CO₂ Quantification for Typical Mobile Machine Application
Processes in Road Building, Earthmoving

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Outline

I. CO$_2$- quantification method
II. Application on a representative example
III. Sample calculation
IV. Results
V. Conclusion
I. CO₂- quantification method

A. Common method
I. CO₂- quantification method

A. CECE - CO₂ quantification method

System boundary

CO₂ from:
- Production of construction material
- Transport of material to and from the site
- Construction machines
- Production process of primary energy carrier (only from database)

Picture source: Liebherr & Wirtgen
I. CO$_2$- quantification method

A. CECE - CO$_2$ quantification method

Picture source: Liebherr & Wirtgen
II. Application on a representative example

- **Proceeding:**
  - Application of the *method*
  - For a *road construction*

- **Representative example:**

*Construction of a road BK10 in Karlsruhe*

**Earthmoving**

- Overburden
- Road

**Road building**

- Road BK10

I.  
II.  
III.  
IV.  
V.
I. CO₂-quantification method

- **Background:**
  EU objective: reduction of CO₂ emissions in construction sites

- **Aim:**
  Show a market driven reduction of CO₂ emissions

- **Procedure:**
  A. Similar approach as convince EU
  B. Develop a method to quantify the attained and potential CO₂-reduction
II. Procedure for the CO$_2$ quantification

**Determination of:**
*Earthmoving / Pavement*

1. Work tasks
   *(e.g. earth moved / road type)*

2. Conditions / Requirements
   *(e.g. soil class / thickness of the layers)*

3. Construction site & working conditions

4. Material

5. Machines (on the construction site)

6. Number of machines

7. Distance driven by the machines

- Machine efficiency
- Process efficiency
- Operation efficiency
- Alternative energy sources

CO$_2$
II. Application on the representative example

1. Work tasks & 2. Conditions / Requirements

- Adjustment of the representative example
  - Soil: Brown earth & luvisol from wind & terrace sand (in Karlsruhe) \((1+2)\)
    - No cohesive,
    - sand, gravel, silt, clay
    - **Soil class 3** (DIN 18300)

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Planum of the road

- Soil box: 1500 m³
- 7,5 m
- 5 m
- 50 m
- 6 m
- 1 km

---
II. Procedure for the construction of a road

1. Determination of the road type

Pavement

Ground level (planum)

Earthmoving

Past

Present

Future

II

BK10

BK10

Riding course

Binder course

Base course

Antifreeze layer
II. Procedure for the construction of a road

1. Determination of the road type & 2. Thicknesses of the layers

- **Pavement**
  - Ground level (planum)
  - **Past**
  - **Present**
  - **Future**

- **Earthmoving**
  - **Past**
  - **Present**
  - **Future**

**Past**
- II
- 4
- 8
- 14
- 44
- 70 cm

**Present**
- BK10
- 4
- 8
- 14
- 39
- 65 cm

**Future**
- BK10
- 2
- 10
- 14
- 39
- 65 cm

---

1. Determination of the road type & 2. Thicknesses of the layers

<table>
<thead>
<tr>
<th>Past</th>
<th>Present</th>
<th>Future</th>
</tr>
</thead>
<tbody>
<tr>
<td>II</td>
<td>BK10</td>
<td>BK10</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>14</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>44</td>
<td>39</td>
<td>39</td>
</tr>
<tr>
<td>70 cm</td>
<td>65 cm</td>
<td>65 cm</td>
</tr>
</tbody>
</table>
II. Procedure for the construction of a road

3. Material

Pavement

<table>
<thead>
<tr>
<th></th>
<th>Past</th>
<th>Present</th>
<th>Future</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground level (planum)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Earthmoving</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gravel</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>II.</td>
<td>4</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>0/8S</td>
<td>8</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>0/22S</td>
<td>14</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>C 0/32</td>
<td>44</td>
<td>39</td>
<td>39</td>
</tr>
</tbody>
</table>

Water fine lime

White lime 800/ CL80-Q

http://www.digibib.tu-bs.de/?docid=00059308
II. Procedure for the construction of a road

4. Machines

- Hydraulic excavator (25-27t ; 112-140 kW)
- Truck (265 kW)
- Crawler dozer (120 kW)
- Grader (142 kW)
- Vibratory roller (10-11,5 t ; 74 kW for asphalt ; 119 kW for earth)
- Limestone tank truck (41t ; 405 kW)
- Soil stabilizer (315 kW)
- Padfoot compactor (11,5 t ; 115 kW)
- Spreader (300 kW)
- Paver (127 kW)
- Material feeder (160kW)
II. Procedure for the construction of a road

5. Process

Entire process: NEW ROAD CONSTRUCTION

Material production
- Limestone
- Asphalt production
- Gravel

Earthmoving
- 1. Overburden
- 2. Ground level

Pavement
- Antifreeze layer
- Base course
- Binder course
- Riding course

I. II. III. IV. V.
II. Procedure for the construction of a road

5. Process

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- Base course
- Binder course
- Riding course
### III. Sample calculation: Asphalt production

<table>
<thead>
<tr>
<th>General information</th>
<th>AC32TS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt production</td>
<td>46 kg CO₂/t</td>
</tr>
<tr>
<td>Thickness</td>
<td>0,14 m</td>
</tr>
<tr>
<td>Total quantity</td>
<td>1050 m³</td>
</tr>
<tr>
<td>Density</td>
<td>2312 kg/m³ (4)</td>
</tr>
<tr>
<td>Total weight</td>
<td>2427 t</td>
</tr>
</tbody>
</table>

Asphalt production:

\[ 46 \text{ kg CO}_2/\text{t} \times 2427 \text{ t} = 111,7 \text{ t CO}_2 \]
III. Sample calculation: Base course

<table>
<thead>
<tr>
<th>Aim</th>
<th>2. Base course</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process</td>
<td>2.1 Pavement</td>
</tr>
<tr>
<td>Subprocesses</td>
<td>Transport</td>
</tr>
<tr>
<td>Machines Type</td>
<td>Rear-dump truck</td>
</tr>
<tr>
<td>Type</td>
<td>265 kW – 13m³</td>
</tr>
</tbody>
</table>

Source: bauforum24.biz

Source: AMMANN
III. Sample calculation: Base course

Aim

2. Base course

2.1 Pavement

Subprocesses

Transport | Unloading | Paving | Precompaction | Compaction

Machines

Rear-dump truck

265 kW – 13m³

Paver

127 kW – 7,5m width

Tandem roller static

74kW 10t-11,5t

Tandem roller dynamic

74kW 10t-11,5t

Material

AC32TS

Source: bauforum24.biz

Source: AMMANN

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III. Sample calculation: Base course, paver

- **Asphalt quantity**: 1050 m³

- **Paver data**:
  - Working velocity: \( v_{\text{paver}} = 480 \text{ m/h} \)
  - Working width: \( b' = 7.5 \text{ m} \)
  - Engine performance: \( P_{\text{max}} = 127 \text{ kW} \)
  - Consumption: \( b = 175 \text{ g/kWh} \)

\[ d = 14 \text{ cm} \]

_Paver data source (3) + Wirtgen group_
III. CO₂ quantification basics for mobile machines

- CO₂ quantification emitted by mobile machines:
  \[ CO₂ = B \times (2.6 + 0.4) \]
  \[ CO₂e = B \times (2.6 + 0.6) \]

- Total consumption for the subprocess: \[ B = P \times b \times t_i \]

- Performance: \[ P = 0.7 \times P_{\text{max}} \]

- Working time (3): \[ t_i = \frac{\text{Volume of material}}{Q_E} \]

- Effective capacity (3): \[ Q_E = Q_B \times 0.75 \times 0.9 \]
  
- Firm capacity (3): \[ Q_B = \frac{\text{nominal machine volume}}{\text{time}} \]

Emissions for diesel production (6+7):
- 0.4 kg CO₂/lₐₙₜₜₜ or 0.6 kg CO₂e/lₐₙₜₜₜₜₜₜ

CO₂ emissions for diesel combustion (CO₂~CO₂e) (5):
- 2.63 kg CO₂/lₐₙₜₜₜₜₜₜ
III. Sample calculation: paver

- CO₂ quantification emitted by mobile machines:
  \[ CO_2 = B \times (2.6 + 0.4) = 0.177 \text{ t} \]
  \[ CO_2 e = B \times (2.6 + 0.6) = 0.184 \text{ t} \]

- Total consumption for the subprocess: \( B = P \times b \times t_i = 57.9 \text{ l} \)

- Performance: \( P = 0.7 \times P_{max} = 88.9 \text{ kW} \)

- Working time: \( t_i = \frac{\text{Volume of material}}{Q_E} = 3.1 \text{ h} \)

- Effective capacity: \( Q_E = Q_B \times 0.75 \times 0.9 = 340 \text{ m}^3/\text{h} \)

- Firm capacity: \( Q_B = b' \times v_{paver} \times d = 504 \text{ m}^3/\text{h} \)
III. Sample calculation: Base course

Source: bauforum24.biz

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<td>Paver</td>
</tr>
<tr>
<td>Type</td>
<td>265 kW – 13m³</td>
<td>127 kW – 7,5m width</td>
</tr>
<tr>
<td></td>
<td>8,99 t CO₂</td>
<td>0,177 t CO₂</td>
</tr>
</tbody>
</table>

Material AC32TS

111,7 t CO₂

Total: 121,3 t CO₂
IV. Results
IV. Results: differences between earthmoving - pavement - material

**CO₂ emissions for the new road construction**

**CO₂ quantification out from Q_{AE}** - effective performance data

<table>
<thead>
<tr>
<th>Activity</th>
<th>CO₂ Emissions (t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earthmoving</td>
<td>6%</td>
</tr>
<tr>
<td>Pavement</td>
<td>11%</td>
</tr>
<tr>
<td>Material production</td>
<td>83%</td>
</tr>
</tbody>
</table>

Present
IV. Results: Material production

**CO₂ emissions for material**

Reduction:
- Less fuel
- 30% recycling material
- Different furnace technology

- 33 %
- 10 %
- 26 %

**Material production**

- Limestone
- Binder course
- Antifreeze layer
- Base course
- Riding course

- 33 %
- 26 %
- 10 %
IV. Results: job-site processes

Machine efficiency: lower fuel consumption

Reduction:

- 23 %
- 18 %
- 36 %

Earthmoving

- Common rail injection
- Ecomode
- Management System
- …

Pavement

IV. Results: job-site processes

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- Ecomode
- Management System
- …

Pavement
IV. Results: Influences of the 4 pillar approach on a simulation example
IV. Results: Simulation example

- **Operation efficiency:** 10% better site/working conditions
  - Utilisation factor: 0.75 → 0.85

- **Process efficiency:**
  1. Same truck capacity with 10% less trucks: e.g. 33 → 30 trucks
  2. “Hot on Hot”
     - High interdigation
     - Different material ratio
     - Different machines:
       - “+ 1 paver”
       - + 1 material feeder
       - - 2 rollers

- **Machine efficiency:** lower fuel consumption
IV. Results: Influences of the 4 pillar approach

- Only operation efficiency
  **Operation efficiency**
  **Utilisation factor: 0.75 → 0.85**

- • Tyre pressure control
- • Correct settings
- • Driving cycle amelioration
- ...

![Graph showing CO2 and CO2e emissions for Present and Future](chart)

Amount [t]

- 13%

- Riding course
- Binder course
- Base course
- Antifreeze layer
- Ground level
- Overburden

<table>
<thead>
<tr>
<th></th>
<th>CO2</th>
<th>CO2e</th>
<th>CO2</th>
<th>CO2e</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present</td>
<td>60</td>
<td>50</td>
<td>50</td>
<td>40</td>
</tr>
<tr>
<td>Future</td>
<td>50</td>
<td>40</td>
<td>50</td>
<td>40</td>
</tr>
</tbody>
</table>

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IV. Results: Influences of the 4 pillar approach

- Only process efficiency

Process efficiency:
10 % less trucks: e.g. 33 → 30 trucks

- Lower fuel consumption
- Bigger Volume

\[ \text{Process efficiency:} \]
\[ 10 \% \text{ less trucks: e.g. } 33 \rightarrow 30 \text{ trucks} \]

- 13%

![Graph showing CO2 emissions](chart.png)

- Riding course
- Binder course
- Base course
- Antifreeze layer
- Ground level
- Overburden

Amount [t]

<table>
<thead>
<tr>
<th>Process</th>
<th>Present</th>
<th>Future</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO2</td>
<td>70</td>
<td>60</td>
</tr>
<tr>
<td>CO2e</td>
<td>80</td>
<td>70</td>
</tr>
<tr>
<td>CO2</td>
<td>50</td>
<td>40</td>
</tr>
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</tr>
<tr>
<td>CO2</td>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td>CO2e</td>
<td>40</td>
<td>30</td>
</tr>
<tr>
<td>CO2</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>CO2e</td>
<td>20</td>
<td>10</td>
</tr>
</tbody>
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IV. Results: Influences of the 4 pillar approach

- Only process efficiency (not material)

**Process efficiency: only “Hot on Hot”**

- + 1 material feeder
- - 2 rollers

### IV. Results: Influences of the 4 pillar approach

- Only process efficiency (not material)

**Process efficiency: only “Hot on Hot”**

- + 1 material feeder
- - 2 rollers

![Bar chart showing CO2 and CO2e emissions for present and future.](chart.png)

- Riding course
- Binder course
- Base course
- Antifreeze layer
- Ground level
- Overburden

- **Amount [t]**

  - **Present**
    - CO2
    - CO2e

  - **Future**
    - CO2
    - CO2e

- Process efficiency: only “Hot on Hot” for present (7.2%) and future (7.0%).
V. Conclusion

Summary
- Elaboration of the method
- Application on a new road construction of type BK10
- Identification of the material & processes & machines
- CO₂ quantification & CO₂ attained and potential reduction

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Job-site processes</td>
<td>23 %</td>
<td>36 %</td>
</tr>
<tr>
<td>Material</td>
<td>10 %</td>
<td>26 %</td>
</tr>
</tbody>
</table>
List of references

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(7) R. Edwards, J. Larivé et al.; WELL-TO-TANK Appendix 2 – Version 4a; European Commission, Joint Research Centre, Institute for energy and transport