### 3.2.1 Dinamómetro

El dinamómetro usado para las pruebas es un modelo de rodillos Sáenz BPVI 800 que cuenta con la inercia adecuada para pruebas de alta calidad capaz de soportar cualquier tipo de vehículo. [21]

### 3.2.2 Medidor de gases de escape

El analizador de gases QGA-6000 está configurado para realizar mediciones mediante (NDIR) infrarrojo no dispersivo para analizar CO, CO2 y HC, y por método electroquímico para analizar O2 y NOx. En el método de análisis NDIR una rampa que destella rayos infrarrojos está sujeta a un extremo de una celda de muestra mientras que el otro se acopla al sensor de detección que analiza los componentes de un gas para luego calcular su densidad, el método electroquímico mide la densidad del gas usando la cantidad de electrones producidos durante el tiempo de oxidación y reduciendo la reacción del gas. [22]

### 3.2.3 Vehículos

Para los vehículos estudiados se toma en cuenta las marcas Chevrolet, Volkswagen, y Kia debido que han presentado una gran participación en el mercado ecuatoriano desde el año 2012, siendo la mayor concentración de vehículos en la provincia de pichincha con porcentajes de 39,8% en automóviles, 27% SUV para Chevrolet, 58,7% en automóviles para Volkswagen, y 41,7% en SUV para Kia, todos estos datos fueron obtenidos mediante un estudio realizado por la AEADE en marzo 2021. [23]

**Tabla 2.** Ficha técnica Volkswagen Gol 1.6L 2012

| **Motor** | |
|---|---|
| Desplazamiento | 1598 cm3 |
| Disposición árbol de levas | OHC |

| | |
|---|---|
| Número de cilindros | 4 |
| Potencia Hp @ rpm | 101 @ 5250 |
| Torque Nm @ rpm | 143 @ 2500 |
| Válvulas | 8 |

**Fuente:** Ficha técnica VW Gol 2012[24]

**Tabla 3.** Ficha técnica Chevrolet Gran Vitara 2.0L 2015

| **Motor** | |
|---|---|
| Desplazamiento | 1995 cm3 |
| Disposición árbol de levas | OHC |
| Número de cilindros | 4 |
| Potencia Hp @ rpm | 127 @ 6000 |
| Torque Nm @ rpm | 182 @ 3000 |
| Válvulas | 16 |

**Fuente:** Ficha técnica Motor J20 Grand Vitara 2015[25]

**Tabla 4.** Ficha técnica Kia Sportage 2019 2.0L

| **Motor** | |
|---|---|
| Desplazamiento | 1999 cm3 |
| Disposición árbol de levas | CVVT DUAL |
| Número de cilindros | 4 |
| Potencia Hp @ rpm | 155 @ 6200 |
| Torque Nm @ rpm | 196 @ 4000 |
| Válvulas | 16 |

**Fuente:** Ficha técnica Kia Sportage 2019 [26]

**Tabla 5.** Ficha técnica Chevrolet Aveo 2018 1.5L

| **Motor** | |
|---|---|
| Desplazamiento | 1445 cm3 |
| Disposición árbol de levas | SOHC |
| Número de cilindros | 4 |
| Potencia Hp @ rpm | 83 @ 5600 |
| Torque Nm @ rpm | 128 @ 3000 |
| Válvulas | 8 |

**Fuente:** Ficha técnica Chevrolet Aveo 2018 [27]

**Tabla 6.** Ficha técnica Chevrolet Beat 2020 1.2 L

| **Motor** | |
|---|---|
| Desplazamiento | 1198 cm3 |
| Disposición árbol de levas | DOHC |
| Número de cilindros | 4 |
| Potencia Hp @ rpm | 80,5 @ 6400 |
| Torque Nm @ rpm | 108 @ 4800 |
| Válvulas | 16 |

**Fuente:** Ficha técnica Chevrolet Beat 2020 [28]

# 4. RESULTADOS Y DISCUSION

## 4.1.1 Requerimientos iniciales de prueba

Los vehículos deben estar en temperatura de funcionamiento optimo antes de realizarse las pruebas requeridas, se toma en cuenta la altura de 2850 metros sobre el nivel del mar, el combustible utilizado en todos los vehículos es la gasolina extra. Cabe recalcar que todos los autos en el estudio se encontraban en estado optimo realizados previamente su mantenimiento respectivo.

## 4.1.2 Resultados de laboratorio

Los valores de emisiones de Co, Co2, y O2 se obtuvieron a partir de los parámetros de medición basados en FTP-75, donde los vehículos realizan una prueba de rodaje en un banco de rodillos inercial a una velocidad máxima de 90 km/h a 3500 rpm y aplicando el método de conducción eficiente que no sobrepasa las 2500 por un lapso de 1700s, al escape es introducido una sonda para medición de gases la cuál presenta valores dinámicos a lo largo de la prueba presentados en la tabla 13.

**Tabla 13.** Valores de emisiones a 3500 y 2500 RPM (Volkswagen)

| **Volkswagen gol 1.6 2012 @ 3500 rpm** | | | | **Volkswagen gol 1.6 2012 @ 2500 rpm** | | |
|---|---|---|---|---|---|---|
| **Co** | | **Co2** | **O2** | **Co** | **Co2** | **O2** |
| 0.06 | | 13.2 | 0.25 | 0.15 | 12.5 | 0.82 |
| 0.05 | | 13.1 | 0.34 | 0.21 | 11.6 | 0.96 |
| 0.07 | | 13.1 | 0.33 | 0.15 | 12.5 | 0.84 |
| 0.08 | | 13.1 | 0.33 | 0.19 | 12.5 | 0.85 |
| 0.09 | | 13.0 | 0.42 | 0.17 | 12.5 | 0.87 |
| **Promedio** | 0.07 | 13.2 | 0.33 | 0.17 | 12.3 | 0.86 |

**Fuente:** Autor.

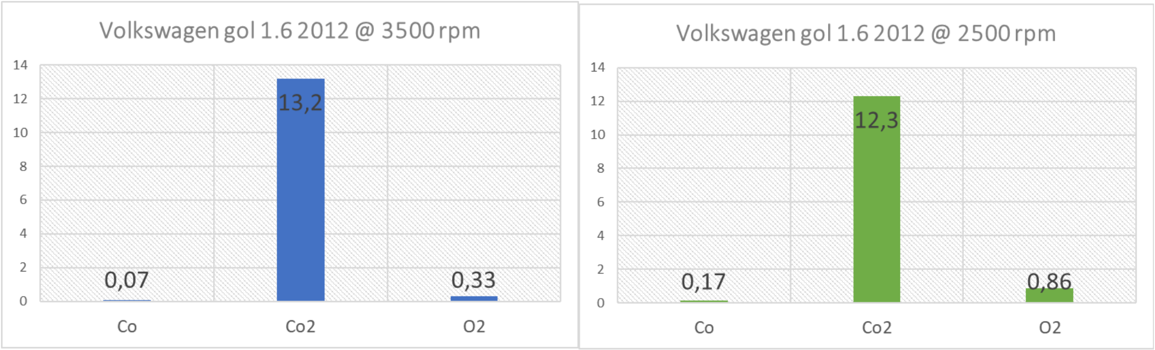

**Figura 5.** Valores de emisiones Volkswagen gol 2012.
**Fuente:** Autor.

**Tabla 14.** Valores de emisiones a 3500 y 2500 RPM (Grand Vitara).

| **Grand Vitara 2015 2.0 @ 3500 rpm** | | | | **Grand Vitara 2015 2.0 @ 2500 rpm** | | |
|---|---|---|---|---|---|---|
| **Co** | | **Co2** | **O2** | **Co** | **Co2** | **O2** |
| 0 | | 15.2 | 0.23 | 0.02 | 14.8 | 0.16 |
| 0 | | 15.2 | 0.25 | 0.05 | 14.9 | 0.20 |
| 0 | | 15.2 | 0.23 | 0.02 | 15.1 | 0.14 |
| 0 | | 15.2 | 0.21 | 0.06 | 15.2 | 0.20 |
| 0 | | 15.2 | 0.19 | 0.02 | 15.1 | 0.16 |
| **Promedio** | 0.03 | 15.2 | 0,17 | 0 | 15.2 | 0,22 |

**Fuente:** Autor.

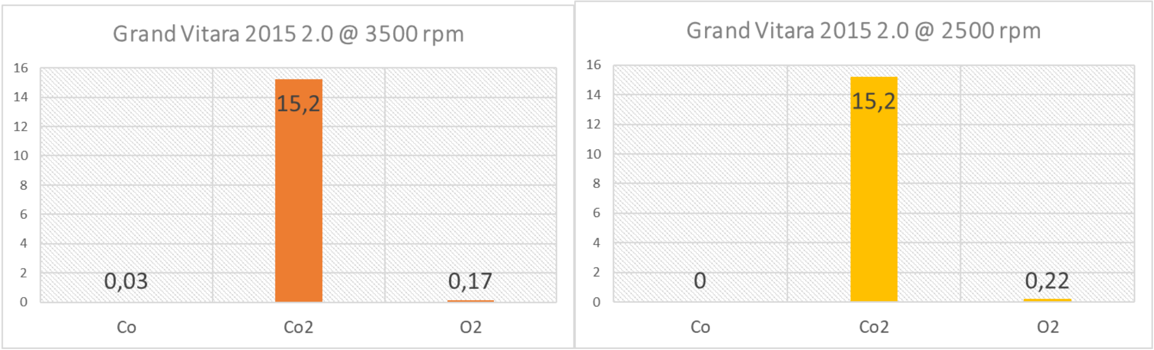

**Figura 6.** Valores de emisiones Grand Vitara 2015.
**Fuente:** Autor.

**Tabla 15.** Valores de emisiones 3500 y 2500 RPM (Kia Sportage).

| **Kia Sportage 2019 2.0 @ 3500 rpm** | | | **Kia Sportage 2019 2.0 @ 2500 rpm** | | |
|---|---|---|---|---|---|
| **Co** | **Co2** | **O2** | **Co** | **Co2** | **O2** |
| 1,34 | 11,9 | 0.15 | 1,13 | 17,3 | 0.11 |
| 0,91 | 11,2 | 0.14 | 1,79 | 18,9 | 0,11 |
| 0.86 | 10,8 | 0,17 | 1,75 | 15,7 | 0,11 |
| 1.36 | 11.4 | 0.14 | 0,99 | 15,2 | 0.13 |
| 1,11 | 11,3 | 0.14 | 0,76 | 15,1 | 0.14 |

|  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|
| **Promedio** | 1.11 | 11,3 | 0,14 | 1.28 | 16,44 | 0,12 |

**Fuente:** Autor

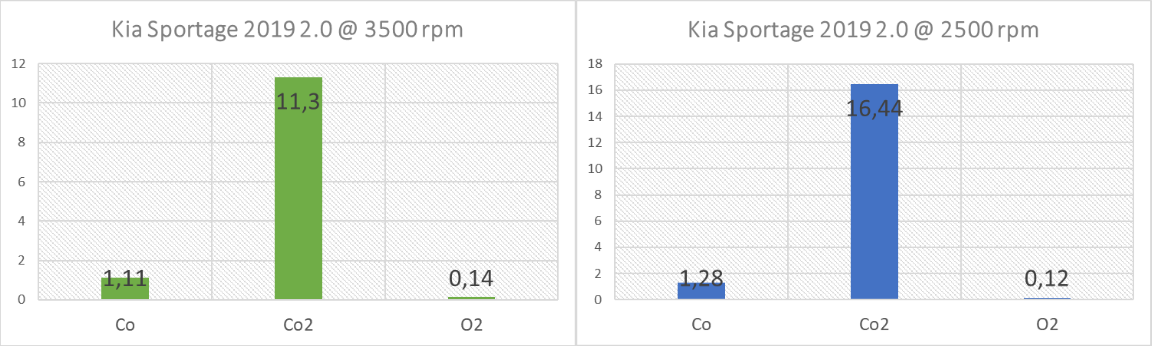

**Figura 7.** Valores de emisiones Kia Sportage 2019.
**Fuente:** Autor.

**Tabla 16.** Valores de emisiones 3500 y 2500 RPM (Chevrolet Aveo).

| **Chevrolet Aveo 2018 1.5 @ 3500 rpm** |  |  |  | **Chevrolet Aveo 2018 1.5 @ 2500 rpm** |  |  |
|---|---|---|---|---|---|---|
| **Co** |  | **Co2** | **O2** | **Co** | **Co2** | **O2** |
| 0,04 |  | 13.2 | 0.20 | 2,58 | 12,3 | 0.20 |
| 0,01 |  | 13.0 | 0.17 | 2.10 | 12.2 | 0,52 |
| 0,27 |  | 13,5 | 0,11 | 1,18 | 15,1 | 1,21 |
| 0,34 |  | 13.6 | 0.11 | 1.19 | 15.5 | 0,45 |
| 0.09 |  | 12.9 | 0,13 | 2.39 | 16.9 | 0,07 |
| **Promedio** | 0.15 | 13,2 | 0,14 | 1.88 | 14,4 | 0,49 |

**Fuente:** Autor

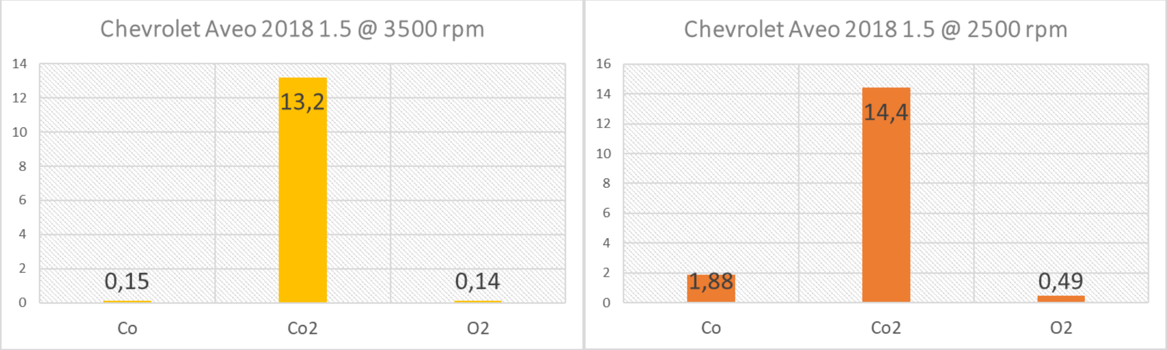

**Figura 8.** Valores de emisiones Chevrolet Aveo 2018.
**Fuente:** Autor.

**Tabla 17.** Valores de emisiones 3500 y 2500 RPM (Chevrolet Beat).

| **Chevrolet Beat 2010 1.2 @ 3500 rpm** |  |  | **Chevrolet Beat 2010 1.2 @ 2500 rpm** |  |  |
|---|---|---|---|---|---|
| **Co** | **Co2** | **O2** | **Co** | **Co2** | **O2** |
| 0.12 | 15.5 | 0.13 | 0.19 | 15 | 0,10 |
| 0,02 | 15,5 | 0,12 | 0.39 | 15 | 0,10 |
| 0 | 15,6 | 0,11 | 0,87 | 15 | 0,10 |

|  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|
|  | 0,01 | 15,6 | 0,10 | 0,58 | 15,4 | 0,09 |
|  | 0,05 | 15.5 | 0,10 | 0,83 | 14,9 | 0,14 |
| **Promedio** | 0,04 | 15,5 | 0,11 | 0,57 | 15.09 | 0,10 |

**Fuente:** Autor.

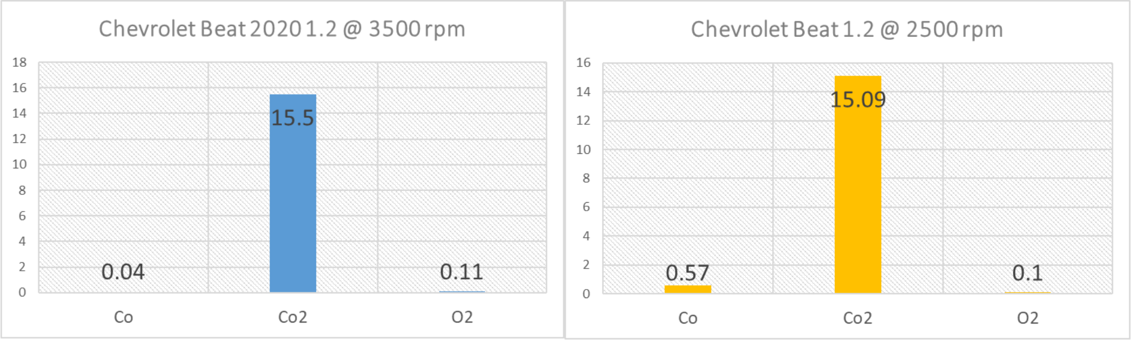

**Figura 9.** Valores de emisiones Chevrolet Beat.

**Fuente:** Autor

Una vez obtenidos todos los valores de emisiones son promediados para utilizarlos como variantes a introducir el en modelo automatizado para la detección de huella de carbono, estos valores son presentados en la tabla 14.

**Tabla 18.** Valores de kg de Co2/Kg de combustible (3500 y 2500 rpm)

| **Cálculo de Kg de Co2** |  |  |
|---|---|---|
| **Vehículo** | **3500 rpm** | **2500 rpm** |
| VW gol 2012 | 3.06 kg | 3.03 kg |
| Grand vitara 2015 | 3.08 kg | 3.07 kg |
| Sportage 2019 | 2.80 kg | 2.85 kg |
| Chevrolet Aveo 2018 | 3.04 kg | 2.72 kg |
| Chevrolet beat 2020 | 3.07 kg | 2.96 kg |

**Fuente:** Autor.

## 4.2 Discusión

Los resultados obtenidos que presenta el cálculo de huella de carbono según el tipo de conducción convencional frente a conducción eficiente Eco-Driving la cuál presenta una reducción de la cantidad de kilogramos de Co2 emitidos al ambiente esta listada de la siente manera;

Para el vehículo Volkswagen Gol son del 3,06 Kg de co2/Kg de combustible frente a 3,03 kg de co2/Kg de combustible teniendo una reducción del 0,98%, para Grand Vitara son del 3.08 Kg de co2/Kg de combustible frente a 3.07 Kg de co2/Kg de combustible con un porcentaje de reducción de 0,32%, para Kia Sportage son 2.80 Kg de co2/Kg de combustible frente a 2.85 Kg de co2/Kg de combustible, en este caso Eco-Driving no presentó una reducción en las emisiones de Co2 lo que significa que no es recomendable aplicar esta técnica de conducción en este vehículo.

Para Chevrolet Aveo los valores son de 3.04 Kg de co2/Kg de combustible frente a 2.72 Kg de co2/Kg de combustible presentando un porcentaje de reducción de 10.53%, finalmente para Chevrolet Beat los valores son de 3.07 Kg de co2/Kg de combustible frente a 2.96 Kg de co2/Kg de combustible con una reducción de 3.58%.

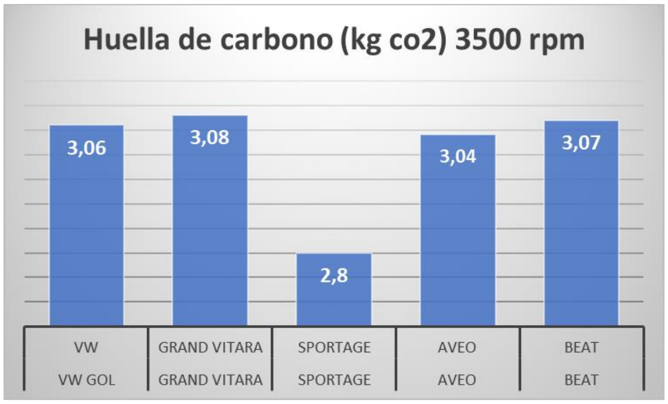

**Figura 10.** Huella de carbono a 3500 rpm
**Fuente:** Autor.

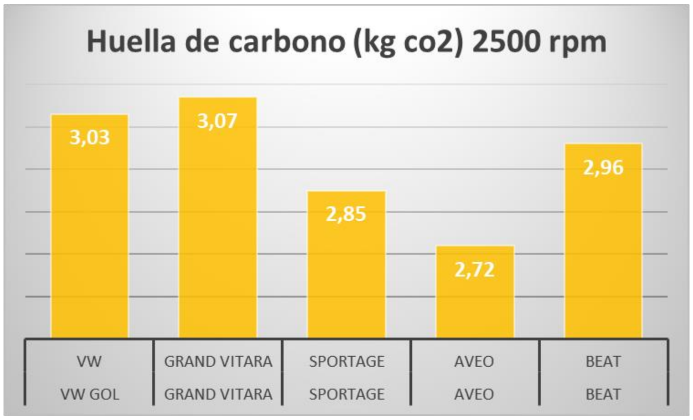

**Figura 11.** Huella de carbono a 2500 rpm
**Fuente:** Autor.

En Ecuador para el año 2020 se matricularon 2,361.175 vehículos motorizados registrados por la INEC. [29]

| Principales variables investigadas | 2019 | 2020 |
|---|---|---|
| Vehículos motorizados matriculados | 2.311.960 | 2.361.175 |
| Pasajeros transportados por ferrocarril | 109.627 | 19.887 |
| Entrada internacional de pasajeros por vía aérea | 2.199.087 | 721.691 |
| Salida internacional de pasajeros por vía aérea | 2.239.931 | 783.476 |
| Entrada internacional de pasajeros por vía marítima | 25.728 | 10.510 |
| Salida internacional de pasajeros por vía marítima | 19.999 | 10.510 |
| Siniestros de tránsito | 24.595 | 16.972 |

**Figura 12.** Resumen 2020 estadística de transporte
**Fuente.** INEC. [29]

En el caso hipotético de que todos los vehículos matriculados ocupen el mismo combustible, y los valores promediados de los 5 vehículos en los que se realizaron las pruebas se mantuvieran como una constante reflejando los valores huella de carbono a 3500 y 2500 rpm se procede a realizar el cálculo para determinar el porcentaje de Co2 final como se puede observar en la tabla 15.

**Tabla 19.** Promedio huella de carbono

| **Promedio huella de carbono entre vehículos analizados** | |
|---|---|
| **3500 rpm** | **Eco-Driving (2500 rpm)** |
| 3.02 kg de Co2/kg de combustible | 2.92 kg de C02/kg de combustible |

**Fuente:** Autor.

Al multiplicar los valores de huella de carbono por el total de vehículos matriculados el cual es 2.361,175, aplicando eco-Driving se obtuvo una diferencia de 236.117 kg de Co2 lo que implica una reducción de 3,31%.

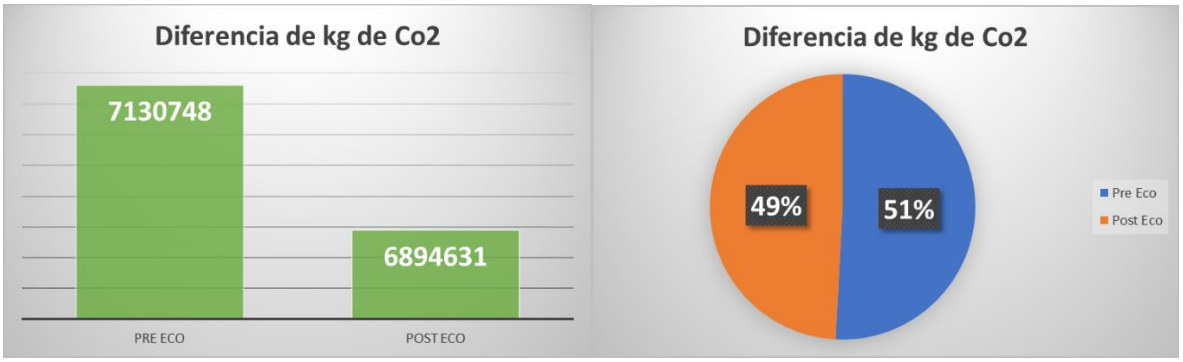

**Figura 13.** Valores de kg de Co2
**Fuente:** Autor

## 5. CONCLUSIONES

Los resultados obtenidos de las pruebas realizadas en los 5 vehículos a distintas revoluciones por minuto permiten concluir que, la conducción eficiente Eco-Driving presenta una reducción de kilogramos de dióxido de carbono del 3.31% tomando en cuenta que ambas pruebas siguieron los mismos parámetros establecidos por FTP-75, aplicar este tipo de conducción eficiente resultaría a nivel nacional, tomando en cuenta el número de vehículos matriculados, la reducción aproximada de 236 mil kilogramos de dióxido de carbono emitido al ambiente.

La aplicación del modelo automatizado de cálculo de huella de carbono puede aplicarse para formar una nueva normativa regularizando la cantidad de Co2 emitido al ambiente, cabe recalcar que el modelo matemático no está sujeto a un solo tipo de combustible ya que todos los parámetros son editables para cualquier tipo de combustible incluyendo aquellos reformulados con etanol.

Debido a que en Ecuador la normativa 2204 no presenta ningún apartado el control de emisiones máximas de Co2 emitidas por vehículos, la inclusión de esta herramienta automatizada facilitará la detección y el valor máximo que deberían tener los vehículos para evitar un exceso de gases de efecto invernadero en el ambiente.

El conducir bajo Eco-Driving en un régimen de hasta 2500 RPM para cambios de marcha y velocidad estándar de motor, permite la disminución de Dióxido de carbono hasta en un 10% a diferencia de la conducción tradicional según el vehículo en el que se lo aplique, la reducción anual que presentaría a nivel nacional da como resultado una cantidad de 7600 toneladas de Co2 frente a las 7.860 toneladas de Co2 que se está presentando anualmente lo que significa una reducción de 260 toneladas de dióxido de carbono emitido al ambiente.

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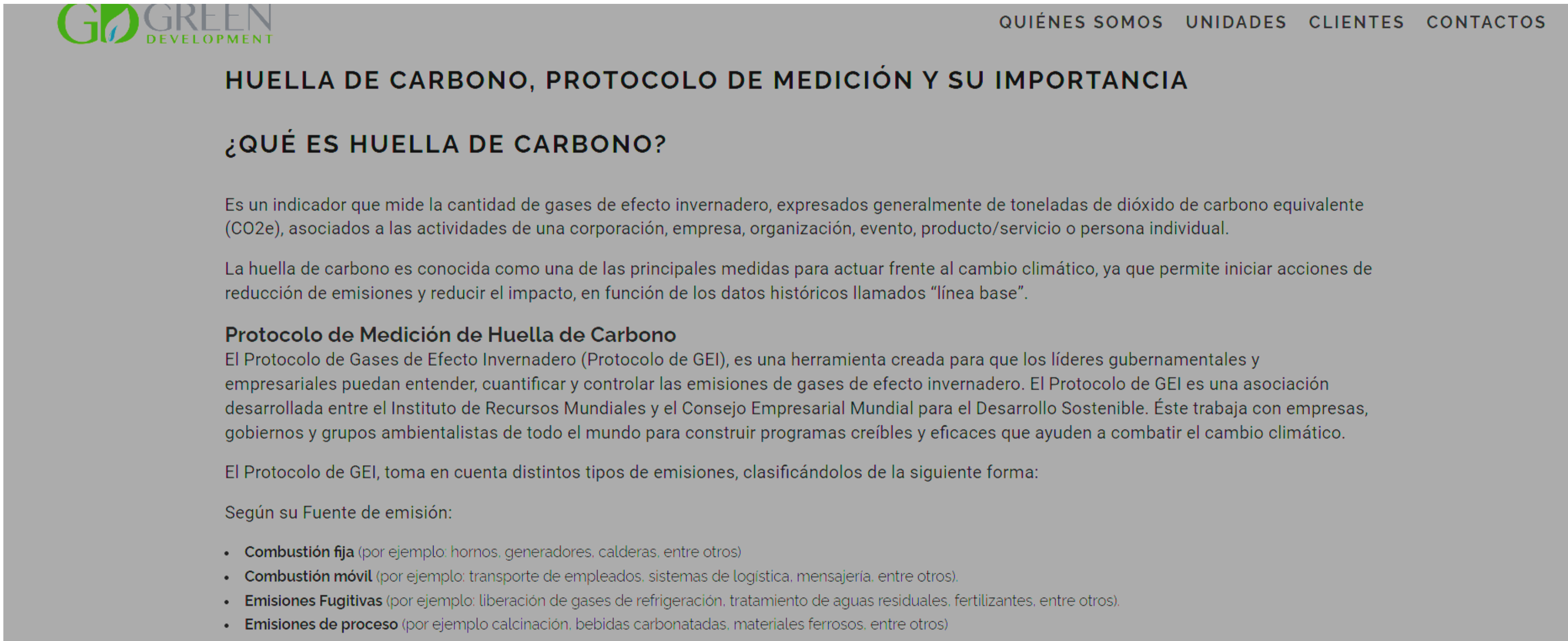
## 7. ANEXOS

### 7.1 ANEXOS INTRODUCCION



HUELLA DE CARBONO, PROTOCOLO DE MEDICIÓN Y SU IMPORTANCIA

¿QUÉ ES HUELLA DE CARBONO?

Es un indicador que mide la cantidad de gases de efecto invernadero, expresados generalmente de toneladas de dióxido de carbono equivalente (CO2e), asociados a las actividades de una corporación, empresa, organización, evento, producto/servicio o persona individual.

La huella de carbono es conocida como una de las principales medidas para actuar frente al cambio climático, ya que permite iniciar acciones de reducción de emisiones y reducir el impacto, en función de los datos históricos llamados “línea base”.

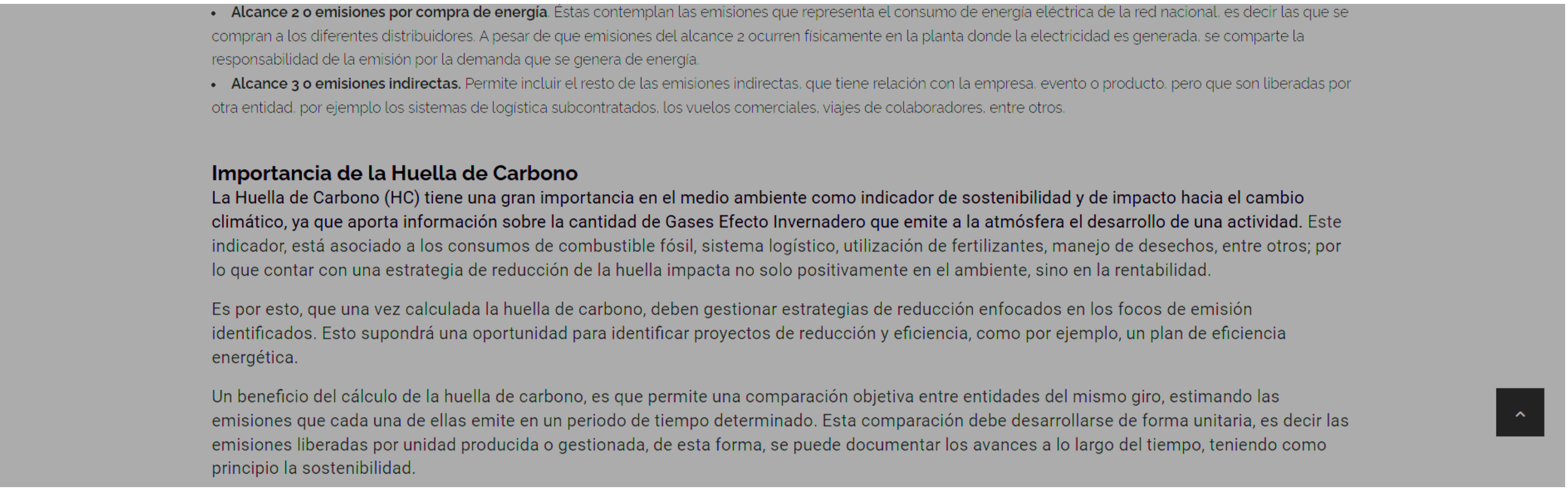
**Protocolo de Medición de Huella de Carbono**

El Protocolo de Gases de Efecto Invernadero (Protocolo de GEI), es una herramienta creada para que los líderes gubernamentales y empresariales puedan entender, cuantificar y controlar las emisiones de gases de efecto invernadero. El Protocolo de GEI es una asociación desarrollada entre el Instituto de Recursos Mundiales y el Consejo Empresarial Mundial para el Desarrollo Sostenible. Éste trabaja con empresas, gobiernos y grupos ambientalistas de todo el mundo para construir programas creíbles y eficaces que ayuden a combatir el cambio climático.

El Protocolo de GEI, toma en cuenta distintos tipos de emisiones, clasificándolos de la siguiente forma:

Según su Fuente de emisión:

- **Combustión fija** (por ejemplo: hornos, generadores, calderas, entre otros)
- **Combustión móvil** (por ejemplo: transporte de empleados, sistemas de logística, mensajería, entre otros).
- **Emisiones Fugitivas** (por ejemplo: liberación de gases de refrigeración, tratamiento de aguas residuales, fertilizantes, entre otros).
- **Emisiones de proceso** (por ejemplo calcinación, bebidas carbonatadas, materiales ferrosos, entre otros)



- **Alcance 2 o emisiones por compra de energía**. Éstas contemplan las emisiones que representa el consumo de energía eléctrica de la red nacional, es decir las que se compran a los diferentes distribuidores. A pesar de que emisiones del alcance 2 ocurren físicamente en la planta donde la electricidad es generada, se comparte la responsabilidad de la emisión por la demanda que se genera de energía.
- **Alcance 3 o emisiones indirectas.** Permite incluir el resto de las emisiones indirectas, que tiene relación con la empresa, evento o producto, pero que son liberadas por otra entidad, por ejemplo los sistemas de logística subcontratados, los vuelos comerciales, viajes de colaboradores, entre otros.

## Importancia de la Huella de Carbono

**La Huella de Carbono (HC) tiene una gran importancia en el medio ambiente como indicador de sostenibilidad y de impacto hacia el cambio climático, ya que aporta información sobre la cantidad de Gases Efecto Invernadero que emite a la atmósfera el desarrollo de una actividad.** Este indicador, está asociado a los consumos de combustible fósil, sistema logístico, utilización de fertilizantes, manejo de desechos, entre otros; por lo que contar con una estrategia de reducción de la huella impacta no solo positivamente en el ambiente, sino en la rentabilidad.

Es por esto, que una vez calculada la huella de carbono, deben gestionar estrategias de reducción enfocados en los focos de emisión identificados. Esto supondrá una oportunidad para identificar proyectos de reducción y eficiencia, como por ejemplo, un plan de eficiencia energética.

Un beneficio del cálculo de la huella de carbono, es que permite una comparación objetiva entre entidades del mismo giro, estimando las emisiones que cada una de ellas emite en un periodo de tiempo determinado. Esta comparación debe desarrollarse de forma unitaria, es decir las emisiones liberadas por unidad producida o gestionada, de esta forma, se puede documentar los avances a lo largo del tiempo, teniendo como principio la sostenibilidad.

# A Definition of 'Carbon Footprint'

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## Abstract

The term 'carbon footprint' has become tremendously popular over the last few years and is now in widespread use across the media – at least in the United Kingdom. With climate change high up on the political and corporate agenda, carbon footprint calculations are in strong demand. Numerous approaches have been proposed to provide estimates, ranging from basic online calculators to sophisticated life-cycle-analysis or input-output-based methods and tools. Despite its ubiquitous use however, there is an apparent lack of academic definitions of what exactly a 'carbon footprint' is meant to be. The scientific literature is surprisingly void of clarifications, despite the fact that countless studies in energy and ecological economics that could have claimed to measure a 'carbon footprint' have been published over decades.

This report explores the apparent discrepancy between public and academic use of the term 'carbon footprint' and suggests a scientific definition based on commonly accepted accounting principles and modelling approaches. It addresses methodological question such as system boundaries, completeness, comprehensiveness, units and robustness of the indicator.

## Keywords

carbon footprint, ecological footprint, indirect carbon emissions, indicators, environmental accounting, input-output analysis, life-cycle analysis, hybrid analysis

## Introduction

'Carbon footprint' has become a widely used term and concept in the public debate on responsibility and abatement action against the threat of global climate change. It had a tremendous increase in public appearance over the last few months and years and is now a buzzword widely used across the media, the government and in the business world.

But what exactly is a 'carbon footprint'? Despite its ubiquitous appearance there seems to be no clear definition of this term and there is still some confusion what it actually means and measures and what unit is to be used. While the term itself is rooted in the language of Ecological Footprinting (Wackernagel 1996), the common baseline is that the carbon footprint stands for a certain amount of gaseous emissions that are relevant to climate change and associated with human production or consumption activities. But this is almost where the commonality ends. There is no consensus on how to measure or quantify a carbon footprint. The spectrum of definitions ranges from direct $CO_2$ emissions to full life-cycle greenhouse gas emissions and not even the units of measurement are clear.

Questions that need to be asked are: Should the carbon footprint include just carbon dioxide ($CO_2$) emissions or other greenhouse gas emissions as well, e.g. methane? Should it be restricted to carbon-based gases or can it include substances that don't have carbon in their molecule, e.g. $N_2O$, another powerful greenhouse gas? One could even go as far as asking whether the carbon footprint should be restricted to substances with a greenhouse warming potential at all. After all, there are gaseous emissions such as carbon monoxide (CO) that are based on carbon and relevant to the environment and health. What's more, CO can be converted into $CO_2$ through chemical processes in the atmosphere. Also, should the measure include all sources of emissions, including those that do not stem from fossil fuels, e.g. $CO_2$ emissions from soils?

A very central question is whether the carbon footprint needs to include indirect emissions embodied in upstream production processes or whether it is sufficient to look at just the direct, on-site emissions of the product, process or person under consideration. In other words, should the carbon footprint reflect all life-cycle impacts of goods and services used? If yes, where should the boundary be drawn and how can these impacts be quantified?

Finally, the term 'footprint' seems to suggest a measurement (expression) in area-based units. After all, a linguistically close relative, the 'Ecological Footprint' is expressed (measured) in hectares or 'global hectares'. This question, however, has even more far-reaching implications as it goes down to the very decision whether the carbon footprint should be a mere 'pressure' indicator expressing (just) the amount of carbon emissions (measured e.g. in tonnes) or whether it should indicate a (mid-point) impact, quantified in tonnes of $CO_2$ equivalents (t $CO_2$-eq.) if the impact is global warming potential, or in an area-based unit if the impact is 'land appropriation'.

Many of these questions have been discussed in the disciplines of ecological economics and life-cycle assessment for many years and therefore some answers are at hand. So far, however, they have not been applied to the term carbon footprint and thus a clear definition is currently missing.

This report addresses the questions above and attempts a clarification. We provide a literature overview, propose a working definition of the term 'carbon footprint' and discuss methodological implications.

## A brief literature review

A literature search in June 2007 for the term "carbon footprint" (i.e. where these two words stand next to each other in this order) in all scientific journals and all search fields covered by Scopus[1] and ScienceDirect[2] for the years 1960 to

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[1] Scopus (www.scopus.com) is currently the largest abstract and citation database of peer-reviewed

## A definition of 'carbon footprint'

We propose the following definition of the term 'carbon footprint':

**"The carbon footprint is a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product."**

This includes activities of individuals, populations, governments, companies, organisations, processes, industry sectors etc. Products include goods and services. In any case, all direct (on-site, internal) and indirect emissions (off-site, external, embodied, upstream, downstream) need to be taken into account.

The definition provides some answers to the questions posed at the beginning. We include only $CO_2$ in the analysis, being well aware that there are other substances with greenhouse warming potential. However, many of those are either not based on carbon or are more difficult to quantify because of data availability. Methane could easily be included, but what information is gained from a partially aggregated indicator, that includes just two of a number of relevant greenhouse gases? A comprehensive greenhouse gas indicator should include all these gases and could for example be termed 'climate footprint'. In the case of 'carbon footprint' we opt for the most practical and clear solution and include only $CO_2$.

The definition also refrains from expressing the carbon footprint as an area-based indicator. The 'total amount' of $CO_2$ is physically measured in mass units (kg, t, etc) and thus no conversion to an area unit (ha, $m^2$, $km^2$, etc) takes place. The conversion into a land area would have to be based on a variety of different assumptions and increases the uncertainties and errors associated with a particular footprint estimate (see e.g. Lenzen 2006). For this reason accountants usually try to avoid unnecessary conversions and attempt to express any phenomenon in the most appropriate measurement unit (e.g. Keuning 1994; Stahmer 2000). Following this rationale a land-based measure does not seem appropriate and we prefer the more accurate representation in tonnes of carbon dioxide.

Whilst it is important for the concept of 'carbon footprint' to be all-encompassing and to include all possible causes that give rise to carbon emissions, it is equally important to make clear what this includes. The correct measurement of carbon footprints gains a particular importance and precariousness when it comes to carbon offsetting. It is obvious that a clear definition of scope and boundaries is essential when projects to reduce or sequester $CO_2$ emissions are sponsored. When accounting for indirect emissions, methodologies need to be applied that avoid under-counting as well as double-counting of emissions, therefore the word 'exclusive' in the definition.[5] Furthermore, a full life-cycle assessment of products means that all the stages of this life cycle need to be evaluated correctly (with "full" meaning "untruncated"). In the following section we discuss the methodological implications of these requirements.

## Methodological issues

The task of calculating carbon footprints can be approached methodologically from two different directions: bottom-up, based on Process Analysis (PA) or top-down, based on Environmental Input-Output (EIO) analysis. Both methodologies need to deal with the challenges outlined above and strive to capture the full life cycle impacts, i.e. inform a full Life Cycle Analysis/Assessment (LCA). Here, only a brief impression of some of their main merits and drawbacks can be provided.

Process analysis (PA) is a bottom-up method, which has been developed to understand the environmental impacts of individual products from cradle to grave. The bottom-up nature of PA-LCAs (process-based LCAs) means that they suffer from a system boundary problem - only on-site, most first-order, and some second-order impacts are considered (Lenzen 2001). If PA-LCAs are used for deriving carbon footprint estimates, a strong emphasis therefore needs to be given to the identification of appropriate system boundaries, which minimise this truncation error. PA-based LCAs run into further difficulties once carbon footprints for larger entities such as government, households or particular industrial sectors have to be established. Even though estimates can be derived by extrapolating information contained in life-cycle databases, results will get increasingly patchy as these procedures usually require the assumption that a subset of individual products are representative for a larger product grouping and the use of information from different databases, which are usually not consistent (see e.g. Tukker and Jansen 2006).

Environmental input-output (EIO) analysis provides an alternative top-down approach to carbon footprinting (see e.g. Wiedmann et al. 2006). Input-output tables are economic accounts providing a picture of all economic activities at the meso (sector) level. In combination with consistent environmental account data they can be used to establish carbon footprint estimates in a comprehensive and robust way taking into account all higher order impacts and setting the whole economic system as boundary. However, this completeness comes at the expense of detail. The suitability of environmental input-output

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[5] Compare with the discussion of 'shared reponsibility' as outlined by Lenzen et al. (2007).

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|---|---|
| Grub & Ellis (2007) | "A carbon footprint is a measure of the amount of carbon dioxide emitted through the combustion of fossil fuels. In the case of a business organization, it is the amount of $CO_2$ emitted either directly or indirectly as a result of its everyday operations. It also might reflect the fossil energy represented in a product or commodity reaching market." |

# Carbon footprint: current methods of estimation

**Divya Pandey · Madhoolika Agrawal ·
Jai Shanker Pandey**

Received: 7 April 2010 / Accepted: 23 August 2010

**Abstract** Increasing greenhouse gaseous concentration in the atmosphere is perturbing the environment to cause grievous global warming and associated consequences. Following the rule that only measurable is manageable, mensuration of greenhouse gas intensiveness of different products, bodies, and processes is going on worldwide, expressed as their carbon footprints. The methodologies for carbon footprint calculations are still evolving and it is emerging as an important tool for greenhouse gas management. The concept of carbon footprinting has permeated and is being commercialized in all the areas of life and economy, but there is little coherence in definitions and calculations of carbon footprints among the studies. There are disagreements in the selection of gases, and the order of emissions to be covered in footprint calculations. Standards of greenhouse gas accounting are the common resources used in footprint calculations, although there is no mandatory provision of footprint verification. Carbon footprinting is intended to be a tool to guide the relevant emission cuts and verifications, its standardization at international level are therefore necessary. Present review describes the prevailing carbon footprinting methods and raises the related issues.

**Keywords** Carbon footprint · Direct emissions · Embodied emissions · Greenhouse gases

## Introduction

The Intergovernmental Panel on Climate Change (IPCC) in its fourth assessment report has strongly recommended to limit the increase in global temperature below 2°C as compared to preindustrial level (i.e., measured from 1750) to avoid serious ecological and economic threats. A rise in temperature by 0.74°C has already been recorded and hence climate scientists are focusing on an urgent action to curb global warming (IPCC 2007; Kerr 2007). The imbalances caused in natural systems due to warming are already being signaled in the form of extreme weather events and climate change. The mountainous snow cover, permafrost, and glaciers are melting and Greenland, Antarctic, and Arctic ice packs are experiencing a

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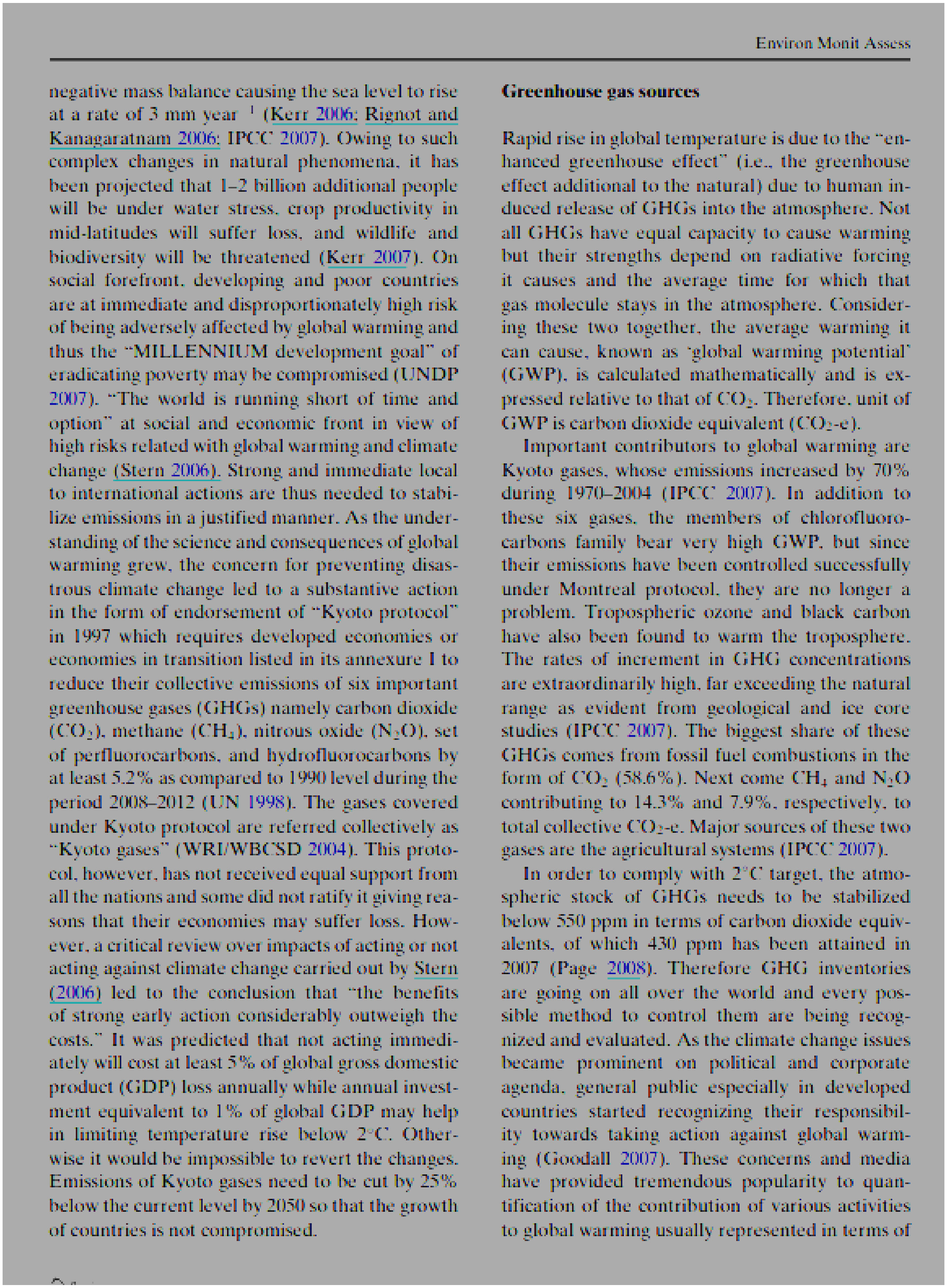


negative mass balance causing the sea level to rise at a rate of 3 mm year$^{-1}$ (Kerr 2006; Rignot and Kanagaratnam 2006; IPCC 2007). Owing to such complex changes in natural phenomena, it has been projected that 1–2 billion additional people will be under water stress, crop productivity in mid-latitudes will suffer loss, and wildlife and biodiversity will be threatened (Kerr 2007). On social forefront, developing and poor countries are at immediate and disproportionately high risk of being adversely affected by global warming and thus the "MILLENNIUM development goal" of eradicating poverty may be compromised (UNDP 2007). "The world is running short of time and option" at social and economic front in view of high risks related with global warming and climate change (Stern 2006). Strong and immediate local to international actions are thus needed to stabilize emissions in a justified manner. As the understanding of the science and consequences of global warming grew, the concern for preventing disastrous climate change led to a substantive action in the form of endorsement of "Kyoto protocol" in 1997 which requires developed economies or economies in transition listed in its annexure I to reduce their collective emissions of six important greenhouse gases (GHGs) namely carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$), set of perfluorocarbons, and hydrofluorocarbons by at least 5.2% as compared to 1990 level during the period 2008–2012 (UN 1998). The gases covered under Kyoto protocol are referred collectively as "Kyoto gases" (WRI/WBCSD 2004). This protocol, however, has not received equal support from all the nations and some did not ratify it giving reasons that their economies may suffer loss. However, a critical review over impacts of acting or not acting against climate change carried out by Stern (2006) led to the conclusion that "the benefits of strong early action considerably outweigh the costs." It was predicted that not acting immediately will cost at least 5% of global gross domestic product (GDP) loss annually while annual investment equivalent to 1% of global GDP may help in limiting temperature rise below 2°C. Otherwise it would be impossible to revert the changes. Emissions of Kyoto gases need to be cut by 25% below the current level by 2050 so that the growth of countries is not compromised.

## Greenhouse gas sources

Rapid rise in global temperature is due to the "enhanced greenhouse effect" (i.e., the greenhouse effect additional to the natural) due to human induced release of GHGs into the atmosphere. Not all GHGs have equal capacity to cause warming but their strengths depend on radiative forcing it causes and the average time for which that gas molecule stays in the atmosphere. Considering these two together, the average warming it can cause, known as 'global warming potential' (GWP), is calculated mathematically and is expressed relative to that of $CO_2$. Therefore, unit of GWP is carbon dioxide equivalent ($CO_2$-e).

Important contributors to global warming are Kyoto gases, whose emissions increased by 70% during 1970–2004 (IPCC 2007). In addition to these six gases, the members of chlorofluorocarbons family bear very high GWP, but since their emissions have been controlled successfully under Montreal protocol, they are no longer a problem. Tropospheric ozone and black carbon have also been found to warm the troposphere. The rates of increment in GHG concentrations are extraordinarily high, far exceeding the natural range as evident from geological and ice core studies (IPCC 2007). The biggest share of these GHGs comes from fossil fuel combustions in the form of $CO_2$ (58.6%). Next come $CH_4$ and $N_2O$ contributing to 14.3% and 7.9%, respectively, to total collective $CO_2$-e. Major sources of these two gases are the agricultural systems (IPCC 2007).

In order to comply with 2°C target, the atmospheric stock of GHGs needs to be stabilized below 550 ppm in terms of carbon dioxide equivalents, of which 430 ppm has been attained in 2007 (Page 2008). Therefore GHG inventories are going on all over the world and every possible method to control them are being recognized and evaluated. As the climate change issues became prominent on political and corporate agenda, general public especially in developed countries started recognizing their responsibility towards taking action against global warming (Goodall 2007). These concerns and media have provided tremendous popularity to quantification of the contribution of various activities to global warming usually represented in terms of "carbon footprint". However, information available on carbon footprinting beset with uncertainty and inconsistency (Schiermeier 2006; Wiedmann and Minx 2007; Kenny and Gray 2008; Padgett et al. 2008). The objective of the present review is to systematically analyze the relevant available information on global warming, GHG emissions and characteristics, carbon footprinting concepts, calculation of carbon footprints, methodology followed for estimation, and uses of this by general public, corporate sector, industries, and governments.

## Concept of carbon footprint

Origin of carbon footprint can be traced back to as a subset of "ecological footprint" proposed by Wackernagel and Rees (1996). Ecological footprint refers to the biologically productive land and sea area required to sustain a given human population expressed as global hectares. According to this concept, carbon footprint refers to the land area required to assimilate the entire $CO_2$ produced by the mankind during its lifetime. In due course of time as the global warming issue took prominence in the world environmental agenda, use of carbon footprint became common independently, although in a modified form (East 2008). The concept of carbon footprinting has been in use since several decades but known differently as life cycle impact category indicator global warming potential (Finkbeiner 2009). Therefore, the present form of carbon footprint may be viewed as a hybrid, deriving its name from "ecological footprint", and conceptually being a global warming potential indicator. There are few studies that report carbon footprint in terms of global hectares notwithstanding the modern nexus about it (Browne et al. 2009). Besides its widespread favorable public reputation as an indicator of contribution of an entity to the global warming, there are confusions over what it exactly means (Wiedmann and Minx 2007; East 2008; Finkbeiner 2009; Peters 2010). It is also remarked that the scientific literature on the subject is scarce and the most studies have been carried out by private organizations and companies predominantly due to their business sense rather than their environmental responsibility (Kleiner 2007; Wiedmann and Minx 2007; East 2008). Other terms used associated or sometimes as a synonym of carbon footprint in the available literature are embodied carbon, carbon content, embedded carbon, carbon flows, virtual carbon, GHG footprint, and climate footprint (Wiedmann and Minx 2007; Courchene and Allan 2008; Edgar and Peters 2009; Peters 2010). There is little uniformity in the definitions of carbon footprint within the available literature and studies (Wiedmann and Minx 2007). Based on their survey, Wiedmann and Minx (2007) defined that the carbon footprint is a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product. A new term "climate footprint" was proposed as a comprehensive GHG indicator, i.e., if all the GHGs originating from within the boundary are quantified. However, new studies and methods followed for carbon footprint calculation, suggest including other GHGs as well, apart from only $CO_2$ (Office of sustainability and environment, City of Seattle 2002; Kelly et al. 2009; Eshel and Martin 2006; Bokowski et al. 2007; Ferris et al. 2007; T C Chan Center for Building Simulation & Energy Studies/Penn Praxis 2007; Garg and Dornfeld 2008; Good Company 2008; Johnson 2008, Edgar and Peters 2009; Browne et al. 2009).

There is a lack of uniformity over the selection of direct and embodied emissions. Direct emissions are those that are made directly during the progress of a process. As an example, $CO_2$ released during combustion in a gasoline fired industrial boiler is a direct emission. On the other hand in electrically heated boiler, no direct emissions will be observed. But if the electricity used in the boiler was generated in a thermal power plant, the amount of $CO_2$ released in generation and transmission of the units of electricity consumed in the boiler is referred as the embodied or indirect emission. It becomes complex to include all possible emissions and thus most studies report only direct or first order indirect emissions (Carbon Trust 2007b; Wiedmann and Minx 2007; Matthews et al. 2008b). In absence of consistencies among selection of characteristic properties of carbon footprint viz. gases selected and boundaries drawn for the carbon footprint

## Green house Effects:

The greenhouse effect is caused by greenhouse gases; the most important greenhouse gases in Earth's atmosphere are: water vapor, carbon dioxide (CO2), and methane. When there is more greenhouse gas in the air, the air holds more heat. This is why more greenhouse gases cause climate change and global warming.

## Greenhouse gases:

Greenhouse gases are those that absorb and emit infrared radiation in the wavelength range emitted by Earth. Carbon dioxide (0.04%), nitrous oxide, methane and ozone are trace gases that account for almost one tenth of 1% of Earth's atmosphere and have an appreciable greenhouse effect.

The two main gases responsible for the greenhouse effect (and not only its recent increase) are : Water vapour (H2O),carbon dioxyde (CO2).

There are others such gases, and even many others. Some of them are "natural", which means that they were present in the atmosphere before the apparition of men, and other can be called "artificial", in the sense that they are present in the atmosphere only because of us.

Beyond water and CO2, the other important "natural" greenhouse gases are :

methane (CH4), which is nothing else than the cooking gas we use in our stoves, Nitous oxyde (N2O), the scholarly name for laughing gas (which is not so much amusing here),

ozone (O3), which molecule comprises 3 oxygen atoms (the molecules of the "regular" oxygen gas have only 2 atoms of oxygen). When we say that these gases are "natural", it does not mean that men did not play a role in the amount we can find in the atmosphere today. It just means that there are also natural sources (or natural cycles). For these 3 above mentionned gases, humanity "simply" adds its part to natural emissions and therefore significally increases their concentration in the air.

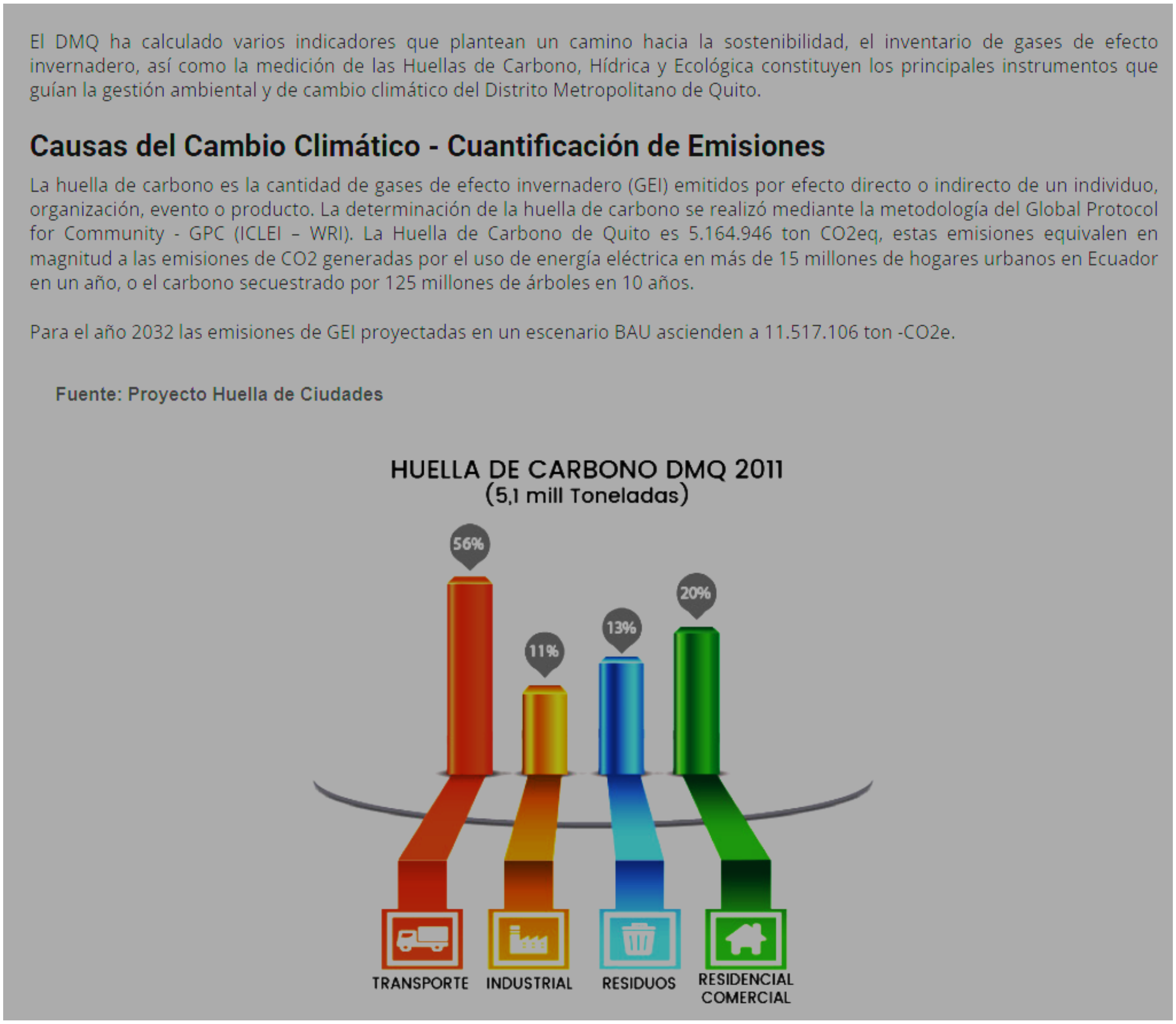
## Acid rain:

Rainfall made so acidic by atmospheric pollution that it causes environmental harm, chiefly to forests and lakes. The main cause is the industrial burning of coal and other fossil fuels, the waste gases from which contain sulphur and nitrogen oxides which combine with atmospheric water to form acids.

Acid rain is a result of air pollution. Some of these gases (especially nitrogen oxides and sulphur dioxide) react with the tiny droplets of water in clouds to form sulphuric and nitric acids. The rain from these clouds then falls as very weak acid - which is why it is known as "acid rain".

Acidity is measured using a scale called the pH scale. This scale goes from 0 to 14. 0 is the most acidic and 14 is the most alkaline (opposite of acidic). Something with a pH value of 7, we call neutral, this means that it is neither acidic nor alkaline. Very strong acids will burn if they touch your skin and can even destroy metals. Acid rain is much, much weaker than this, never acidic enough to burn your skin. Rain is always slightly acidic because it mixes with naturally occurring oxides in the air. Unpolluted rain would have a pH value of between 5 and 6. When the air becomes more polluted with nitrogen oxides and sulphur dioxide the acidity can increase to a pH value of 4. Some rain has even been recorded as being pH2.

Vinegar has a pH value of 2.2 and lemon juice has a value of pH2.3. Even the strongest recorded acid rain is only about as acidic as lemon juice or vinegar and we know that these don't harm us - so why do we worry about acid rain?



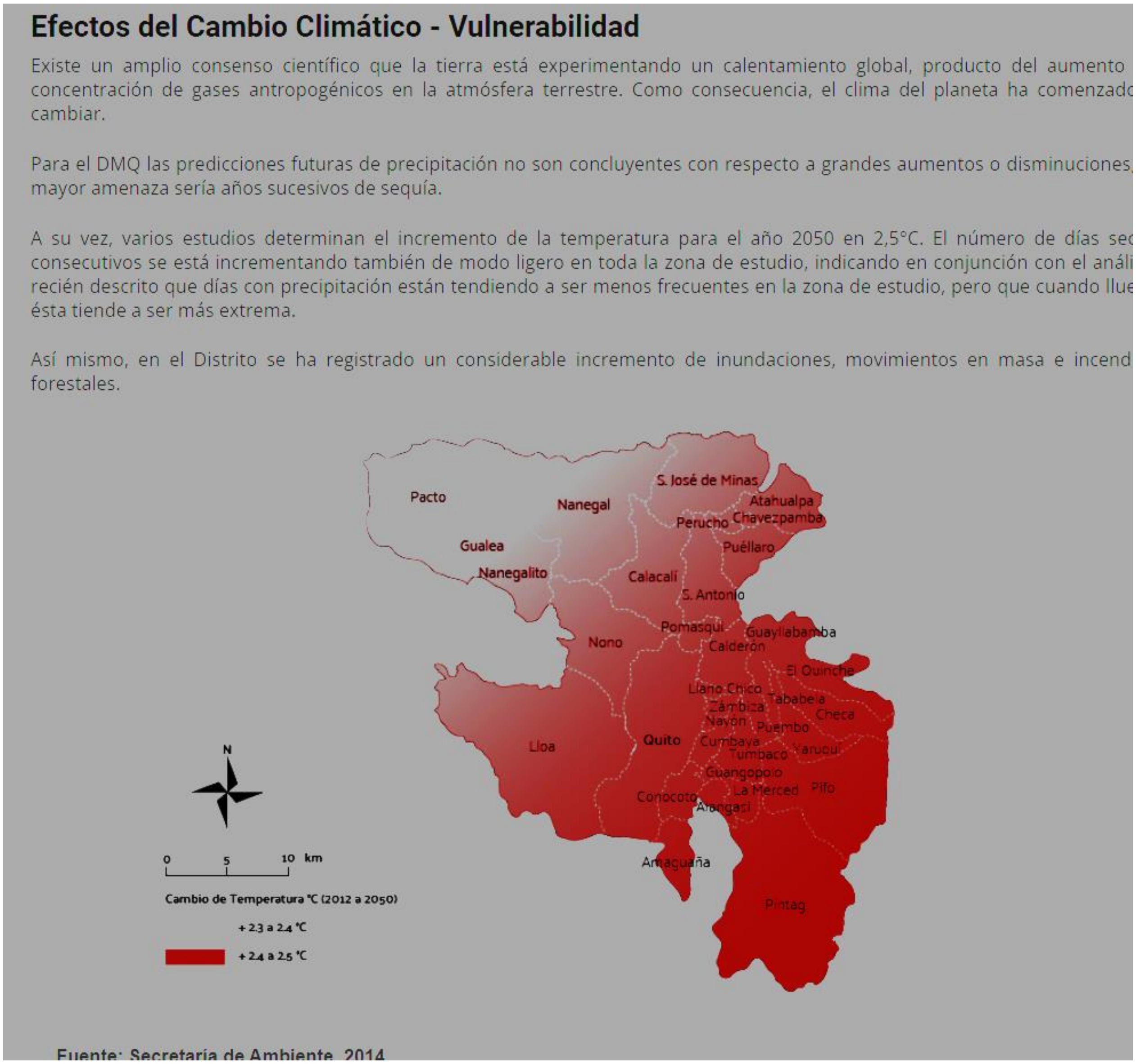
El DMQ ha calculado varios indicadores que plantean un camino hacia la sostenibilidad, el inventario de gases de efecto invernadero, así como la medición de las Huellas de Carbono, Hídrica y Ecológica constituyen los principales instrumentos que guían la gestión ambiental y de cambio climático del Distrito Metropolitano de Quito.

## Causas del Cambio Climático - Cuantificación de Emisiones

La huella de carbono es la cantidad de gases de efecto invernadero (GEI) emitidos por efecto directo o indirecto de un individuo, organización, evento o producto. La determinación de la huella de carbono se realizó mediante la metodología del Global Protocol for Community - GPC (ICLEI – WRI). La Huella de Carbono de Quito es 5.164.946 ton CO2eq, estas emisiones equivalen en magnitud a las emisiones de CO2 generadas por el uso de energía eléctrica en más de 15 millones de hogares urbanos en Ecuador en un año, o el carbono secuestrado por 125 millones de árboles en 10 años.

Para el año 2032 las emisiones de GEI proyectadas en un escenario BAU ascienden a 11.517.106 ton -CO2e.

**Fuente: Proyecto Huella de Ciudades**



## Efectos del Cambio Climático - Vulnerabilidad

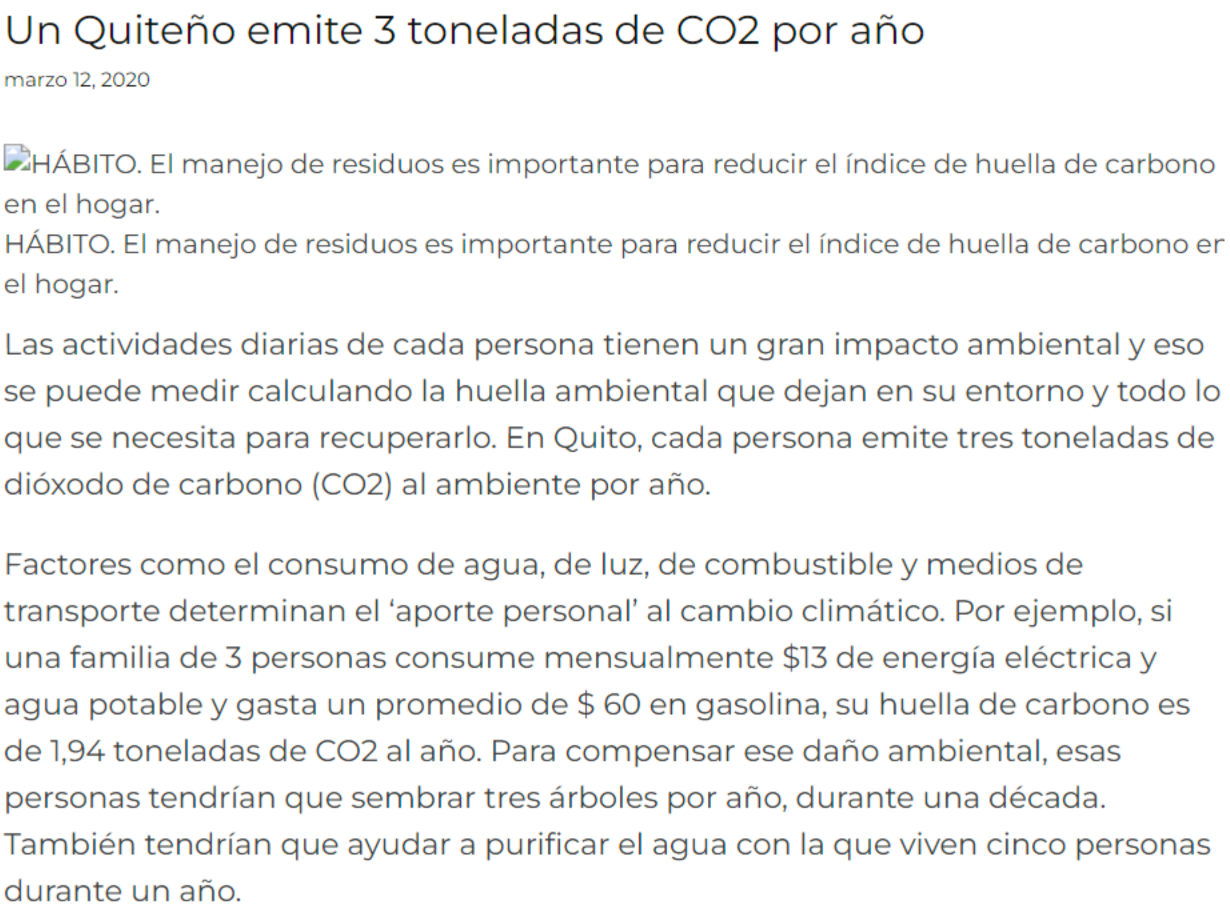
Existe un amplio consenso científico que la tierra está experimentando un calentamiento global, producto del aumento
concentración de gases antropogénicos en la atmósfera terrestre. Como consecuencia, el clima del planeta ha comenzad
cambiar.

Para el DMQ las predicciones futuras de precipitación no son concluyentes con respecto a grandes aumentos o disminuciones
mayor amenaza sería años sucesivos de sequía.

A su vez, varios estudios determinan el incremento de la temperatura para el año 2050 en 2,5°C. El número de días sec
consecutivos se está incrementando también de modo ligero en toda la zona de estudio, indicando en conjunción con el análi
recién descrito que días con precipitación están tendiendo a ser menos frecuentes en la zona de estudio, pero que cuando llue
ésta tiende a ser más extrema.

Así mismo, en el Distrito se ha registrado un considerable incremento de inundaciones, movimientos en masa e incend
forestales.

Fuente: Secretaría de Ambiente, 2014



# Un Quiteño emite 3 toneladas de CO2 por año

marzo 12, 2020

HÁBITO. El manejo de residuos es importante para reducir el índice de huella de carbono en el hogar.

HÁBITO. El manejo de residuos es importante para reducir el índice de huella de carbono en el hogar.

Las actividades diarias de cada persona tienen un gran impacto ambiental y eso se puede medir calculando la huella ambiental que dejan en su entorno y todo lo que se necesita para recuperarlo. En Quito, cada persona emite tres toneladas de dióxodo de carbono (CO2) al ambiente por año.

Factores como el consumo de agua, de luz, de combustible y medios de transporte determinan el ‘aporte personal’ al cambio climático. Por ejemplo, si una familia de 3 personas consume mensualmente $13 de energía eléctrica y agua potable y gasta un promedio de $ 60 en gasolina, su huella de carbono es de 1,94 toneladas de CO2 al año. Para compensar ese daño ambiental, esas personas tendrían que sembrar tres árboles por año, durante una década. También tendrían que ayudar a purificar el agua con la que viven cinco personas durante un año.

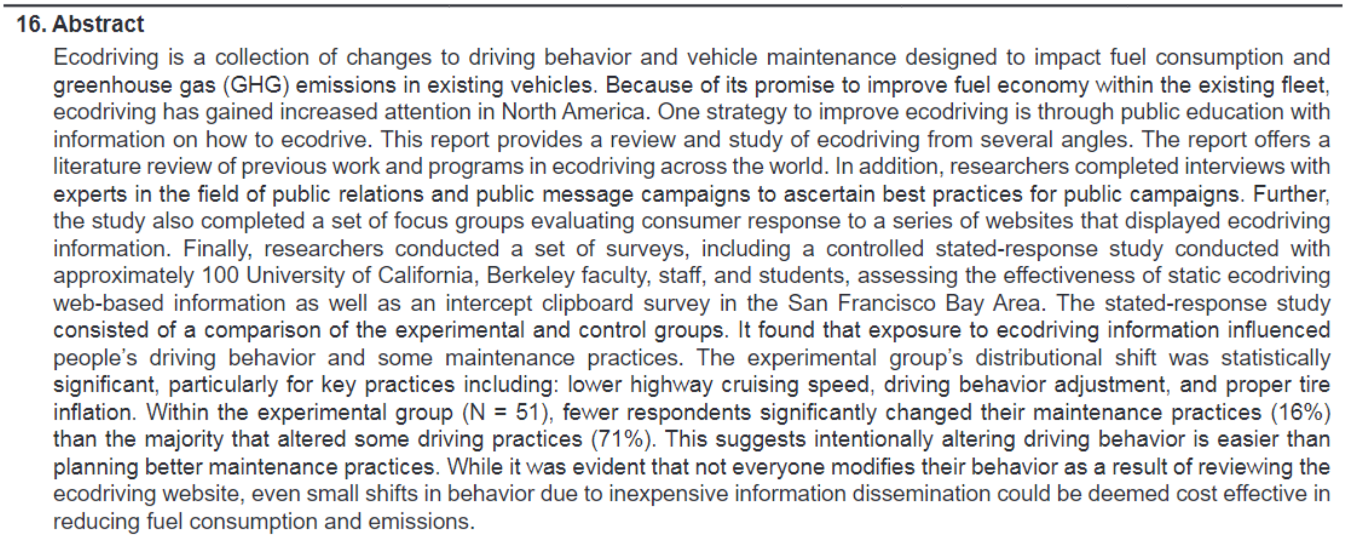
Mónica Abril, técnica de Cambio Climático de la Secretaría de Ambiente, asegura que en Quito se calcula de forma periódica el inventario de emisiones de gases de efecto invernadero. El último infome de ese inventario se realizó en 2015. Ahí se llegó a la conclusión de que la huella de carbono es de 7,6 millones de toneladas de CO2 equivalentes, de las cuales el 39% corresponde al transporte, 26% a energía estacionaria, 24% a la agricultura y cambio de uso de suelo y 10% a los residuos.

Verónica Arias, exsecretaria de Ambiente, comentó que luego de este informe se llegó a la conclusión de que cada quiteño emite anualmente 3 toneladas de Co2 y requiere 2 hectáreas de hábitat para vivir cada año. "El estándar internacional menciona que una persona debería tener una hectárea para vivir tranquilamente cada año, nosotros duplicamos esta cifra, y nos estamos comiendo nuestro propio hábitat".

**Referencias**
Los datos que se destacan en los estudios de huella ambiental de la ciudad se pueden corroborar a diario. El sector del transporte es el que más incidencia tiene. Según datos de la Agencia Metropolitana de Tránsito (AMT), el número de vehículos matriculados en 2019 fue de 465.908, considerado el más alto de los últimos 6 años.

**EL DATO**
Calcule su huella ambiental:En el caso de la energía estacionaria lo determinan el consumo de las centrales termoeléctricas, también lo determina el consumo de gas licuado de petróleo (GLP), en el caso del sector residencial y finalmente el consumo de combustibles de las industrias y comercios regulados.

El sector transporte genera 3'004.296 toneladas de Co2 equivalente, el 66% de éstas corresponde al consumo de gasolina, mientras que el 33% a diésel.
En el manejo de residuos, la cifra en Quito también es grande, pues según datos de la Empresa Metropolitana de Aseo, a diario se recogen entre 2.200 y 2.300 toneladas de basura.



**16. Abstract**

Ecodriving is a collection of changes to driving behavior and vehicle maintenance designed to impact fuel consumption and greenhouse gas (GHG) emissions in existing vehicles. Because of its promise to improve fuel economy within the existing fleet, ecodriving has gained increased attention in North America. One strategy to improve ecodriving is through public education with information on how to ecodrive. This report provides a review and study of ecodriving from several angles. The report offers a literature review of previous work and programs in ecodriving across the world. In addition, researchers completed interviews with experts in the field of public relations and public message campaigns to ascertain best practices for public campaigns. Further, the study also completed a set of focus groups evaluating consumer response to a series of websites that displayed ecodriving information. Finally, researchers conducted a set of surveys, including a controlled stated-response study conducted with approximately 100 University of California, Berkeley faculty, staff, and students, assessing the effectiveness of static ecodriving web-based information as well as an intercept clipboard survey in the San Francisco Bay Area. The stated-response study consisted of a comparison of the experimental and control groups. It found that exposure to ecodriving information influenced people's driving behavior and some maintenance practices. The experimental group's distributional shift was statistically significant, particularly for key practices including: lower highway cruising speed, driving behavior adjustment, and proper tire inflation. Within the experimental group (N = 51), fewer respondents significantly changed their maintenance practices (16%) than the majority that altered some driving practices (71%). This suggests intentionally altering driving behavior is easier than planning better maintenance practices. While it was evident that not everyone modifies their behavior as a result of reviewing the ecodriving website, even small shifts in behavior due to inexpensive information dissemination could be deemed cost effective in reducing fuel consumption and emissions.

## 7.2 ANEXOS FUNDAMENTACION TEORICA

### Green house Effects:

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### Greenhouse gases:

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Beyond water and CO2, the other important "natural" greenhouse gases are :

methane (CH4), which is nothing else than the cooking gas we use in our stoves, Nitous oxyde (N2O), the scholarly name for laughing gas (which is not so much amusing here),

ozone (O3), which molecule comprises 3 oxygen atoms (the molecules of the "regular" oxygen gas have only 2 atoms of oxygen). When we say that these gases are "natural", it does not mean that men did not play a role in the amount we can find in the atmosphere today. It just means that there are also natural sources (or natural cycles). For these 3 above mentionned gases, humanity "simply" adds its part to natural emissions and therefore significally increases their concentration in the air.

### Acid rain:

Rainfall made so acidic by atmospheric pollution that it causes environmental harm, chiefly to forests and lakes. The main cause is the industrial burning of coal and other fossil fuels, the waste gases from which contain sulphur and nitrogen oxides which combine with atmospheric water to form acids.

Acid rain is a result of air pollution. Some of these gases (especially nitrogen oxides and sulphur dioxide) react with the tiny droplets of water in clouds to form sulphuric and nitric acids. The rain from these clouds then falls as very weak acid - which is why it is known as "acid rain".

Acidity is measured using a scale called the pH scale. This scale goes from 0 to 14. 0 is the most acidic and 14 is the most alkaline (opposite of acidic). Something with a pH value of 7, we call neutral, this means that it is neither acidic nor alkaline. Very strong acids will burn if they touch your skin and can even destroy metals. Acid rain is much, much weaker than this, never acidic enough to burn your skin. Rain is always slightly acidic because it mixes with naturally occurring oxides in the air. Unpolluted rain would have a pH value of between 5 and 6. When the air becomes more polluted with nitrogen oxides and sulphur dioxide the acidity can increase to a pH value of 4. Some rain has even been recorded as being pH2.

Vinegar has a pH value of 2.2 and lemon juice has a value of pH2.3. Even the strongest recorded acid rain is only about as acidic as lemon juice or vinegar and we know that these don't harm us - so why do we worry about acid rain?

**ECE+EUDC.** The ECE+EUDC test cycle—also known as the MVEG-A cycle—was used for EU type approval testing of emissions and fuel consumption from light duty vehicles [EEC Directive 90/C81/01]. The test is performed on a chassis dynamometer. The entire cycle includes four ECE segments (Figure 1) repeated without interruption, followed by one EUDC segment (Figure 2). Before the test, the vehicle is allowed to soak for at least 6 hours at a test temperature of 20-30°C. It is then started and allowed to idle for 40s.

**NEDC.** Effective year 2000, that idling period has been eliminated, i.e., engine starts at 0 s and the emission sampling begins at the same time. This modified cold-start procedure is referred to as the *New European Driving Cycle* (NEDC) or as the MVEG-B test cycle.

The full test starts with four repetitions of the ECE cycle (Figure 1). The ECE is an urban driving cycle, also known as UDC. It was devised to represent city driving conditions, e.g. in Paris or Rome. It is characterized by low vehicle speed, low engine load, and low exhaust gas temperature.

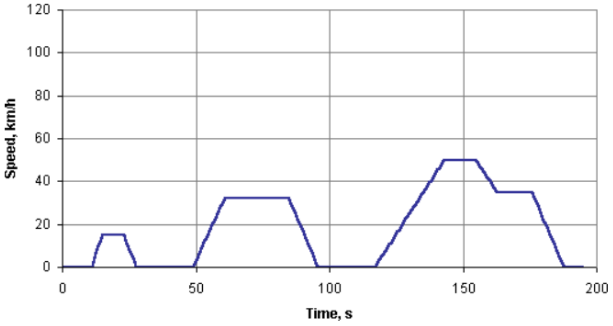


**Figure 1.** ECE 15 Cycle

The EUDC (Extra Urban Driving Cycle) segment has been added after the fourth ECE cycle to account for more aggressive, high speed driving modes. The maximum speed of the EUDC cycle is 120 km/h. An alternative EUDC cycle for low-powered vehicles has also been defined with a maximum speed limited to 90 km/h, Figure 3.

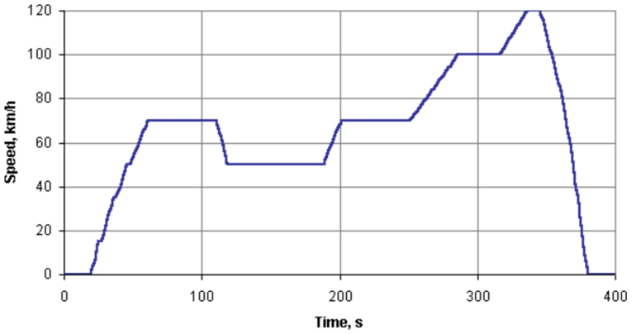
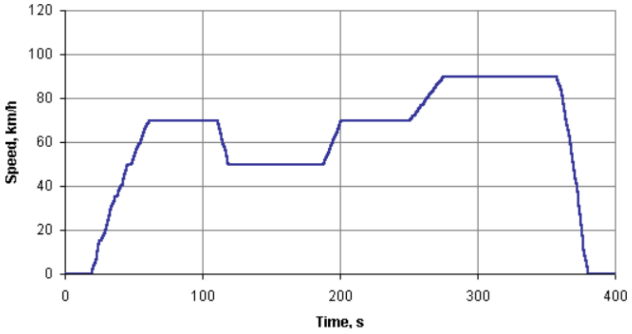


**Figure 2.** EUDC Cycle



Emissions are sampled during the cycle according to the constant volume sampling (CVS) technique, analyzed, and expressed in g/km for each of the pollutants.

The following table includes a summary of selected parameters for the ECE 15, EUDC and NEDC cycles.

| Characteristics | Unit | ECE 15 | EUDC | NEDC† |
|---|---|---|---|---|
| Distance | km | 0.9941 | 6.9549 | 10.9314 |
| Total time | s | 195 | 400 | 1180 |
| Idle (standing) time | s | 57 | 39 | 267 |
| Average speed (incl. stops) | km/h | 18.35 | 62.59 | 33.35 |
| Average driving speed (excl. stops) | km/h | 25.93 | 69.36 | 43.10 |
| Maximum speed | km/h | 50 | 120 | 120 |
| Average acceleration[1] | $m/s^2$ | 0.599 | 0.354 | 0.506 |
| Maximum acceleration[1] | $m/s^2$ | 1.042 | 0.833 | 1.042 |

† Four repetitions of ECE 15 followed by one EUDC

[1] Calculated using central difference method

**Type I, II and III Tests.** The urban driving cycle—ECE 15, Figure 1—represents Type I test, as defined by the original ECE 15 emissions procedure. Type II test is a warmed-up idle tailpipe CO test conducted immediately after the fourth cycle of the Type I test. Type III test is a two-mode (idle and 50 km/h) chassis dynamometer procedure for crankcase emission determination.

The FTP-75 (Federal Test Procedure) has been used for emission certification and fuel economy testing of light-duty vehicles in the United States [2656]. The test is often referred to as simply 'FTP' (this should not be confused with the FTP test for heavy-duty engines).

The FTP-75 and the FTP-72 are two variants of the EPA Urban Dynamometer Driving Schedule (UDDS). The FTP-75 cycle is derived from the FTP-72 by adding a third phase of 505 s, identical to the first phase of FTP-72 but with a hot start. The third phase starts after the engine is stopped for 10 minutes. Thus, the entire FTP-75 cycle consists of the following segments:

1. Cold start transient phase (ambient temperature 20-30°C), 0-505 s,
2. Stabilized phase, 506-1372 s,
3. Hot soak (min 540 s, max 660 s),
4. Hot start transient phase, 0-505 s.

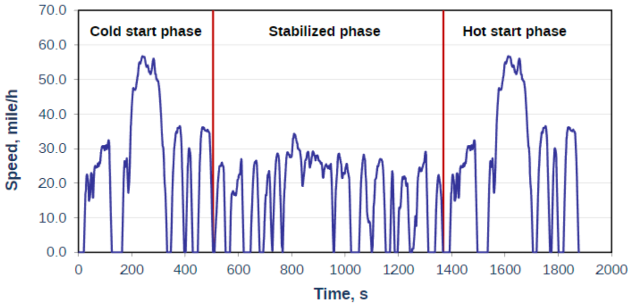


**Figure 1**. US EPA Urban Dynamometer Driving Schedule (FTP-75)

Emissions from each phase are collected in a separate teflon bag, analyzed and expressed in g/mile (g/km). The weighting factors are 0.43 for the cold start phase, 1.0 for the 'stabilized' phase and 0.57 for the hot start phase.

The following are some basic parameters of the cycle:

- Duration: 1877 s
- Distance traveled: 11.04 miles (17.77 km)
- Average speed: 21.2 mph (34.12 km/h).
- Maximum speed: 56.7 mph (91.25 km/h).

For emission certification, vehicles must meet the applicable FTP emission standards. From model year 2000, vehicles have to be additionally tested on two Supplemental Federal Test Procedures (SFTP) designed to address shortcomings with the FTP-75 in the representation of (1) aggressive, high speed driving (US06), and (2) the use of air conditioning (SC03).

CAFE fuel economy values are calculated on the basis of FTP and HWFET testing. Until model year 2007, EPA on-road fuel economy values shown on new vehicle's labels were calculated on the basis of FTP testing for the city rating, while the HWFET test was used for the highway rating. Since model year 2008, the FTP is used for the determination of the EPA on-road fuel economy ratings using the EPA 5-cycle method. The 5-cycle results are calculated based on the results of two FTP tests—one regular and one cold temperature test, run at a lab temperature of 20°F (-6.7°C)—as well as the HWFET, US06 and SC03.

The FTP-75 cycle is known in Australia as the ADR 37 (Australian Design Rules) cycle and in Brazil as test standard NBR6601.

A *four-segment* variant of the FTP-75 cycle—where the stabilized phase is run again after the completion of the hot start phase—is sometimes used in certain applications, for instance in some hybrid vehicle tests.

# On-Road Motor Vehicle Emissions and Fuel Consumption in Urban Driving Conditions

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## ABSTRACT

This paper reports on the analysis of on-road vehicle speed, emission, and fuel consumption data collected by four instrumented vehicles. Time-, distance-, and fuel-based average fuel consumption, as well as CO, HC, $NO_x$, and soot emission factors, were derived. The influences of instantaneous vehicle speed on emissions and fuel consumption were studied. It was found that the fuel-based emission factors varied much less than the time- and distance-based emission factors as instantaneous speed changed. The trends are similar to the results obtained from laboratory tests. The low driving speed contributed to a significant portion of the total emissions over a trip. Furthermore, the on-road data were analyzed using the modal approach. The four standard driving modes are acceleration, cruising, deceleration, and idling. It was found that the transient driving modes (i.e., acceleration and deceleration) were more polluting than the steady-speed driving modes (i.e., cruising and idling) in terms of g/km and g/sec. These results indicated that the on-road emission measurement is feasible in deriving vehicle emissions and fuel consumption factors in urban driving conditions.

IMPLICATIONS

The emissions and fuel consumption factors used in Hong Kong were developed in the United States and Europe, but the driving cycle developed for Hong Kong indicated substantial differences from those in the United States and Europe. Therefore, the emissions and fuel consumption factors obtained in this study can be used to estimate vehicular emissions and fuel consumption in Hong Kong. To achieve more definitive results, more instrumented test vehicles could be used to measure on-road emission rates and vehicle operating parameters. The current study suggests that the acceleration and deceleration modes are more polluting than steady-speed driving modes. Moreover, low driving speed contributes to a high percentage of total emissions. Great emphasis should be placed on minimizing vehicle stops in urban areas to speed traffic and to smooth acceleration and deceleration. Traffic engineers should devise control measures to improve traffic progressions and thus the pollutant emissions per vehicle.

## INTRODUCTION

Emissions from motor vehicles are a major cause of air pollution in urban areas of Hong Kong. According to the Environmental Protection Department of Hong Kong (HKEPD), CO, $NO_x$, and particulates come mainly from vehicular emissions. It was indicated that particulates and $NO_x$ emissions were fairly high in urban areas and constantly exceeded the Hong Kong Air Quality Objective (HKAQO). In 1997, the highest annual particulate level at street level was almost 68% above the statutory limit in Hong Kong.[1] Therefore, the reduction of motor vehicle emissions will contribute significantly to the improvement of air quality in Hong Kong. To achieve this goal, it is necessary to understand actual vehicle emissions and identify the important operational factors affecting vehicular emissions and fuel consumption.

Conventionally, emission testings are conducted by driving the vehicle through standard driving cycles in a laboratory on chassis dynamometers. The merit of this method is simple, but the test conditions are restrictive in that they may not represent actual on-road driving conditions. A study found that fuel consumption and exhaust emission depended on whether they were measured at a steady speed or an on-road driving pattern.[2] It was found that emissions measured on actual speed driving cycles were generally higher than those measured on the laboratory driving cycles. Even for actual speed driving cycles, the engine operating conditions differ significantly from those of the on-road driving test.[3,4]

In fact, actual on-road driving is more complex than driving cycle simulations. There are large variations in operating conditions during real-world driving. Some factors are difficult to simulate on test beds.[5,6] Therefore, on-road emission, fuel consumption, and engine operating condition measurements are necessary. However, emission data directly measured from the tailpipes of on-road vehicles are limited, and relatively few vehicles have been tested for each study.[5] St. Denis et al.[4] tested a petrol van in California. They found that the data obtained from the on-road test differ significantly from those obtained from the Federal Test Procedure (FTP) driving cycle. Cicero-Fernandez et al.[7] examined the grade effect by a single test vehicle driving on a hill. Both of these studies have used limited numbers of vehicles for their on-road testing, which limited the scope of these studies. Several other variables of interest for vehicle operating parameters could not be assessed.

In this study, emissions were measured directly from the tailpipe of four test vehicles under actual on-road driving conditions. The test vehicles were chosen to represent the typical traffic mix in the urban areas of Hong Kong, which enabled the investigation of more variables of interest. Although only one vehicle from each vehicle category was tested, it is believed that the study would produce indicative results for actual on-road vehicle emission behavior of contemporary driving patterns in urban areas, and the ways in which such behavior differs from mandated certification procedures. The study can also produce supplementary results to laboratory tests.

This paper describes a series of on-road test runs that were conducted in the urban areas of the Hong Kong Special Administrative Region. Four test vehicles were employed to collect on-road speed, emission, and fuel consumption data. Average and modal emissions, as well as fuel consumption factors, were then calculated in terms of g/sec, g/km, and g/kg fuel. Finally, the behaviors of the exhaust emissions and fuel consumption were examined with reference to operational variables such as speed and acceleration.

## DATA COLLECTION

In order to capture different on-road driving patterns in urban areas, test vehicles were driven in two typical urban districts—MongKok and Central—located in the Kowloon Peninsula (KLN) and Hong Kong Island (HKI), respectively. The roads in KLN are more spread out on flat land, while those in the HKI are bounded on the northern shore of the island, one side by the hill and the other side by Victoria Harbor. MongKok and Central were chosen to represent two distinct driving environments in Hong Kong that have a great impact on air pollution. Air quality in these areas is of great concern and the government has installed several roadside air quality monitoring stations to monitor traffic emissions. The vehicle speed seldom exceeds 50 km/hr. The driving cycle for Hong Kong developed from these two districts has an average speed of 15.5 km/hr, average running speed of 21.7 km/hr, and idling and cruising proportions of 31.4 and 9.1%, respectively.[8] Driving in Hong Kong is thus relatively slow compared to cities in the United States and Europe, due to the large number of signal junctions in Hong Kong.

Four vehicles of different models, sizes, and weights were employed in the collection of instantaneous speed, emissions, and fuel consumption data. The specifications of these test vehicles are shown in Table 1. These four test vehicles were chosen to represent the typical traffic mix in Hong Kong. The Hong Kong Annual Traffic Census 1997[9] stated that among all vehicles traveling in the urban areas of HKI during peak hours, 50.6% were passenger cars, 31.4% were light-duty vans and diesel taxis, and 7.7% were buses. In the urban areas of KLN, the peak hour traffic mix was composed of 41.0% passenger cars, 27.4 % light-duty vans and diesel taxis, and 6.5% buses. Although buses occupy only a small proportion of the traffic mix, they are a major source of vehicular particulate emissions.

The test vehicles were driven by professional drivers. The passenger car, petrol van, and diesel van were driven by the same driver, and the double-decker bus was driven by a professional bus driver. This reduced the effect of different driver behaviors. The driving environments for the test vehicles were basically the same. The drivers were asked to drive randomly through the above-mentioned districts. A single test run was performed for the double-decker bus, while two test runs were performed for the other three test vehicles. The reason for not choosing a fixed route is that it may not necessarily reflect the whole picture of urban driving. On the other hand, changing routes for each test run allows the testing of different driving conditions in the prescribed urban districts.

The arrangement of the on-board measurement system is outlined in Figure 1. The gas filter connected with the gas analyzer is used to filter out water vapor and particulates in diesel vehicles. Otherwise, the gas analyzer would easily be blocked by the particulate emissions. Engine speed and the transmission shaft rotational speed were measured by infrared photoelectric sensors. Incorporated with a PICO data acquisition system, the speed data were collected into a computer. Vehicle speed could then be calculated from the shaft speed by a simple equation. The error and response time of the speed measurement were less than 2% and 0.01 sec, respectively. The resolution of the speed measurement was lower than 0.03 km/hr for the four test vehicles.

The error and response time of the smoke meter were less than 2% and 0.1 sec. respectively.

The fuel consumption rate and gas emission concentrations were related to the speed measurement. However, a time lag exists between the fuel meter, gas analyzer, and speed measurement. The experiment was conducted to determine the time lag under various engine speeds by the method of sudden acceleration and one-cylinder misfire. The time lag of the instrument was calibrated and was taken to be 5 sec in the data analysis.

The data were collected at the morning peak traffic period, from 8:00 to 11:00 a.m., and the off-peak period, from 2:00 to 5:00 p.m., from March to June 1998 during calm and dry weather conditions.

## METHODOLOGY

Data obtained for each test vehicle were grouped together. Thus, there are four sets of instantaneous speed, emissions, and fuel consumption data by vehicle types: the light-duty diesel van, petrol passenger car, light-duty petrol van, and double-decker public bus. The equations for instantaneous mass emission rate (g/sec) are shown in the appendix. The instantaneous emission rates of CO, HC, and $NO_x$ of the petrol vehicles, in g/sec, were calculated by standard methods described in the SAE Handbook.[10] For the diesel vehicles, the mass concentrations of soot were obtained from the smoke intensity based on a conversion chart in the SAE Handbook.[11] The mass emission rate of soot can be calculated accordingly when the instantaneous engine speed and its swept volume are known. These data form a basis for emission and fuel consumption analysis of this study.

Emissions and fuel consumption are usually calculated as average value over several test runs and then parameterized in terms of the corresponding average speed. In fact, on-road driving is random combinations of the four standard driving modes: acceleration, cruising, deceleration, and idling. It is of great interest to characterize emissions and fuel consumption behaviors during different driving modes. In the following sections, both global and modal analysis will be used to analyze the emissions and fuel consumption data.

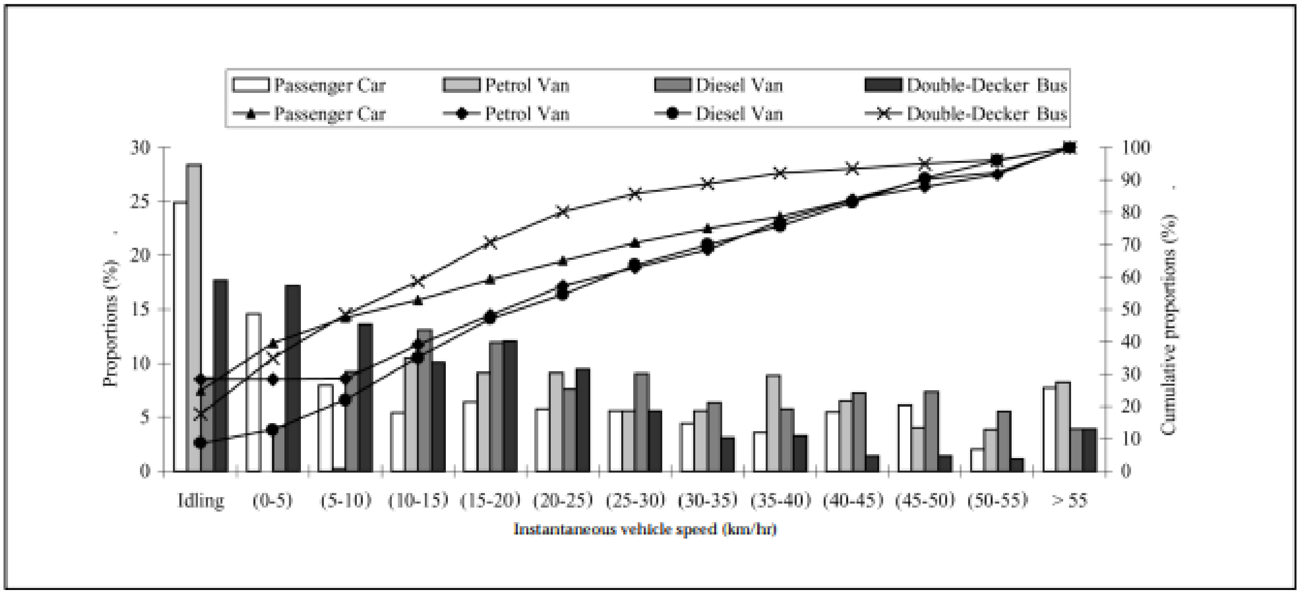
Vehicular emissions can be expressed in terms of grams of pollutants emitted per unit time, per unit distance traveled, or per unit fuel consumed. Accordingly, three terms are defined to describe vehicular emissions and fuel consumption: emissions, fuel consumption rate (g/sec); emissions, fuel consumption factor (g/km); and emissions index (g/kg fuel).

It is a common practice to describe emissions and fuel consumption from motor vehicles by an average value over a trip. In general, average vehicular emissions and fuel consumption over a trip were expressed in distance-based (g/km) unit or fuel-based (g/kg fuel) unit. Average emissions, fuel consumption factors, and indices of the vehicles were calculated by eqs 1–3. All of the factors and indices were calculated over the whole data sample for each vehicle and were compared to the fleet average emission factors used by the HKEPD.

$$\text{Average emission factor [g/km]} = \frac{3600 \times \sum e \text{ [g/sec]}}{\sum v \text{ [km/hr]}} \quad (1)$$

$$\text{Average Fuel Consumption Factor [g/km]} = \frac{3600 \times \sum f \text{ [g/sec]}}{\sum v \text{[km/hr]}} \quad (2)$$

$$\text{Average Emission Index [g/(kg fuel)]} = \frac{3600 \times \sum e \text{[g/sec]}}{\sum f \text{[km/hr]}} \quad (3)$$



where *e* is the instantaneous emission rates of the subject gas pollutant, *f* is the instantaneous fuel consumption rate, and *v* is the instantaneous vehicle speed.

With the acquired instantaneous speed data, acceleration rates were calculated using the method of central difference. The corresponding emissions and fuel consumption data were then classified according to various driving modes. The four standard driving modes were defined as follows:

- idling mode: zero speed and acceleration.
- acceleration mode: positive incremental speed changes of more than 0.1 m/sec/sec during the 1-sec interval.
- cruising mode: absolute incremental speed changes of less than or equal to 0.1 m/sec/sec during the 1-sec interval.
- deceleration mode: negative incremental speed changes of more than 0.1 m/sec/sec during the 1-sec interval.

The value of 0.1 m/sec/sec has been used extensively by other researchers in defining driving modes.[8,12-16] For each vehicle, the instantaneous emission and fuel consumption rates (g/sec) for each driving mode were averaged to give the modal emission and fuel consumption rates.

## RESULTS AND DISCUSSION

### Description of the Data Sample

Characteristics of the four sets of data for each test vehicle are shown in Table 2. It can be seen that the average speeds are generally higher than those of the Hong Kong driving cycle. The speed distributions for each vehicle during the test runs are shown in Figure 2. The bars are the proportions of each speed class, while the lines represent the cumulative proportions. It can be seen that for more than 90% of the time, test vehicles are driving at speeds lower than 50 km/hr, a typical driving phenomenon in urban areas. About 30% of the time, the petrol van idled, which is the largest percentage among the four test vehicles. However, very few data were recorded at the speed range of 0–10 km/hr, indicating that the petrol van accelerated and decelerated hard during the test runs. The passenger car and the double-decker bus spent most of the time driving at lower speeds. For over 90% of the time, the double-decker bus was driven at speeds lower than 30 km/hr. For the diesel van, the driving time spread through the speed range below 50 km/hr. The largest proportion was in the speed range of 10–15 km/hr.

Table 2. Characteristics of test runs.

| | Duration (sec) | Average Speed (km/hr) | Total Distance (km) |
|---|---|---|---|
| Passenger Car | 2613 | 19.47 | 14.13 |
| Petrol Van | 6500 | 23.85 | 43.06 |
| Diesel Van | 3133 | 24.91 | 21.68 |
| Diesel Bus | 1690 | 15.32 | 7.19 |

### Global Analysis

*Average Emission and Fuel Consumption.* Average emission, fuel consumption factors, and indices of the test vehicles are shown in Table 3. The double-decker bus was shown to have the largest emission factors and indices probably because it was the oldest and had the largest engine capacity as well as the highest maximum power output. Apart from the bus, the highest CO emissions were found in the petrol van, followed by the passenger car. The smaller size and engine capacity of the passenger car may contribute to the relatively low emission level, but the major factor was the catalytic converter in the passenger car, which can oxidize a majority of the HCs to $CO_2$ and $H_2O$. However, the emissions and fuel consumption of the catalyzed passenger car were still higher than expected, probably due to the low speed and irregularity of driving in Hong Kong,[8] which restricted the optimal performance of the catalytic converter. Moreover, the maximum power output of the catalyzed passenger car was higher than that of the petrol van.

CO and HC emissions from the diesel van were lower than those from the petrol vehicles. $NO_x$ emissions from the petrol van, which did not have a catalytic converter, were higher than those of the diesel van. However, the passenger car emitted less $NO_x$ than the diesel van. In general, diesel engines have a fuel economy advantage over petrol engines, owing to efficient combustion, and as a result, diesel engines emit less CO, HC, and $NO_x$.[17] However, if the engines were installed in vehicles and used practically, emissions and fuel consumption would be governed by vehicle operating variables and the driving conditions, such as engine capacity, vehicle speed, payload, road grades (i.e., uphill or downhill), and so on. It can be observed that the fuel consumption factor of the diesel van was larger than those of the petrol vehicles, probably because of its larger engine capacity.

Table 4 shows the measured average emission factors of the four test vehicles and the fleet average emission factors for the corresponding type of vehicle in Hong Kong. The fleet average emission factors are provided by the HKEPD. However, the vehicle fleet used with HKEPD classifications is not the same as that shown in Table 4. The diesel and petrol vans were categorized by the HKEPD as a public light bus and a passenger van, respectively. And it is understood that a significant proportion of passenger vans are in fact diesel vehicles.

The HKEPD fleet average emission factors for the passenger van were clearly not derived solely for petrol vans.

# Impact of Stops on Vehicle Fuel Consumption and Emissions

Hesham Rakha[1] and Yonglian Ding[2]

## ABSTRACT

Macroscopic emission models use average speed as a sole traffic-related explanatory variable. Research, however, has demonstrated that the use of average speed as a single traffic-related explanatory variable is insufficient in estimating vehicle emissions. The objective of this paper is to attempt to quantify, using simple examples, the impact of vehicle stops on fuel consumption and emissions of hydrocarbons, carbon monoxide, and oxides of nitrogen.

This study indicates that the vehicle fuel consumption rate is more sensitive to cruise speed levels than to vehicle stops. The aggressiveness of a vehicle stop, as represented by the vehicle's acceleration and deceleration level, does have a significant impact on vehicle emission rates. Specifically, HC and CO emission rates are highly sensitive to the level of acceleration when compared to cruise speeds in the range of 10 to 120 km/h. Alternatively, the impact of deceleration levels on all measures of effectiveness is relatively small. Noteworthy is the fact that at high speeds the introduction of vehicle stops involving extremely mild deceleration and acceleration levels can actually reduce vehicle emission rates.

## INTRODUCTION

The primary sources of motor vehicle emissions are exhaust emissions from chemical compounds that leave the engine through the tail pipe system and crankcase, and evaporative emissions from the fueling system, which mainly volatile organic compounds (VOCs) (EPA, 1993). For gasoline vehicles, exhaust emissions are originally generated as a result of fuel combusting in the engine (called engine-out emissions), and are reduced by passing through the catalytic converter (called tail pipe or exhaust emissions). Currently, diesel-powered engines cannot use catalytic oxidizers due to plugging from particulate matter (PM).

Carbon monoxide (CO) and VOCs are products of incomplete combustion of motor fuels and, in the case of VOCs, of fuel vapors emitted from the engine and fuel system (EPA, 1993). Oxides of nitrogen ($NO_x$) emissions are the products of high-temperature chemical processes that occur during the combustion itself.

### Limitations of Current State-of-Practice Macroscopic Models

Current estimates of vehicle emission rates are produced by macroscopic models, namely the MOBILE5a and EMFAC models. In these models, vehicle emissions are expressed as functions of average speed and are based on vehicle testing on a limited number of standard drive cycles. For example, the MOBILE5a model utilizes baseline emission rates that are derived from the Federal Test Procedure (FTP), which is the vehicle test procedure commonly used for light-duty vehicle testing and is composed of three different phases: a cold start phase, a stabilized phase, and a hot start phase. In the MOBILE5a model, the emissions from vehicles operating in all three phases are used to estimate baseline emissions. The baseline emission rates for a vehicle class are computed as the average of the three phases of the FTP cycle, which corresponds to an average speed of 31.6 km/h (19.6 mph). In the latest EMFAC model (EMFAC2000), the baseline emission rate is derived from the Unified Drive Cycle (LA92) with an average operating speed of 39.4 km/h (24.6 mph). Emission rates at other average speeds are multiplied by an appropriate Speed Correction Factor (SCF) that is specific

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using linear regression based on measured data and showed that fuel consumption will decrease 2.8 L/km with every 0.1 m/s$^2$ increase in deceleration, and 1.8 L/km with the same increase in mean acceleration. For urban driving vehicles, due to a large number of stop-and-go situations, reducing the intensity of acceleration and deceleration is the most effective for reducing energy consumption [33]. Chio et al. [34] studied the critical acceleration values that caused the fuel consumption of LPG passenger vehicles to increase sharply during parking acceleration and driving acceleration, which were 2.598 m/s$^2$ and 1.4705 m/s$^2$, respectively.

In addition, different from the smooth driving and constant speed cruise strategy, there is also a pulse-and-glide (PNG) dynamic cruise fuel-saving strategy. PNG means that the vehicle first accelerates from the low-speed phase to high-speed phase (acceleration phase), and then freely reduces from the high-speed phase to the low-speed phase (the coasting phase). The two phases form a complete PNG, where the average speed is equal to the desired speed [35]. This strategy was first studied by E. Gilbert, who theoretically deduced and compared the fuel-saving effects of "quasi-relaxed steady state (QRSS)" and "periodic control" and verified that the periodic control is better in cruise mode [36]. Researchers in recent years have shown that the PNG driving strategy also has good fuel-saving effects in hybrid and electric vehicles [37,38]. Automatic vehicles seem to be a good carrier for this driving strategy because it requires periodic control of power components, which is difficult for the driver to implement.

Shifting up as soon as possible. Shifting up as soon as possible increases the engine load rate and helps control the engine speed in the economic zone [26]. Beusen et al. [39,40] studied the gear information of drivers whose fuel consumption had been significantly reduced after eco-driving training and found that the average shift point changed significantly (moved closer to the optimal 2000 revolutions per minute (r/min)). Choosing the right shift point (generally, 2000 r/min–2500 r/min) and driving the vehicle using the highest gear possible are effective methods to reduce fuel consumption for conventional vehicles. However, as automatic transmissions become more and more popular in vehicles, this energy-saving driving strategy is losing its meaning.

Reducing idling time. Idling is a working condition in which the engine is idling but does not output power, resulting in fuel consumption. If the vehicle is idling for more than half a minute, the driver is recommended to turn off the engine, because the fuel required to restart the engine is less than the fuel consumed while the engine is idling. If the above practices are avoided, combined with other factors, the savings can be up to 20% [8]. An important reason why hybrid and electric vehicles have better fuel-saving effects than ICE vehicles is the elimination of idling conditions. For hybrid vehicles, the engine is directly controlled by the motor to start and stop, so the engine does not have an idling condition to reduce fuel consumption.

The rule-based eco-driving theory is derived from the summary of experiences or experiments and it has the advantages of strong guidance and fast fuel-saving effects. The training and research of eco-driving projects in many countries are carried out by teaching drivers this kind of rule-based driving theory [41,42]. However, because eco-driving theory is a qualitative description of energy-saving driving operation, the fuel-saving mechanism is not clear, and it is not the optimal solution in practical applications. In addition, this rule-based eco-driving strategy is a group-oriented eco-driving suggestion, and it cannot provide targeted suggestions on the driving behavior of individual drivers.

### 2.2. Optimization-Based Eco-Driving Theory

Optimization-based eco-driving theory refers to the optimal vehicle control strategy, which is solved through optimization algorithms based on the vehicle model combined with the current geographic or traffic information. Compared with the rule-based eco-driving theory, theoretically, it has the optimality of fuel-saving effects due to the optimal matching of driving behavior and traffic elements.

# Long-term effect of eco-driving education on fuel consumption using an on-board logging device

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## Abstract

This paper describes the measured long-term effects on fuel consumption of eco-driving education. The results are part of the long-term survey within the Flemish research program "An activity-based approach for surveying and modelling travel behaviour". During several months, the travel and driving behaviour of 28 respondents was monitored. The methodology consists of using an on-board vehicle device and a web-application. The on-board device is equipped with a GPRS-modem, a WiFi connection, a GPS system and a CAN-interface. The GPS system allows the monitoring of travel behaviour. Driving behaviour is studied by logging various CAN-parameters (e.g. revs per minute, chosen gear etc). Data is transmitted to a central server through the GPRS-network. Alternatively, data can be transmitted using a WiFi connection when present. Respondents can access the data on a web-application and provide additional information. The gathered information is used on the one hand to develop a regional activity-based travel model (not discussed in this paper). On the other hand, the data is used to assess the long-term effect of an eco-driving course by analyzing the change in driving behaviour and monitoring fuel consumption, and using these inputs to simulate the emissions before and after such training. The data might also be used as feedback to the driver, to visualize his driving behaviour, and to help him understand what he can do to further improve his driving style. This paper discusses the long-term effect of an eco-driving course on fuel economy and driving style for eight participants.

*Keywords: on-board logging device, eco-driving, fuel consumption, driving behaviour, driving style, CAN.*

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# 1 Introduction

Recently policy makers are developing an increased interest in fuel-efficient driving behaviour, commonly known in Europe as 'eco-driving'. The focus here lies on reducing greenhouse gas emissions from vehicles, and at the same time benefiting from the positive effect a more steady driving style has on road safety [1]. Several countries in Europe are incorporating the promotion of fuel efficient driving behaviour in their policies, claiming that fuel savings can mount up to 10% or more [1, 2]. Furthermore, driving style differences have been shown to have significant impacts on emissions [3] and are thus of importance to policies that try to reduce emissions [4, 5]. Also environmental groups are disseminating information on fuel efficient driving, as well as insurance institutions [6, 7].

Several studies have indeed proven the short-term effect of fuel efficient driving [8–13], but only a few have studied the effect on the longer term. Where short-term studies indicate fuel saving potentials of 10% or even more, the few studies covering a longer period conclude that fuel consumption decreases only by 2% [14, 15].

This paper describes the preliminary results of an ongoing survey with a duration of one year, using an on-board vehicle device for the collection of data regarding driving behaviour. The survey's results on driving behaviour will provide insight into the long-term effects of training on fuel efficient driving and will eventually contribute to better methods for emission estimation [16].

# 2 Previous studies using in-vehicle data recorders

In-vehicle data recorders (IVDR) are on-board devices that record information about the movement, control and performance of the vehicle [17]. The first application of onboard data loggers, commonly known as in-vehicle data recorders (IVDR), was the 'Event Data Recorder' (EDR) which collects technical and driver-related data in the seconds just before, during and immediately after a crash. In the last couple of years, EDR technology is becoming standard equipment in cars, and is mostly implemented as an extra functionality in the airbag control system.

Lately, the functionality of in-vehicle data recorders has been extended to also record non-crash related information. A number of IVDR systems have been developed in recent years. While their details and capabilities vary, the information they commonly collect may be classified in several categories [18]:

1. Vehicle movement, which includes the longitudinal and lateral accelerations and the speed of the vehicle.
2. Driver control, which includes variables such as the engine throttle and brake application and wheel-angle.
3. Engine parameters, such as RPM.
4. State of the vehicle safety systems, such as air bags, seat belts, ABS and traction control.
5. Vehicle location, using GPS systems.
6. Time.
7. Visual documentation both inside and outside the vehicle.

Notes and comments

# Using on-board logging devices to study the longer-term impact of an eco-driving course

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ABSTRACT

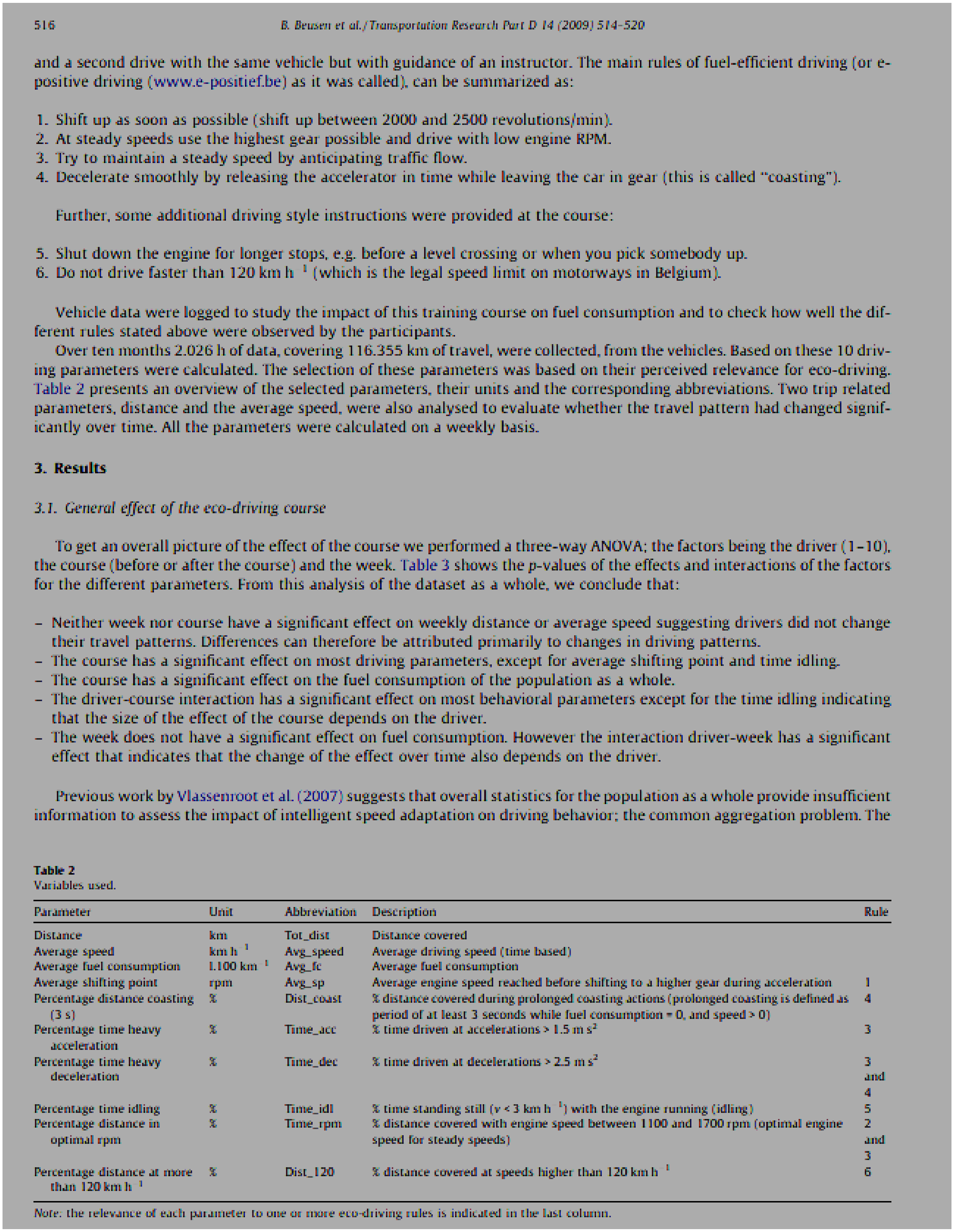
In this paper the long-term impact of an eco-driving training course is evaluated by monitoring driving behavior and fuel consumption for several months before and after the course. Cars were equipped with an on-board logging device that records the position and speed of the vehicle using GPS tracking as well as real time as electronic engine data extracted from the controller area network. The data includes mileage, number of revolutions per minute, position of the accelerator pedal, and instantaneous fuel consumption. It was gathered over a period of 10 months for 10 drivers during real-life conditions thus enabling an individual drive style analysis. The average fuel consumption four months after the course fell by 5.8%. Most drivers showed an immediate improvement in fuel consumption that was stable over time, but some tended to fall back into their original driving habits.

## 1. Introduction

Road transport $CO_2$ emissions form an important component of greenhouse gas generated in most developed countries and are projected to rise in the future. Among the policy options to reduce these emissions is eco-driving. Reducing fuel consumption significantly by teaching drivers how to change their driving behavior is potentially a very cost-efficient way to reduce energy use and emissions (International Energy Agency, 2005).

Numerous studies have looked at the short-term impact of eco-driving on fuel consumption. European Conference of Ministers of Transport/International Energy Agency (2005) found an average estimated 5% reduction for OECD (Organisation for Economic Cooperation and Development) regions based on an expert analysis of available literature. Few studies report on the long-term impacts of fuel-efficient driving courses. Wahlberg (2007) monitored fuel consumption reduction in busses and recorded 2% fuel savings during the 12 months after training. Zarkadoula et al. (2007) mention fuel savings on busses of 4.35% during a post training monitoring period of two months. Both studies report, however, that after a time drivers partially slip back to less environmentally friendly driving habits resulting in lower fuel savings than originally attributed to the courses.

Here we look at a long-term passenger car monitoring campaign that recorded driving patterns and fuel consumption from people participating in an eco-driving course. A panel of drivers was followed for up to 10 months to analyze the impact on fuel consumption and on different driving parameters.



and a second drive with the same vehicle but with guidance of an instructor. The main rules of fuel-efficient driving (or e-positive driving (www.e-positief.be) as it was called), can be summarized as:

1. Shift up as soon as possible (shift up between 2000 and 2500 revolutions/min).
2. At steady speeds use the highest gear possible and drive with low engine RPM.
3. Try to maintain a steady speed by anticipating traffic flow.
4. Decelerate smoothly by releasing the accelerator in time while leaving the car in gear (this is called "coasting").

Further, some additional driving style instructions were provided at the course:

5. Shut down the engine for longer stops, e.g. before a level crossing or when you pick somebody up.
6. Do not drive faster than 120 km h$^{-1}$ (which is the legal speed limit on motorways in Belgium).

Vehicle data were logged to study the impact of this training course on fuel consumption and to check how well the different rules stated above were observed by the participants.

Over ten months 2.026 h of data, covering 116.355 km of travel, were collected, from the vehicles. Based on these 10 driving parameters were calculated. The selection of these parameters was based on their perceived relevance for eco-driving. Table 2 presents an overview of the selected parameters, their units and the corresponding abbreviations. Two trip related parameters, distance and the average speed, were also analysed to evaluate whether the travel pattern had changed significantly over time. All the parameters were calculated on a weekly basis.

## 3. Results

### 3.1. *General effect of the eco-driving course*

To get an overall picture of the effect of the course we performed a three-way ANOVA; the factors being the driver (1–10), the course (before or after the course) and the week. Table 3 shows the *p*-values of the effects and interactions of the factors for the different parameters. From this analysis of the dataset as a whole, we conclude that:

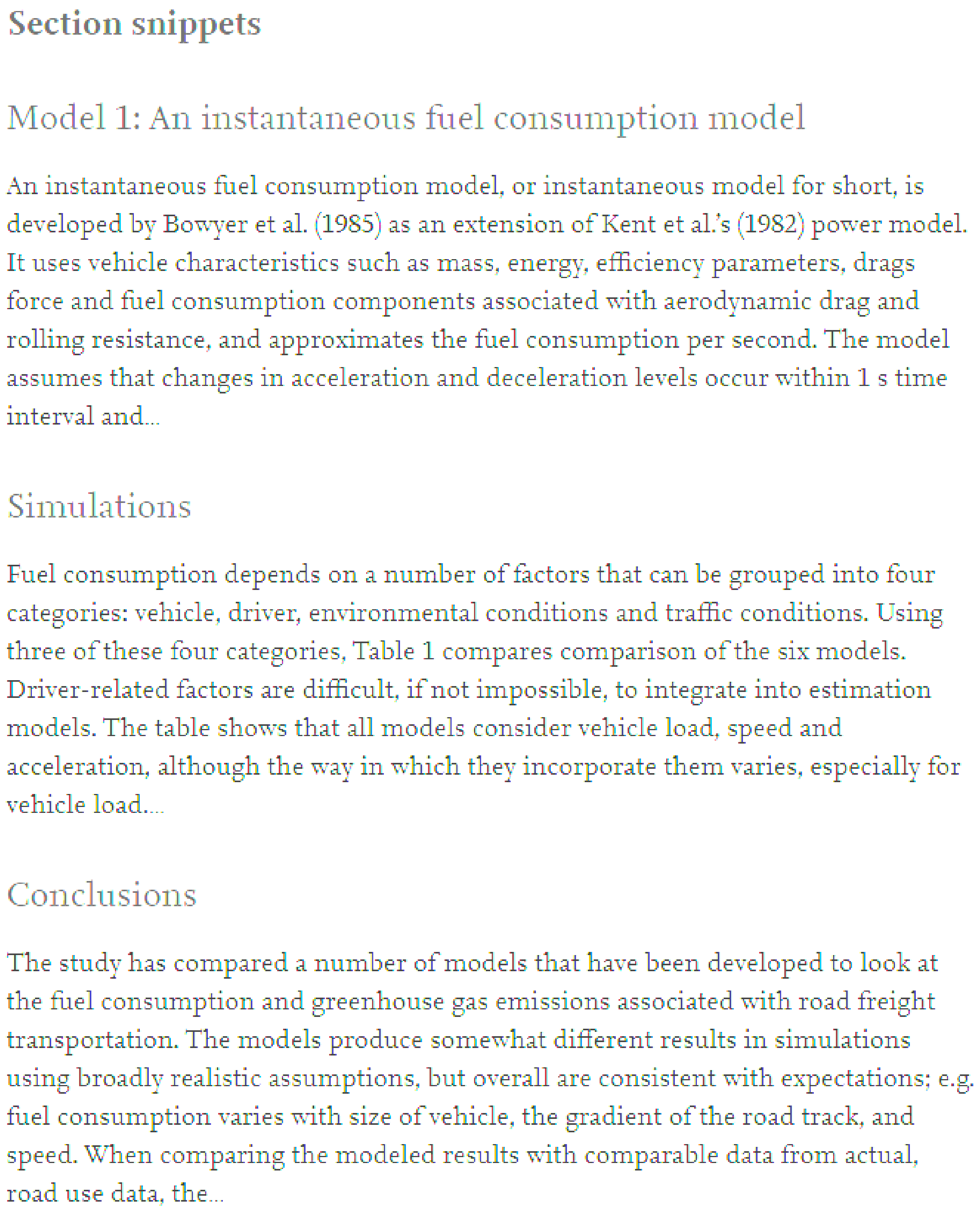
- Neither week nor course have a significant effect on weekly distance or average speed suggesting drivers did not change their travel patterns. Differences can therefore be attributed primarily to changes in driving patterns.
- The course has a significant effect on most driving parameters, except for average shifting point and time idling.
- The course has a significant effect on the fuel consumption of the population as a whole.
- The driver-course interaction has a significant effect on most behavioral parameters except for the time idling indicating that the size of the effect of the course depends on the driver.
- The week does not have a significant effect on fuel consumption. However the interaction driver-week has a significant effect that indicates that the change of the effect over time also depends on the driver.

Previous work by Vlassenroot et al. (2007) suggests that overall statistics for the population as a whole provide insufficient information to assess the impact of intelligent speed adaptation on driving behavior; the common aggregation problem. The

**Table 2**
Variables used.

| Parameter | Unit | Abbreviation | Description | Rule |
|---|---|---|---|---|
| Distance | km | Tot_dist | Distance covered | |
| Average speed | km h$^{-1}$ | Avg_speed | Average driving speed (time based) | |
| Average fuel consumption | l.100 km$^{-1}$ | Avg_fc | Average fuel consumption | |
| Average shifting point | rpm | Avg_sp | Average engine speed reached before shifting to a higher gear during acceleration | 1 |
| Percentage distance coasting (3 s) | % | Dist_coast | % distance covered during prolonged coasting actions (prolonged coasting is defined as period of at least 3 seconds while fuel consumption = 0, and speed > 0) | 4 |
| Percentage time heavy acceleration | % | Time_acc | % time driven at accelerations > 1.5 m s$^{2}$ | 3 |
| Percentage time heavy deceleration | % | Time_dec | % time driven at decelerations > 2.5 m s$^{2}$ | 3 and 4 |
| Percentage time idling | % | Time_idl | % time standing still ($v < 3$ km h$^{-1}$) with the engine running (idling) | 5 |
| Percentage distance in optimal rpm | % | Time_rpm | % distance covered with engine speed between 1100 and 1700 rpm (optimal engine speed for steady speeds) | 2 and 3 |
| Percentage distance at more than 120 km h$^{-1}$ | % | Dist_120 | % distance covered at speeds higher than 120 km h$^{-1}$ | 6 |

*Note:* the relevance of each parameter to one or more eco-driving rules is indicated in the last column.



## Section snippets

### Model 1: An instantaneous fuel consumption model

An instantaneous fuel consumption model, or instantaneous model for short, is developed by Bowyer et al. (1985) as an extension of Kent et al.'s (1982) power model. It uses vehicle characteristics such as mass, energy, efficiency parameters, drags force and fuel consumption components associated with aerodynamic drag and rolling resistance, and approximates the fuel consumption per second. The model assumes that changes in acceleration and deceleration levels occur within 1 s time interval and...

### Simulations

Fuel consumption depends on a number of factors that can be grouped into four categories: vehicle, driver, environmental conditions and traffic conditions. Using three of these four categories, Table 1 compares comparison of the six models. Driver-related factors are difficult, if not impossible, to integrate into estimation models. The table shows that all models consider vehicle load, speed and acceleration, although the way in which they incorporate them varies, especially for vehicle load....

### Conclusions

The study has compared a number of models that have been developed to look at the fuel consumption and greenhouse gas emissions associated with road freight transportation. The models produce somewhat different results in simulations using broadly realistic assumptions, but overall are consistent with expectations; e.g. fuel consumption varies with size of vehicle, the gradient of the road track, and speed. When comparing the modeled results with comparable data from actual, road use data, the...

## 7.3 ANEXOS MATERIALES Y MÉTODOS

### BPVI - Banco de rodillos inerciales e inercial con freno eléctrico - Doble y Simple Tracción

El BPVI es un dinamómetro de muy fácil instalación, simplemente de debe preparar la fosa para colocar el chasis y queda listo para funcionar. No requieren instalación de agua. La operación es muy sencilla y rápida, con un nuevo sistema de adquisición de datos de última tecnología que les da gran precisión y repetitividad. Se fabrican diversos modelos de acuerdo a la potencia a medir, doble y simple tracción y con la opción de acoplar un freno de corrientes parásitas.

Se fabrican diversos modelos de acuerdo a la potencia a medir. En las pruebas inerciales no hay límite físico de ensayo, cualquier vehículo se puede montar sobre los rodillos y realizar una tirada de aceleración. La limitación va a ser en estos casos la calidad de la medición: a medida que se prueba con más potencia y la inercia no es suficiente, la tirada será demasiado rápida. En estos casos la medición será poco consistente y repetitiva, con un margen de error importante. Nuestros dinamómetros de rodillos cuentan con la inercia adecuada para realizar ensayos de óptima calidad.

Otro punto crítico para realizar buenas mediciones es el diámetro de los rodillos, un buen diámetro asegura una pisada natural de la rueda minimizando errores debido a la deformación lo cuál es cada vez más influyente a medida que aumenta la velocidad de marcha. Todos los rodillos presentan un dibujo especial que evitar el patinamiento y permite reducir la carga del vehículo sobre el rodillo minimizando el calentamiento y la deformación.

## Chapter 3. Introduction of NGA 6000

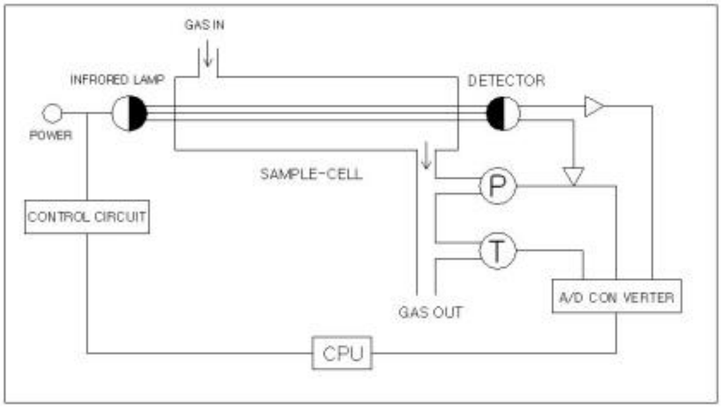
### 3-1 Specification

| | NGA 6000 | | | |
|---|---|---|---|---|
| **Measuring item** | CO, HC, CO2, O2, Lambda(air surplus rate), AFR, NOX (optional) | | | |
| **Measuring method** | CO, HC, CO2 : NDIR Method<br>O2, NOx : Electrochemical Cell | | | |
| **Measuring range** | CO | 0.00 ~ 9.99% | HC | 0 ~ 9999 ppm |
| **Resolution** | | 0.01% | | 1 ppm |
| **Display** | | 4 digit 7segment LED | | 4 or 5 digit 7segment LED |
| **Measuring range** | $CO_2$ | 0.0 ~ 20.0% | $O_2$ | 0.00 ~ 25.00 % |
| **Resolution** | | 0.1% | | 0.01 % |
| **Display** | | 4 digit 7segment LED | | 4 digit 7segment LED |
| **Measuring range** | Lambda | 0 ~ 2.000 | AFR | 0.0 ~ 99.0 |
| **Resolution** | | 0.001 | | 0.1 |
| **Display** | | 4 digit 7segment LED | | 4 digit 7segment LED |
| **Measuring range** | NOx (Option) | 0-5000 ppm | | |
| **Resolution** | | 1 ppm | | |
| **Display** | | 4 digit 7segment LED | | |
| **Repeatability** | Less than ±2% FS | | | |
| **Response time** | Within 10 seconds (more than 90%) | | | |
| **Warming up time** | About 2 ~ 8 minutes | | | |
| **Sample collecting quantity** | 4 ~ 6 L/min | | | |
| **Power** | 220V AC or 110V AC ±10% 50 / 60Hz | | | |
| **Power consumption** | About 50 W | | | |
| **Operation temperature** | 0℃ ~ 40℃ | | | |
| **Dimensions** | 420 (W) × 298 (D) × 180 (H) mm | | | |
| **Weight** | About 6.9 kg | | | |
| **Basic accessories** | Probe, Probe hose, Spare fuse, Leak test cap, Spare filter, Operation manual, Power cord, RS232, Communication cable, Printer, Printer paper | | | |

## Chapter 4. Circuits of NGA 6000

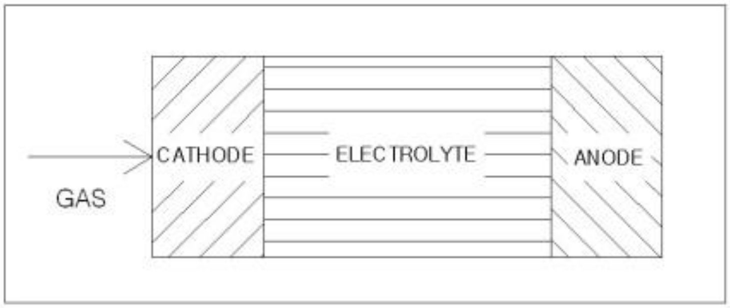
### 4-1 Measuring principal

This analyzer is configured to perform a measurement by applying Non Dispersive Infra-Red (NDIR) method for analyzing CO, HC, and CO2, and electrochemical method for analyzing O2 and NOx. In the NDIR analyzing method, a flashing ramp which flashes the infrared rays is attached at the one end of the sample cell and at the other end a detecting sensor is attached so that it can detect the component of a gas and then calculate the gas density.



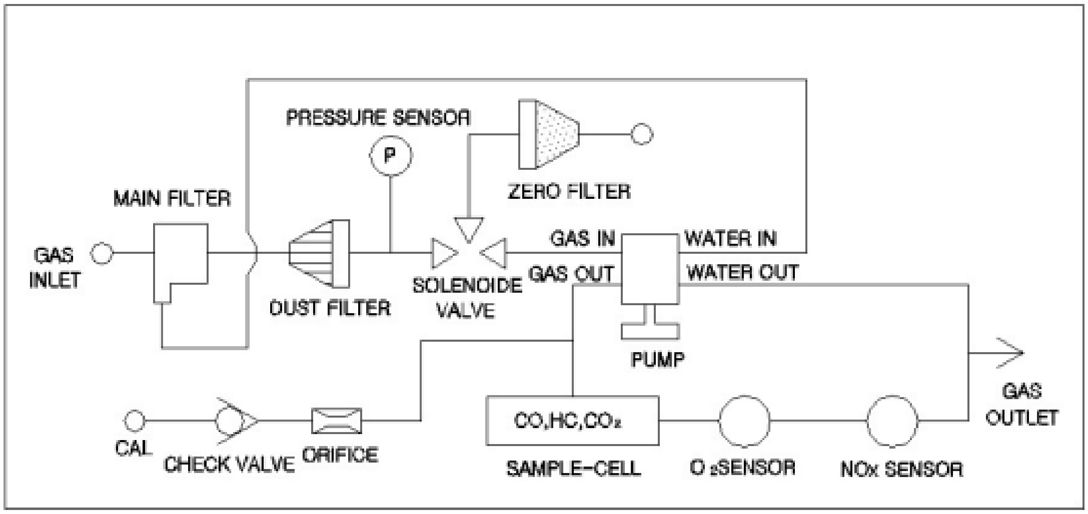
<NDIR method diagram>

The electrochemical method measures the gas density by using the quantity of electron which produced in the time of oxidation and reducing reaction of the gas.

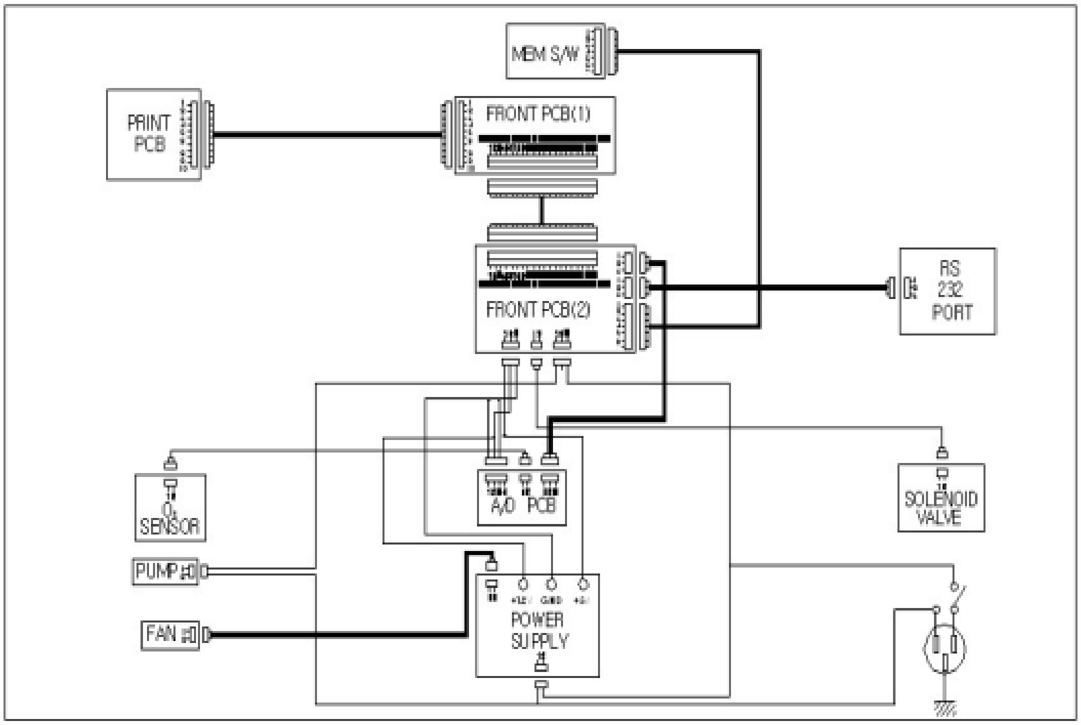


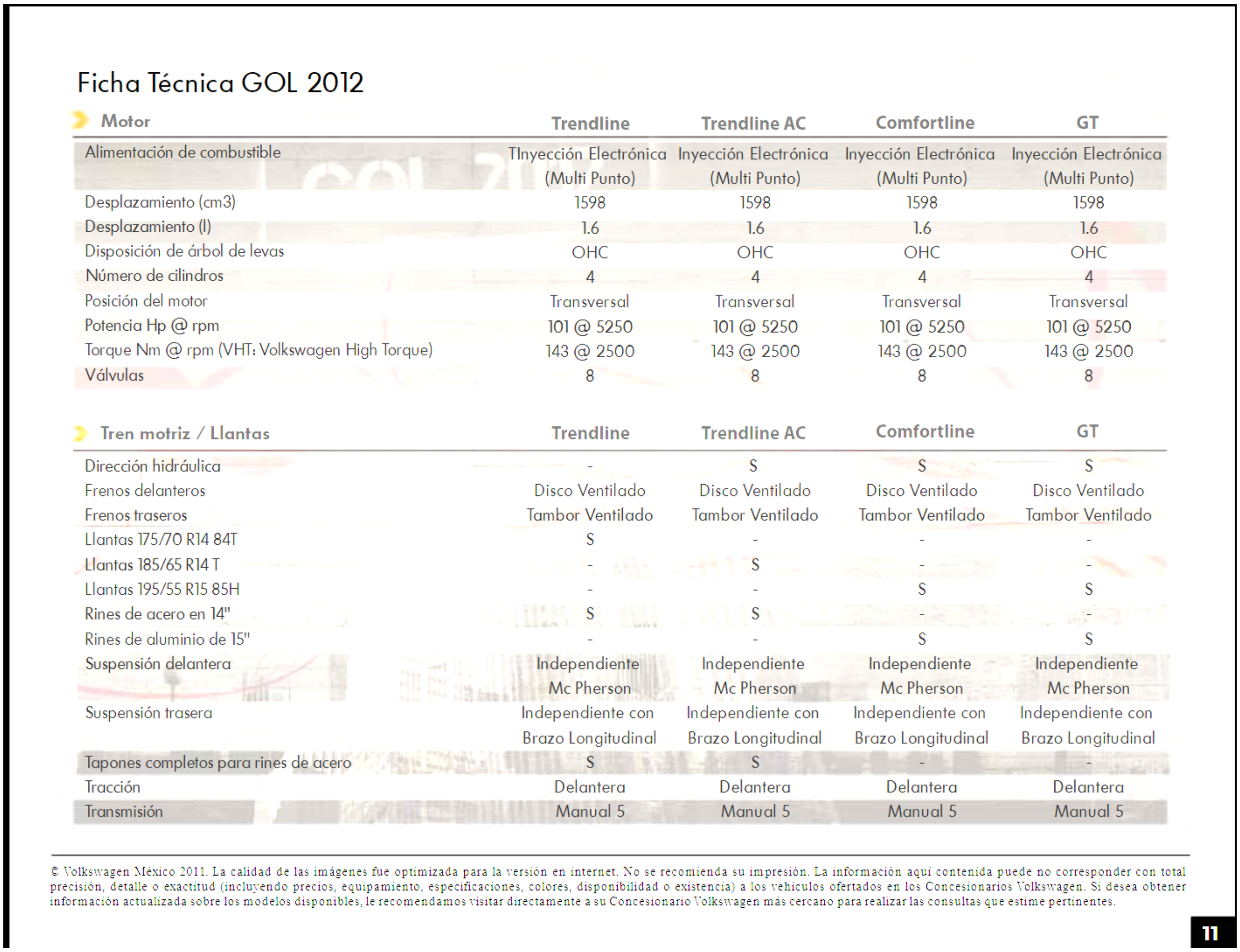
<Electrochemical method diagram>

## 4-2 Guiding diagram



## 4-3 Electrical circuit diagram



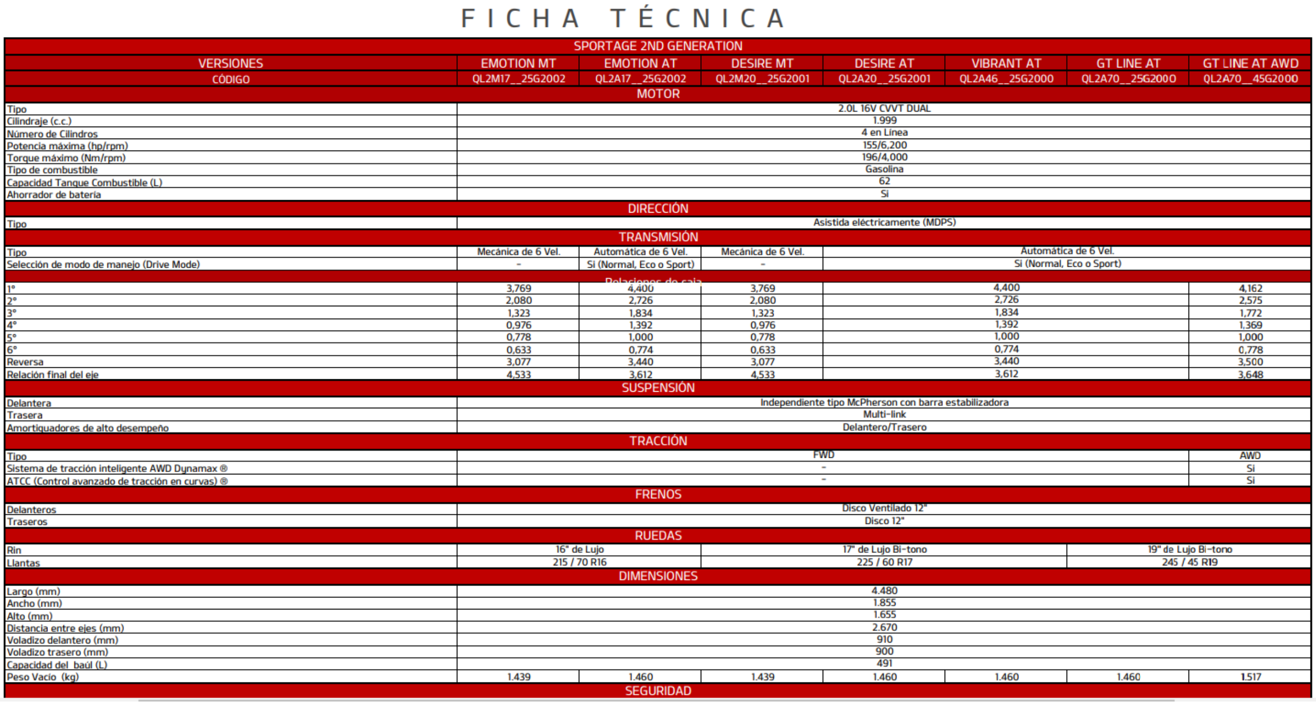


## Ficha Técnica GOL 2012

| Motor | Trendline | Trendline AC | Comfortline | GT |
|---|---|---|---|---|
| Alimentación de combustible | TInyección Electrónica (Multi Punto) | Inyección Electrónica (Multi Punto) | Inyección Electrónica (Multi Punto) | Inyección Electrónica (Multi Punto) |
| Desplazamiento (cm3) | 1598 | 1598 | 1598 | 1598 |
| Desplazamiento (l) | 1.6 | 1.6 | 1.6 | 1.6 |
| Disposición de árbol de levas | OHC | OHC | OHC | OHC |
| Número de cilindros | 4 | 4 | 4 | 4 |
| Posición del motor | Transversal | Transversal | Transversal | Transversal |
| Potencia Hp @ rpm | 101 @ 5250 | 101 @ 5250 | 101 @ 5250 | 101 @ 5250 |
| Torque Nm @ rpm (VHT: Volkswagen High Torque) | 143 @ 2500 | 143 @ 2500 | 143 @ 2500 | 143 @ 2500 |
| Válvulas | 8 | 8 | 8 | 8 |

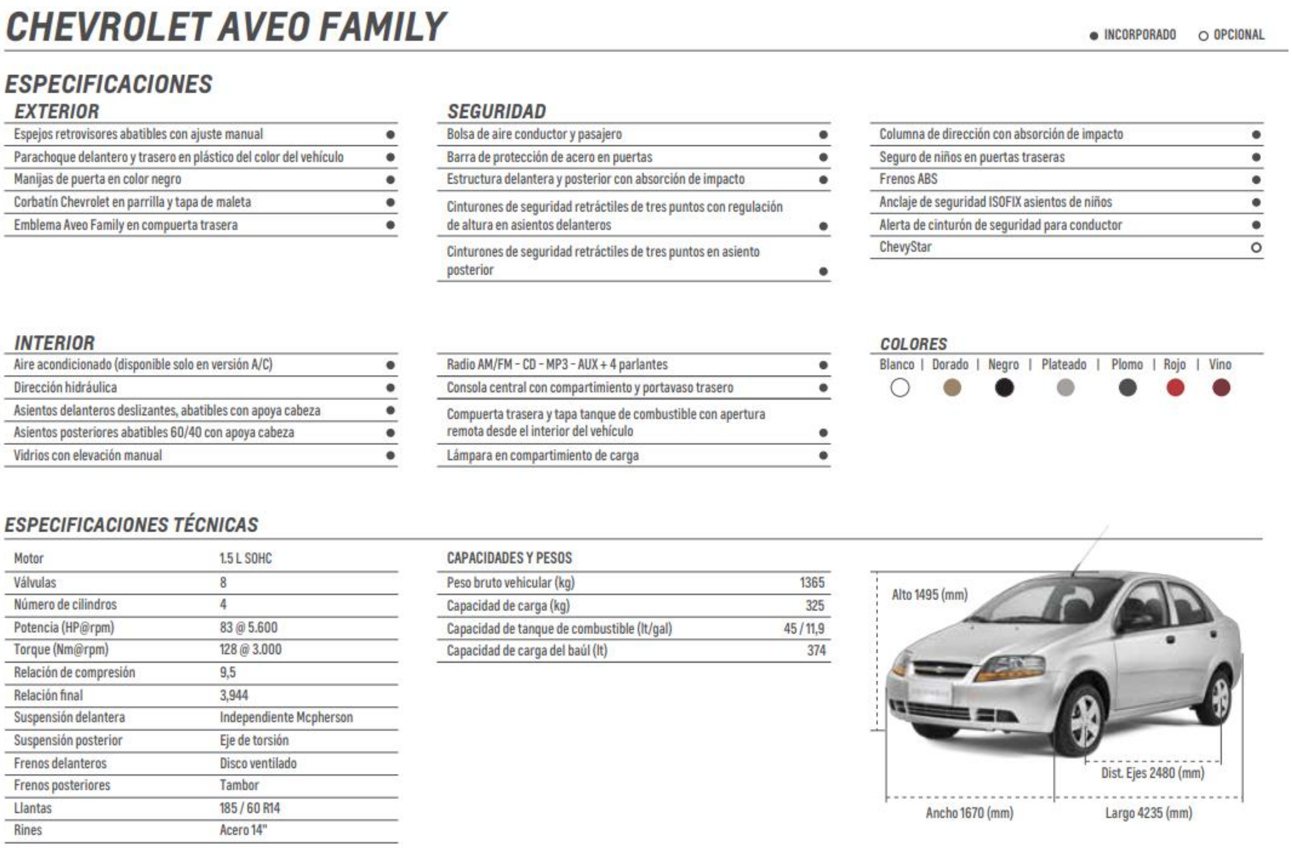
| Tren motriz / Llantas | Trendline | Trendline AC | Comfortline | GT |
|---|---|---|---|---|
| Dirección hidráulica | - | S | S | S |
| Frenos delanteros | Disco Ventilado | Disco Ventilado | Disco Ventilado | Disco Ventilado |
| Frenos traseros | Tambor Ventilado | Tambor Ventilado | Tambor Ventilado | Tambor Ventilado |
| Llantas 175/70 R14 84T | S | - | - | - |
| Llantas 185/65 R14 T | - | S | - | - |
| Llantas 195/55 R15 85H | - | - | S | S |
| Rines de acero en 14" | S | S | - | - |
| Rines de aluminio de 15" | - | - | S | S |
| Suspensión delantera | Independiente Mc Pherson | Independiente Mc Pherson | Independiente Mc Pherson | Independiente Mc Pherson |
| Suspensión trasera | Independiente con Brazo Longitudinal | Independiente con Brazo Longitudinal | Independiente con Brazo Longitudinal | Independiente con Brazo Longitudinal |
| Tapones completos para rines de acero | S | S | - | - |
| Tracción | Delantera | Delantera | Delantera | Delantera |
| Transmisión | Manual 5 | Manual 5 | Manual 5 | Manual 5 |

| Engine Specifications | |
|---|---|
| **Engine code** | J20 |
| **Layout** | Four stroke, Inline-4 (Straight-4) |
| **Fuel type** | Gasoline (petrol) |
| **Production** | – |
| **Displacement** | 2.0 L, 1,995 cm$^3$ (121.7 cu in) |
| **Fuel system** | Multi-point fuel injection (MPFI) |
| **Power adder** | None |
| **Power output** | 130 PS (95 kW; 127 HP) at 6,000 rpm |
| **Torque output** | 182 N·m (18.6 kg·m, 134 ft·lb) at 3,000 rpm |
| **Firing order** | 1-3-4-2 |
| **Dimensions (L x W x H):** | – |
| **Weight** | – |



# FICHA TÉCNICA

| SPORTAGE 2ND GENERATION | | | | | | | |
|---|---|---|---|---|---|---|---|
| **VERSIONES** | **EMOTION MT** | **EMOTION AT** | **DESIRE MT** | **DESIRE AT** | **VIBRANT AT** | **GT LINE AT** | **GT LINE AT AWD** |
| **CÓDIGO** | QL2M17__25G2002 | QL2A17__25G2002 | QL2M20__25G2001 | QL2A20__25G2001 | QL2A46__25G2000 | QL2A70__25G2000 | QL2A70__45G2000 |
| **MOTOR** | | | | | | | |
| Tipo | 2.0L 16V CVVT DUAL | | | | | | |
| Cilindraje (c.c.) | 1.999 | | | | | | |
| Número de Cilindros | 4 en Línea | | | | | | |
| Potencia máxima (hp/rpm) | 155/6,200 | | | | | | |
| Torque máximo (Nm/rpm) | 196/4,000 | | | | | | |
| Tipo de combustible | Gasolina | | | | | | |
| Capacidad Tanque Combustible (L) | 62 | | | | | | |
| Ahorrador de batería | Si | | | | | | |
| **DIRECCIÓN** | | | | | | | |
| Tipo | Asistida eléctricamente (MDPS) | | | | | | |
| **TRANSMISIÓN** | | | | | | | |
| Tipo | Mecánica de 6 Vel. | Automática de 6 Vel. | Mecánica de 6 Vel. | Automática de 6 Vel. | | | |
| Selección de modo de manejo (Drive Mode) | - | Si (Normal, Eco o Sport) | - | Si (Normal, Eco o Sport) | | | |
| **Relaciones de caja** | | | | | | | |
| 1° | 3,769 | 4,400 | 3,769 | 4,400 | | | 4,162 |
| 2° | 2,080 | 2,726 | 2,080 | 2,726 | | | 2,575 |
| 3° | 1,323 | 1,834 | 1,323 | 1,834 | | | 1,772 |
| 4° | 0,976 | 1,392 | 0,976 | 1,392 | | | 1,369 |
| 5° | 0,778 | 1,000 | 0,778 | 1,000 | | | 1,000 |
| 6° | 0,633 | 0,774 | 0,633 | 0,774 | | | 0,778 |
| Reversa | 3,077 | 3,440 | 3,077 | 3,440 | | | 3,500 |
| Relación final del eje | 4,533 | 3,612 | 4,533 | 3,612 | | | 3,648 |
| **SUSPENSIÓN** | | | | | | | |
| Delantera | Independiente tipo McPherson con barra estabilizadora | | | | | | |
| Trasera | Multi-link | | | | | | |
| Amortiguadores de alto desempeño | Delantero/Trasero | | | | | | |
| **TRACCIÓN** | | | | | | | |
| Tipo | FWD | | | | | | AWD |
| Sistema de tracción inteligente AWD Dynamax ® | - | | | | | | Si |
| ATCC (Control avanzado de tracción en curvas) ® | - | | | | | | Si |
| **FRENOS** | | | | | | | |
| Delanteros | Disco Ventilado 12" | | | | | | |
| Traseros | Disco 12" | | | | | | |
| **RUEDAS** | | | | | | | |
| Rin | 16" de Lujo | | 17" de Lujo Bi-tono | | | 19" de Lujo Bi-tono | |
| Llantas | 215 / 70 R16 | | 225 / 60 R17 | | | 245 / 45 R19 | |
| **DIMENSIONES** | | | | | | | |
| Largo (mm) | 4.480 | | | | | | |
| Ancho (mm) | 1.855 | | | | | | |
| Alto (mm) | 1.655 | | | | | | |
| Distancia entre ejes (mm) | 2.670 | | | | | | |
| Voladizo delantero (mm) | 910 | | | | | | |
| Voladizo trasero (mm) | 900 | | | | | | |
| Capacidad del baúl (L) | 491 | | | | | | |
| Peso Vacío (kg) | 1.439 | 1.460 | 1.439 | 1.460 | 1.460 | 1.460 | 1.517 |
| **SEGURIDAD** | | | | | | | |



# CHEVROLET AVEO FAMILY

● INCORPORADO ○ OPCIONAL

## ESPECIFICACIONES

### EXTERIOR

| | |
|---|---|
| Espejos retrovisores abatibles con ajuste manual | ● |
| Parachoque delantero y trasero en plástico del color del vehículo | ● |
| Manijas de puerta en color negro | ● |
| Corbatín Chevrolet en parrilla y tapa de maleta | ● |
| Emblema Aveo Family en compuerta trasera | ● |

### SEGURIDAD

| | |
|---|---|
| Bolsa de aire conductor y pasajero | ● |
| Barra de protección de acero en puertas | ● |
| Estructura delantera y posterior con absorción de impacto | ● |
| Cinturones de seguridad retráctiles de tres puntos con regulación de altura en asientos delanteros | ● |
| Cinturones de seguridad retráctiles de tres puntos en asiento posterior | ● |
| Columna de dirección con absorción de impacto | ● |
| Seguro de niños en puertas traseras | ● |
| Frenos ABS | ● |
| Anclaje de seguridad ISOFIX asientos de niños | ● |
| Alerta de cinturón de seguridad para conductor | ● |
| ChevyStar | ○ |

### INTERIOR

| | |
|---|---|
| Aire acondicionado (disponible solo en versión A/C) | ● |
| Dirección hidráulica | ● |
| Asientos delanteros deslizantes, abatibles con apoya cabeza | ● |
| Asientos posteriores abatibles 60/40 con apoya cabeza | ● |
| Vidrios con elevación manual | ● |
| Radio AM/FM - CD - MP3 - AUX + 4 parlantes | ● |
| Consola central con compartimiento y portavaso trasero | ● |
| Compuerta trasera y tapa tanque de combustible con apertura remota desde el interior del vehículo | ● |
| Lámpara en compartimiento de carga | ● |

### COLORES

| Blanco | Dorado | Negro | Plateado | Plomo | Rojo | Vino |
|---|---|---|---|---|---|---|
| ○ | ● | ● | ● | ● | ● | ● |

## ESPECIFICACIONES TÉCNICAS

| | |
|---|---|
| Motor | 1.5 L SOHC |
| Válvulas | 8 |
| Número de cilindros | 4 |
| Potencia (HP@rpm) | 83 @ 5.600 |
| Torque (Nm@rpm) | 128 @ 3.000 |
| Relación de compresión | 9,5 |
| Relación final | 3,944 |
| Suspensión delantera | Independiente Mcpherson |
| Suspensión posterior | Eje de torsión |
| Frenos delanteros | Disco ventilado |
| Frenos posteriores | Tambor |
| Llantas | 185 / 60 R14 |
| Rines | Acero 14" |

| CAPACIDADES Y PESOS | |
|---|---|
| Peso bruto vehicular (kg) | 1365 |
| Capacidad de carga (kg) | 325 |
| Capacidad de tanque de combustible (lt/gal) | 45 / 11,9 |
| Capacidad de carga del baúl (lt) | 374 |

Alto 1495 (mm)

Dist. Ejes 2480 (mm)

Ancho 1670 (mm)

Largo 4235 (mm)

# NUEVO CHEVROLET BEAT

● INCORPORADO ○ OPCIONAL – NO DISPONIBLE

## ESPECIFICACIONES

### EXTERIOR

| | |
|---|---|
| Espejos retrovisores exteriores eléctricos abatibles manualmente con desempañador | ● |
| Espejos retrovisores del color de la carrocería con luz direccional | ● |
| Luces antiniebla | ● |
| Manijas de puerta en color del vehículo | ● |
| Corbatín "Chevrolet" en la parte delantera y posterior | ● |
| Emblema "Beat" y "Premier" en la parte posterior | ● |

### SEGURIDAD

| | |
|---|---|
| Bolsa de aire conductor y pasajero | ● |
| Barra de protección para impactos laterales | ● |
| Cinturones de seguridad retráctiles de tres puntos en asientos delanteros | ● |
| Cinturones de seguridad retráctiles de tres puntos en asientos traseros | ● |
| ChevyStar | ○ |
| Columna de dirección colapsable | ● |
| Seguro de niños en puertas traseras | ● |
| Bloqueo central | ● |
| Frenos ABS | ● |
| Anclaje de seguridad ISOFIX asientos de niños | ● |
| Alerta de cinturón de seguridad para conductor | ● |

### INTERIOR

| | |
|---|---|
| Aire acondicionado | ● |
| Asientos delanteros tipo butaca | ● |
| Apertura de baúl desde botón interno | ● |
| Control de radio al volante | ● |
| Tapa tanque de combustible con apertura remota desde el interior del vehículo | ● |
| Radio MyLink® con pantalla táctil de 7" compatible con Android Auto con 6 parlantes | ● |
| Vidrios eléctricos delanteros y posteriores | ● |

### COLORES

| Blanco | Plata | Dorado | Plomo | Azul | Rojo | Vino | Negro |
|---|---|---|---|---|---|---|---|
| ○ | ● | ● | ● | ● | ● | ● | ● |

## ESPECIFICACIONES TÉCNICAS

| | |
|---|---|
| Motor | 1.2 L DOHC |
| Válvulas | 16 |
| Número de cilindros | 4 |
| Potencia (HP@rpm) | 80,5 @ 6.400 |
| Torque (Nm@rpm) | 108 @ 4.800 |
| Relación de compresión | 9.8 |
| Relación final | 4.444 |
| Suspensión delantera | Independiente McPherson |
| Suspensión posterior | Eje de torsión |
| Frenos delanteros | Discos sólidos |
| Frenos posteriores | Tambor |
| Barra estabilizadora | Delantera |
| Llantas | 165 / 65 R14 |
| Rines | Aluminio 14" |
| Dirección | Electrónicamente asistida |

| CAPACIDADES Y PESOS | |
|---|---|
| Peso bruto vehicular (kg) | 1400 |
| Capacidad de carga (kg) | 420 |
| Capacidad de tanque de combustible (lt/gal) | 35/ 9 |
| Capacidad de carga de baúl (lt) | 390 |

de combustible que se requiere trabajar. [9]

$$\left[\left(\frac{n}{12}\right)C+\left(\frac{m}{1}\right)H\right]+A\left[\left(\frac{23.3}{32}\right)O_2+\left(\frac{76.7}{28}\right)N_2\right]\rightarrow XCO_2+YN_2+WH_2O$$

A= Relación Aire Combustible.
n= % de Carbono en el combustible.
m= % de Hidrógeno en el combustible.
X, Y, W = número moles de los productos.

Remplazando las incógnitas que se obtienen por el porcentaje de los componentes y porcentajes másicos de la ecuación con el combustible Extra tenemos:

$$[7\,C+15.7\,H]+15[0.728\,O_2+2.739\,N_2]\rightarrow 7CO_2+41.1N_2+7.85H_2O$$

A= 15. Es la mezcla estequiométrica que se necesita para combustionar la gasolina Extra.

Remplazando las incógnitas encontradas de la ecuación con el combustible E5 tenemos:

$$[6.872C+15.554H+\ 0.116\,O]+14.85[0.728\,O_2+2.739\,N_2]\rightarrow 6.87CO_2+40.68N_2+7.77H_2O$$

A= 14.85. Es la mezcla estequiométrica que se necesita para combustionar la gasolina E5.

Remplazando las incógnitas encontradas con el combustible E10 tenemos:

$$[6.75\,C+15.41\,H+\ 0.233\,O]+14.40[0.728\,O_2+2.739\,N_2]\rightarrow 6.75C\,O_2+39.44\,N_2+7.70\,H_2O$$

A= 14.40. Es la mezcla estequiométrica que se necesita para combustionar la gasolina E10.

**Emisiones contaminantes**

En cuanto a la cantidad de gases contaminantes obtenida al utilizar gasolina Extra, se muestra todos los valores tanto en estado de ralentí como de altas RPM según la norma NTE INEN 2203 en la Tabla 7.

**TABLA 7**
**Emisiones contaminantes con combustible Extra.**

| Parámetros | Primera medición | | Segunda medición | | Tercera medición | |
|---|---|---|---|---|---|---|
| | Ralentí | RPM altas | Ralentí | RPM altas | Ralentí | RPM altas |
| CO [%v] | 0,26 | 0,01 | 0,39 | 0,02 | 0,1 | 0,03 |
| CO2 [%v] | 12,9 | 12,9 | 12,7 | 12,9 | 13 | 13 |
| CO corr [%v] | 0,3 | 0,01 | 0,45 | 0,02 | 0,11 | 0,03 |
| O2 [%v] EXTRA | 0,1 | 0,17 | 0,08 | 0,08 | 0,07 | 0,08 |
| Λ | 0,887 | 1,007 | 0,989 | 1,003 | 1 | 1,002 |
| RPM | 780 | 2510 | 790 | 2560 | 810 | 2550 |
| T ACEITE [˚C] | 95 | 94 | 94 | 94 | 94 | 94 |

Una vez reemplazado el combustible extra por E5, se presenta los resultados del análisis en la Tabla 8.

**TABLA 8**
**Misiones contaminantes con combustible E5.**

| Parámetros | Primera medición | | Segunda medición | | Tercera medición | |
|---|---|---|---|---|---|---|
| | Ralentí | RPM altas | Ralentí | RPM altas | Ralentí | RPM altas |
| CO [%v] | 3,42 | 0,05 | 1,01 | 0,1 | 1,49 | 0,03 |
| CO2 [%v] | 10,8 | 12,9 | 12,8 | 12,8 | 12 | 12,8 |
| CO corr [%v] | 3,61 | 0,06 | 1,1 | 0,12 | 1,66 | 0,04 |
| HC [PPM] | 226 | 79 | 111 | 0,12 | 137 | 38 |
| O2 [%v] | 0,1 | 0,13 | 0,16 | 0,38 | 0,06 | 0,08 |
| Λ | 0,887 | 1,001 | 0,971 | 1,013 | 0,948 | 1,001 |
| RPM | 790 | 2500 | 790 | 2520 | 790 | 2500 |
| T ACEITE [˚C] | 92 | 91 | 91 | 89 | 91 | 91 |

Finalmente se tiene la serie de datos tabulados referente a los gases contaminantes estudiados con un combustible E10 como muestra la Tabla 9.

**TABLA 9**
**Emisiones contaminantes con combustible E10.**

| Parámetros | Primera prueba | | Segunda prueba | | Tercera prueba | |
|---|---|---|---|---|---|---|
| | Ralentí | RPM altas | Ralentí | RPM altas | Ralentí | RPM altas |
| CO [%v] | 2,82 | 0,08 | 2,31 | 0,18 | 2,95 | 0,07 |
| CO2 [%v] | 13 | 14,1 | 13,2 | 14,3 | 12,6 | 14,3 |
| CO corr [%v] | 2,82 | 0,08 | 2,31 | 0,19 | 2,95 | 0,07 |
| HC [PPM] E10 | 190 | 68 | 186 | 84 | 155 | 45 |
| O2 [%v] E10 | 0 | 0,08 | 0 | 0 | 0 | 0 |
| Λ | 0,912 | 0,998 | 0,926 | 0,991 | 0,908 | 0,995 |
| RPM | 790 | 2550 | 800 | 2600 | 800 | 2540 |
| T ACEITE [˚C] | 90 | 90 | 90 | 90 | 90 | 90 |

## 13.12 Ejemplo—Relación real entre aire y combustible

Se realizó un análisis de gases de escape para los productos secos del carbón en el ejemplo de §13.10, y se halló que es el 15% $CO_2$, el 3.5% $O_2$ y el 0.2% CO, suponiendo que el resto es nitrógeno, un 81.3% $N_2$, todo considerando volumen de gas seco. ¿Qué cantidad de exceso o deficiencia de aire se suministra?

**Solución aproximada, suponiendo que sólo se conoce la cantidad de carbono.** En el caso del carbón de §13.10, sabemos que el carbono está como 0.6734 kg C/kg (comb. seco), o sea, 5.61 moles por 100 kg de combustible seco. Una ecuación química parcial es

$$\text{(a)}\qquad a[5.61C + \cdots] + \cdots \rightarrow 15CO_2 + 0.2CO + 3.5O_2 + 81.3N_2 + \cdots$$

El análisis de productos secos se escribe como se expresó antes, siendo la base de la ecuación 100 moles de productos. El coeficiente $a$ se obtiene de un balance de carbono

$$\text{C:}\quad 5.61a = 15 + 0.2 \qquad \text{o bien} \qquad a = 2.71 \quad 5.61a = 15.2$$

$$\text{(b)}\qquad 15.2C + \cdots \rightarrow 15CO_2 + 0.2CO + 3.5O_2 + 81.3N_2 + \cdots$$

Según este enfoque suponemos que el nitrógeno mide la cantidad de aire, lo que es una buena hipótesis si no hay $N_2$ en el combustible, puesto que pasa por la reacción ideal sin ser afectado. Los moles de $O_2$ que acompañaron a los 81.3 moles de $N_2$ del aire son: 81.3/3.76 = 21.6 moles de $O_2$; de lo cual, los moles de aire son: 81.3 + 21.6 = 102.9. La masa de aire por unidad de masa de carbono, que se basa en *todo el carbono que se quema* es

$$\text{(c)}\qquad \frac{(102.9)(29)\text{lb(aire)}}{(15.2)(12)\text{lbC}} = 16.36 \text{ lb (aire)/ lb C quemado}$$

Utilizando el contenido conocido de carbono (0.6734) y el de humedad [0.12, o bien, 0.88 kg (comb. seco)/kg (comb. en br.)], se obtiene

**(d)**

$$r_{a/f} = \left(16.36\frac{\text{kg (aire)}}{\text{kg C}}\right)\left(0.6734\frac{\text{kg C}}{\text{kg (comb. seco)}}\right)\left(0.88\frac{\text{kg (comb. seco)}}{\text{kg (comb. en br.)}}\right) = 9.7\frac{\text{kg (aire)}}{\text{kg (comb. en br.)}}$$

en comparación con 8.1 kg de aire para combustión estequiométrica. El exceso es (9.7 – 8.1)/8.1 = 19.8%.

**Solución por el análisis químico.** Cuando se conoce más del análisis de combustible, se puede realizar un cálculo algo más exacto del aire. Excepto en casos extremos, el azufre no se considera (el $SO_2$ esté en el porcentaje de $CO_2$ según el análisis Orsat debido a que el hidróxido de potasio lo absorbe también). Empleando valores molares de la sección §13.10, tenemos

$$\text{(e)}\qquad a[5.61C + 2.33H_2 + 0.265O_2 + 0.045N_2] + bO_2 + 3.76bN_2 \rightarrow$$
$$15CO_2 + 0.2CO + 3.5O_2 + (0.045a + 3.76b)N_2 + dH_2O$$

Si hay hidrógeno en el combustible, tiene que haber alguna cantidad de $H_2O$ en los productos. El coeficiente $a$ se determina a partir del balance del carbono, y se halló anteriormente; por lo tanto, $a = 2.71$. De otros balances de materiales se obtiene

$$H_2:\quad (2.71)(2.33)(2) = 2d \qquad\qquad d = 6.31$$

$$O_2:\quad (2.71)(0.265)(2) + 2b = 30 + 0.2 + 7 + 6.31 \qquad b = 21.03$$

La ecuación balanceada es ($3.76b = 79.07$)

**(f)**

$$[15.2C + 6.31H_2 + 0.72O_2 + 0.122N_2] + 21.03O_2 + 79.07N_2 \rightarrow$$

$$15CO_2 + 0.2CO + 3.5O_2 + 79.19N_2 + 6.31H_2O$$

El aire suministrado es el $O_2$ y $N_2$ en el primer miembro de la ecuación, fuera de los corchetes que delimitan al combustible; se tiene así que $21.03 + 79.07 = 100.1$ moles de aire. Como antes,

**(g)**

$$r_{a/f} = \frac{(100.1)(29)(0.6734)(0.88)}{(15.2)(12)} = 9.43 \text{ lb (aire)/lb (comb. en br.)}$$

Compare esto con la respuesta anterior. Además de los procedimientos diferentes, es de esperar un error experimental al tomar lecturas. La ventaja del segundo método es que cualquier razón deseada se obtiene rápidamente con la ecuación balanceada. Quizá se haya observado, aunque no resulta esencial en este ejemplo hacerlo así, que la cantidad de combustible encerrada por los corchetes es de $100a = 271$ kg/100 moles de productos secos.

### 13.13 Ejemplo—Aire para un hidrocarburo de composición desconocida

Puesto que los combustibles comerciales provenientes del petróleo son mezclas de numerosos hidrocarburos, con frecuencia es ventajoso obtener una estimación de la relación aire-combustible, sin tener que realizar un análisis de combustible (que no hay duda que varíe con las diversas entregas). En el siguiente enfoque, el combustible se supone que está compuesto sólo de carbono e hidrógeno en la fórmula $C_xH_y$ y, por consiguiente, debe contener únicamente pequeñas cantidades de $O_2$, $N_2$ y S para evitar un error de significación.

El escape *seco* de un motor de automóvil a la presión de 1 atm tiene un análisis volumétrico como sigue: 12.5% $CO_2$, 3.1% $O_2$, 0.3% CO, que es la información obtenida del análisis Orsat. (Es necesario que haya también aproximadamente el 0.22% $CH_4$ y el 0.15% $H_2$. Vea la sección §13.11. Estas cantidades pueden incluirse si se desea, pero serán omitidas para abreviar la explicación.) Supóngase que el resto del escape es $N_2 = 84.1\%$. (a) Establecer la ecuación de combustión teórica hallando valores de $x$ y $y$ en $C_xH_y$. (b) Determinar la relación aire-combustible.

**Solución.** (a) El análisis de productos no indica $H_2O$, pero *no hay que olvidar incluirlo*, porque es seguro que haya, en tanto que el combustible contenga hidrógeno. Como se supone que no existe $O_2$ en el combustible, el $O_2$ en el primer miembro de la ecuación química es el que acompaña al $N_2$ existente en el aire; así, $84.1/3.76 = 22.4$ moles de $O_2$.

$$C_xH_y + 22.4O_2 + 84.1N_2 \rightarrow 12.5CO_2 + 3.1O_2 + 0.3CO + 84.1N_2 + aH_2O$$

Balances de material:

C: $x = 12.5 + 0.3$ $\qquad x = 12.8$

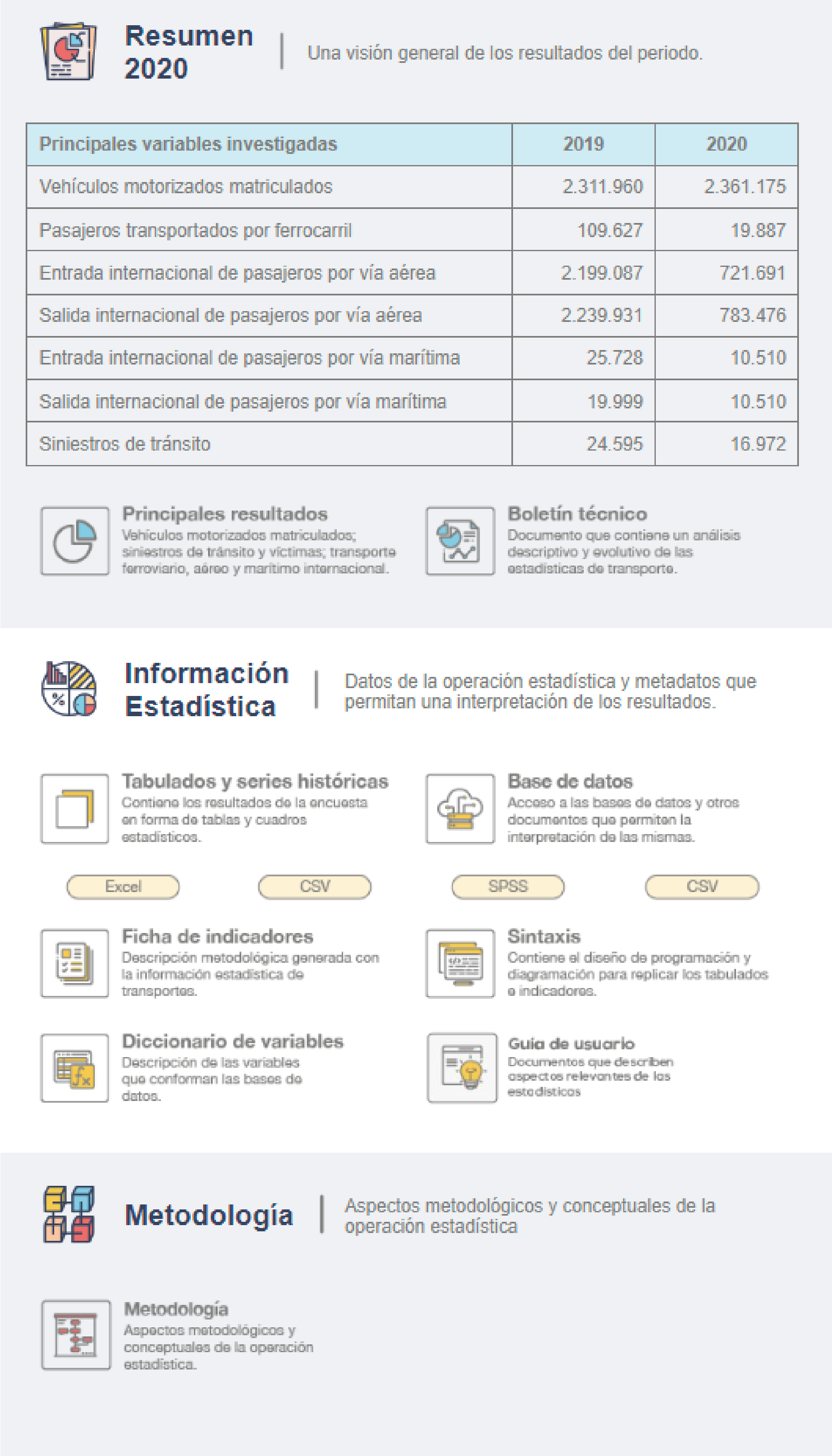
$O_2$: $(2)(22.4) = (2)(12.5) + (2)(3.1) + 0.3 + a$ $\qquad a = 13.3$

$H_2$: $y = 2a = (2)(13.3)$ $\qquad y = 26.6$

En consecuencia, *considerando* que todo el carbono y el hidrógeno se queman, el combustible es una mezcla de hidrocarburos para la cual la molécula media es $C_{12.8}H_{26.6}$, o para la que la relación $y/x = 26.6/12.8$. La ecuación química no dice nada más. La ecuación balanceada es entonces

$$C_{12.8}H_{26.6} + 22.4O_2 + 84.1N_2 \rightarrow 12.5CO_2 + 3.1O_2 + 0.3CO + 84.1N_2 + 13.3H_2O$$

El Anuario de Estadística de Transporte (ANET), procesa registros administrativos para mostrar información relevante sobre: matriculación vehicular, siniestros de tránsito, transporte por ferrocarril, vía aérea y marítimo; datos entregados por las siguientes instituciones: Agencia Nacional de Tránsito-ANT, Empresa de Ferrocarriles del Ecuador-FEEP, Dirección General de Aviación Civil-DGAC y de las diferentes Autoridades Portuarias y Superintendencias Petroleras de orden público.



## Resumen 2020

Una visión general de los resultados del periodo.

| Principales variables investigadas | 2019 | 2020 |
|---|---|---|
| Vehículos motorizados matriculados | 2.311.960 | 2.361.175 |
| Pasajeros transportados por ferrocarril | 109.627 | 19.887 |
| Entrada internacional de pasajeros por vía aérea | 2.199.087 | 721.691 |
| Salida internacional de pasajeros por vía aérea | 2.239.931 | 783.476 |
| Entrada internacional de pasajeros por vía marítima | 25.728 | 10.510 |
| Salida internacional de pasajeros por vía marítima | 19.999 | 10.510 |
| Siniestros de tránsito | 24.595 | 16.972 |

**Principales resultados**
Vehículos motorizados matriculados; siniestros de tránsito y víctimas; transporte ferroviario, aéreo y marítimo internacional.

**Boletín técnico**
Documento que contiene un análisis descriptivo y evolutivo de las estadísticas de transporte.

## Información Estadística

Datos de la operación estadística y metadatos que permitan una interpretación de los resultados.

**Tabulados y series históricas**
Contiene los resultados de la encuesta en forma de tablas y cuadros estadísticos.

**Base de datos**
Acceso a las bases de datos y otros documentos que permiten la interpretación de las mismas.

Excel CSV SPSS CSV

**Ficha de indicadores**
Descripción metodológica generada con la información estadística de transportes.

**Sintaxis**
Contiene el diseño de programación y diagramación para replicar los tabulados e indicadores.

**Diccionario de variables**
Descripción de las variables que conforman las bases de datos.

**Guía de usuario**
Documentos que describen aspectos relevantes de las estadísticas

## Metodología

Aspectos metodológicos y conceptuales de la operación estadística

**Metodología**
Aspectos metodológicos y conceptuales de la operación estadística.