Carbon Footprint of Automobiles
IPRO 322
Intercontinental team: Illinois Institute of Technology (IIT) & Vilnius Gediminas Technical University (VGTU)
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The purpose of this IPRO is to develop and present a “user friendly” way of identifying vehicles with respect to the emission of greenhouse gases throughout their life cycle.
Objectives

• ‘Accurate’ carbon footprint
• Derive a standard for calculating an accurate footprint
• Design consumer-friendly and meaningful way of presenting footprint information
• Steer manufacturing processes
• Research global standards (manufacturing, recycling and use)
Global Climate Change

- A global problem
- 75% of GHGs is CO$_2$
- CO$_2$ primarily emitted by burning of fossil fuels
- Automobiles 2$^{nd}$ highest source of CO$_2$ in U.S.
  - Over 250 million registered vehicles in U.S.
Carbon Footprint

• GHG produced to directly and indirectly support human activities (tons CO$_2$)
• Personal carbon footprint
• U.S. is improving availability of information
• EU mandates manufacturers provide information

• How are these values derived?
• What do these numbers mean?
Carbon Footprint Assessment

• Life-Cycle
  – Production (Materials, Manufacturing, Assembly)
  – Disposal /Recycling

• Fuel-Cycle
  – Extraction and tail pipe (MPG)

• Final Vehicle Choices
  – Audi A3, Mazda 5, Nissan Leaf, Hyundai Sonata, BMW X5d, Chevrolet Impala
LIFE CYCLE assessment

http://www.worldautosteel.org/Environment/Life-Cycle-Assessment.aspx
Carbon footprint of automobiles

Prepared by: AVGrnu09 group students
Advisor: Dr Edita Baltroncei

Vilnius 2010
Chevrolet Impala – The Model Car

• To find values for Manufacturing, Fuel Cycle, and Recycling/Disposal, there were many things to consider
• We will demonstrate how we were able to find these values for one model vehicle
**GREET MODEL**

- **Materials Breakdown** — Vehicle Material Composition by Weight.

<table>
<thead>
<tr>
<th></th>
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<tr>
<td>Steel</td>
<td>61.7%</td>
<td>30.5%</td>
<td>65.2%</td>
<td>30.9%</td>
<td>56.4%</td>
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<tr>
<td>Stainless Steel</td>
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<td>1.1%</td>
<td>0.0%</td>
<td>0.7%</td>
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<tr>
<td>Cast Iron</td>
<td>11.1%</td>
<td>4.2%</td>
<td>6.0%</td>
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<td>1.8%</td>
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<tr>
<td>Wrought Aluminum</td>
<td>2.2%</td>
<td>6.9%</td>
<td>1.8%</td>
<td>6.3%</td>
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<tr>
<td>Cast Aluminum</td>
<td>4.7%</td>
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<td>14.1%</td>
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<tr>
<td>Copper/Brass</td>
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<td>Magnesium</td>
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<td>0.02%</td>
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<tr>
<td>Glass</td>
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<td>2.9%</td>
<td>3.0%</td>
<td>2.6%</td>
<td>2.8%</td>
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<tr>
<td>Average Plastic</td>
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<td>10.6%</td>
<td>12.6%</td>
<td>10.2%</td>
<td>11.7%</td>
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<td>Rubber</td>
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<td>2.6%</td>
<td>1.9%</td>
<td>2.0%</td>
<td>1.8%</td>
<td>1.9%</td>
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<tr>
<td>Carbon Fiber-Reinforced Plastic</td>
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<td>15.1%</td>
<td>0.0%</td>
<td>16.0%</td>
<td>10.0%</td>
<td>26.4%</td>
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<td>Carbon Paper</td>
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<td>PTFE</td>
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<td>0.1%</td>
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<tr>
<td>Carbon &amp; PFSA Suspension</td>
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<td>0.0%</td>
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<td>Platinum</td>
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<td>0.0009%</td>
<td>0.0003%</td>
<td>0.0004%</td>
<td>0.007%</td>
<td>0.007%</td>
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<tr>
<td>Others</td>
<td>1.9%</td>
<td>2.2%</td>
<td>2.2%</td>
<td>2.5%</td>
<td>2.2%</td>
<td>2.6%</td>
</tr>
</tbody>
</table>
Production

- Reduced to 3 main components - ~88%
- Steel (70%) – includes iron
- Plastics (15%) – various plastics
- Glass (3%)
Production

• Calculated from national averages of ~50% Coal and 20% Natural Gas
• 0.6 Kg CO₂/kWh
• kg CO₂/kg material – standard
• Many conversion needed
Impala – Production (Steel)

• From – $\text{Car(lbs)} \times (70\%) \times \left( \frac{1\text{lb}}{2.204\text{kg}} \right) \times \left( \frac{2\text{kgCO}_2}{\text{kg _ steel}} \right)$

• Where – $\left( \frac{3.3\text{kWh}}{\text{kg _ steel}} \right) = \left( \frac{2\text{kgCO}_2}{\text{kg _ steel}} \right)$

• Total CO$_2$ from Steel = 2,258 kg CO$_2$
Impala – Production (Plastic)

- From – $\text{Car (lbs)} \times (15\%) \times \left( \frac{1 \text{ lb}}{2.204 \text{ kg}} \right) \times \left( \frac{7.2 \text{ kg} \text{CO}_2}{\text{kg plastic}} \right)$

- Where –

$$\left( \frac{12 \text{ kWh}}{\text{kg plastic}} \right) = \left( \frac{7.2 \text{ kg} \text{CO}_2}{\text{kg plastic}} \right)$$

- Total $\text{CO}_2$ from Plastic = 1,742 kg $\text{CO}_2$
Impala – Production (Glass)

• From – \[ \text{Car (lbs)} \times (3\%) \times \left( \frac{1\text{lb}}{2.204\text{kg}} \right) \times \left( \frac{0.6\text{kgCO}_2}{\text{kg glass}} \right) \]

• Where – \[ \left( \frac{0.985\text{kWh}}{\text{kg glass}} \right) = \left( \frac{0.6\text{kgCO}_2}{\text{kg glass}} \right) \]

• Total CO\textsubscript{2} from Glass = 29 kg CO\textsubscript{2}
Impala – Production (Total)

• Summary
  – Steel Total = 2,258 kg CO$_2$
  – Plastic total = 1,742 kg CO$_2$
  – Glass Total = 29 kg CO$_2$

• TOTAL CO$_2$ emitted = 4,029 kg
Material Production (kg CO$_2$)

- Audi A3: 3,880
- Mazda 5: 3,878
- Nissan Leaf: 3,174
- Hyundai Sonata: 3,750
- BMW X5d: 5,922
- Chevrolet Impala: 4,029
Impala – Production (Extraction - Steel)

• From –
  \[ \text{car weight(lbs)} \times 70\% \times \left( \frac{1\text{lb}}{2.204\text{kg}} \right) \times \left( \frac{13\text{kg CO}_2}{\text{kg steel}} \right) \]

• Where –
  – 13kg CO$_2$ per 1kg of steel (from greenmatrix.org)

• Total = 14,678 kg CO$_2$ emission produced for virgin steel used

• Plastic – 34kg CO$_2$ / kg_plastic

• Tempered Glass – 10kg CO$_2$ / kg_glass
Impala – Production (Extraction)

• From –
  - Extraction = (Manufacturing + Extraction) – (Manufacturing)

• Where –
  – Total Manufacturing + Extraction CO$_2$ emission
    • 23,388 kg CO$_2$ emission
  – Total Manufacturing CO$_2$ emission
    • 4,029 kg CO$_2$ emission

• Total Extraction only = 19,359 kg CO$_2$ emission
<table>
<thead>
<tr>
<th>Model</th>
<th>Manufacturing + Extraction (kg CO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Audi A3</td>
<td>3,880</td>
</tr>
<tr>
<td>Mazda 5</td>
<td>3,878</td>
</tr>
<tr>
<td>Nissan Leaf</td>
<td>3,174</td>
</tr>
<tr>
<td>Hyundai Sonata</td>
<td>3,750</td>
</tr>
<tr>
<td>BMW X5d</td>
<td>5,922</td>
</tr>
<tr>
<td>Chevrolet Impala</td>
<td>4,029</td>
</tr>
</tbody>
</table>

**Chart:**

- **Title:** Manufacturing + Extraction (kg CO₂)
- **Ground:**
  - Audi A3: 3,880 kg CO₂
  - Mazda 5: 3,878 kg CO₂
  - Nissan Leaf: 3,174 kg CO₂
  - Hyundai Sonata: 3,750 kg CO₂
  - BMW X5d: 5,922 kg CO₂
  - Chevrolet Impala: 4,029 kg CO₂

**Legend:**

- **Extraction**
- **Manufacturing**
Assembly

• UNESCO (United Nations)
  – 20,000MJ per car
    • where: 1kWh/3,600J & 0.6kg CO₂/kWh
    – Total: 3,333 kg CO₂ emission / car

• GREET (United States)
  – 3.9 million Btu per car
    • where: 1kWh/3413Btu & 0.6kg CO₂/kWh
    – Total: 685.6 kg CO₂ emission / car
Impala – Fuel Cycle (Tailpipe)

~Gasoline MPG: 22

\[
\frac{(150,000 \text{ miles})}{\text{life}} \times \frac{1 \text{ gal}_{\text{gasoline}}}{1 \text{ mpg}(\text{mile})} \times \frac{8.834 \text{ kg CO}_2}{1 \text{ gal}_{\text{gasoline}}}
\]

~60,232 kg CO₂

~Where Gas = 8.834 kg CO₂/gal
~Where Diesel = 10.493 kg CO₂/gal
Impala – Fuel Cycle (EPA)

~ EPA Value = 8.3 tons CO₂/Year

\[
\left( \frac{\text{Car} (\text{tons CO}_2)}{1\text{Year}} \right) \times \left( \frac{907.185 (\text{kg})}{1\text{ton}} \right) \times \left( \frac{1\text{Year}}{15,000 (\text{Miles})} \right)
\]

~ .50 Kg/Mile

\[
\left( \frac{\text{Car} (\text{kg CO}_2)}{1\text{Mile}} \right) \times \left( \frac{150,000 (\text{Miles})}{\text{Lifetime}} \right)
\]

~75,321 kg CO₂
Impala – Fuel Cycle

- Fuel-Cycle
  - Tail Pipe: 60,232 kg
  - Fuel Extraction: 15,089 kg
- Total = 75,321 kg
Fuel Cycle (kg of CO₂ emitted)

<table>
<thead>
<tr>
<th>Car</th>
<th>Fuel Production</th>
<th>Tail Pipe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Audi A3</td>
<td>9,971</td>
<td></td>
</tr>
<tr>
<td>Mazda 5</td>
<td>24,429</td>
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<td>Nissan Leaf</td>
<td>13,242</td>
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<tr>
<td>Hyundai Sonata</td>
<td>53,004</td>
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<td>BMW X5d</td>
<td>15,575</td>
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<tr>
<td>Chevrolet Impala</td>
<td>15,089</td>
<td></td>
</tr>
</tbody>
</table>
Vehicle Recycling

• Values are difficult to find for Recycling and Disposal
• Focused on Recycling
• Should Recycling be a CO$_2$ benefit or a CO$_2$ cost
• Recycling as a benefit
• Greenmatrix.org – only available information
Recycled Steel

• From Greenmatrix.org –
  – Virgin Steel – 10 kg CO₂/kg Steel
  – Recycled Steel – 4 kg CO₂/kg Steel

• Values include extraction and production

• Cars can be made of up to 25% recycled steel
Impala – Production (Recycling benefit)

- 75% Virgin Steel and 25% Recycled:

\[
\left[ \text{Car(lbs)} \times (70\%) \times \left( \frac{1lb}{2.204kg} \right) \right] \times \left[ 0.75 \left( \frac{10\, \text{kg CO}_2}{\text{kg Virgin}} \right) + 0.25 \left( \frac{4\, \text{kg CO}_2}{\text{kg Recycled}} \right) \right]
\]

- Total \( \text{CO}_2 \) = 9,597 kg \( \text{CO}_2 \)
- \( \text{CO}_2 \) emissions benefit = 5,081 kg \( \text{CO}_2 \)
Impala – Life-Cycle (Total)

• Life-Cycle:
  – Material Production: 4,030 kg
  – Material Extraction: 19,360 kg
  – Assembly: 3,333 kg or 685.6 kg
  – Recycling: -5,081 kg (Benefit)

• Total = 18,995 - 21,642 kg CO₂
Percentage BreakDown (%)

- Audi A3: Recycling 26, Fuel-cycle 74, Production 21
- Mazda 5: Recycling 0, Fuel-cycle 79, Production 21
- Nissan Leaf: Recycling 5, Fuel-cycle 80, Production 19
- Hyundai Sonata: Recycling 6, Fuel-cycle 78, Production 22
- BMW X5d: Recycling 6, Fuel-cycle 75, Production 25
- Chevrolet Impala: Recycling 5, Fuel-cycle 79, Production 21

Legend:
- Recycling
- Fuel-cycle
- Production
Impala – Car Model

- Production: 21%
- Fuel Cycle: 79%
- Recycling Benefit: 5%
Ethical Issues

• Composed of parties that reside both in the United States and Lithuania.
• Meetings, communication, and collaboration difficult.
• The information on vehicles was not as readily available in the U.S. as it was in the European Union.
• Credit our counterparts and well as keep them involved as much as possible.
• Falsifying data/estimating values.
Conclusions

• Discrepancies exist between calculated value depending on considerations
• U.S. manufacturers do not provide any information
• Not globally mandated
• No standards exist
• Based on too many ‘flexible’ considerations
• Entire Life-cycle costs must be considered
• Environmental impact must be considered
Conclusions

• An accurate life-cycle calculation is important
• Significant differences were found
• Too many considerations; many ignored
  – Too many generalizations of materials
  – Extraction costs
  – Assembly
  – Recycling
• Standards must be created
Recommendations

• Research other models
• Establish more consistent communication with Lithuanian counterparts.
• Work directly with GREET to develop existing model.
Future

• Propose standards for footprints
• Design environmental impact ratings system
• Calculate actual footprint for one material
• Study one manufacturing plant
• Develop Sticker concept
• Study recycling values for an old car
Thank you