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

- **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**
I. CO₂- quantification method

A. Common method

CO₂-SAVING POTENTIALS

- Machine Efficiency
- Process Efficiency
- Operation Efficiency
- Alternative Energy Sources

CO₂-reduction quantification method

Picture source: Liebherr & Wirtgen & CEMA
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. \( \text{CO}_2 \)- quantification method
A. CECE - \( \text{CO}_2 \) quantification method

![Diagram showing material, process, and machines with CO2 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

Road building

Overburden

Road BK10
II. Procedure for the CO₂ 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

CO₂
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)

![Diagram of the road planum and soil cube with dimensions: 1500 m³, 7.5 m, 5 m, 6 m, 50 m, 1 km.](image)
II. Procedure for the construction of a road

1. Determination of the road type

**Pavement**

- Past
- Present
- Future

**Earthmoving**

- Past
- Present
- Future

**Ground level (planum)**

- Past
- Present
- Future

**Riding course**

- BK10

**Binder course**

- BK10

**Base course**

- BK10

**Antifreeze layer**

- BK10
II. Procedure for the construction of a road

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

**Pavement**

**Ground level** (planum)

**Earthmoving**

**Past**

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

**Present**

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

**Future**

- **BK10**
  - 2
  - 10
  - 14
  - 39
  - 65 cm
II. Procedure for the construction of a road

3. Material

**Pavement**

**Past**
- 0/8S
- C 0/32
- Gravel
- 70 cm

**Present**
- BK10
- SMA8S
- AC22BS
- AC32TS
- Gravel
- 65 cm

**Future**
- Bk10
- SMA8S
- AC22BS
- AC32TS
- Recycling Material
- 65 cm

**Earthmoving**

**Past**
- Water fine lime

**Present**
- White lime 800/CL80-Q

**Future**
- I. 10
- II. 2
- III. 10
- IV. 2
- V. 10
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

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
III. Sample calculation: Asphalt production

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

2. Base course

2.1 Pavement

<table>
<thead>
<tr>
<th>Subprocesses</th>
<th>Transport</th>
<th>Unloading</th>
<th>Paving</th>
<th>Precompaction</th>
<th>Compaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machines Type</td>
<td>Rear-dump truck</td>
<td>Paver</td>
<td>Tandem roller static</td>
<td>Tandem roller dynamic</td>
<td></td>
</tr>
<tr>
<td>Type</td>
<td>265 kW – 13m³</td>
<td>127 kW – 7,5m width</td>
<td>74kW 10t-11,5t</td>
<td>74kW 10t-11,5t</td>
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Material: AC32TS

Source: bauforum24.biz

Source: AMMANN
### III. Sample calculation: Base course

Source: bauforum24.biz

#### Source: AMMANN

<table>
<thead>
<tr>
<th>Aim</th>
<th>2. Base course</th>
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I.  
II.  
III.  
IV.  
V.  

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**Source:** bauforum24.biz  
**Source:** AMMANN
III. Sample calculation: Base course, paver

- **Asphalt quantity:** 1050 m³

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

*Paver data source (3) + Wirtgen group*

\[ d = 14 \text{ cm} \]
III. CO₂ quantification basics for mobile machines

- CO₂ quantification emitted by mobile machines:
  \[
  CO_2 = B \times (2.6 + 0.4) \\
  CO_2e = B \times (2.6 + 0.6)
  \]

- Total consumption for the subprocess: \( B = P \times b \times t_i \)

- Performance: \( P = 0.7 \times P_{\text{max}} \)
  \( P_{\text{max}} = \) maximal engine power

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

- Effective capacity \(^{(3)}\): \( Q_E = Q_B \times 0.75 \times 0.9 \)
  \( Q_B = \) nominal machine volume
  \( Q_E = \) effective capacity
  Utilisation factor: 0.75
  Factor for unforeseeable difficulties: 0.9

- Firm capacity \(^{(3)}\): \( Q_B = \frac{\text{nominal machine volume}}{\text{time}} \)

**Emissions for diesel production** \(^{(6+7)}\):
- 0.4 kg CO₂/l_diesel or 0.6 kg CO₂e/l_diesel

**CO₂ emissions for diesel combustion** (CO₂~CO₂e) \(^{(5)}\):
- 2.63 kg CO₂/l_diesel

**Firm capacity** \(^{(3)}\): \( Q_B = \frac{\text{nominal machine volume}}{\text{time}} \)
III. Sample calculation: paver

- CO₂ quantification emitted by mobile machines:
  \[ CO₂ = B \times (2.6 + 0.4) = 0.177 \, t \]
  \[ CO₂e = B \times (2.6 + 0.6) = 0.184 \, t \]

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

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

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

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

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

#### Aim

#### 2. Base course

#### 2.1 Pavement

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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0,177 t CO₂</td>
<td>0,093 t CO₂</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>8,99 t CO₂</td>
<td>0,291 t CO₂</td>
<td></td>
</tr>
<tr>
<td>Material AC32TS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>111,7 t CO₂</td>
<td></td>
</tr>
</tbody>
</table>

**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 Qₐₑ* - effective performance data

<table>
<thead>
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<th>Earthmoving</th>
<th>Pavement</th>
<th>Material production</th>
</tr>
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<tr>
<td><strong>Present</strong></td>
<td></td>
<td></td>
<td>83%</td>
</tr>
<tr>
<td><strong>CO₂ emissions</strong></td>
<td>6%</td>
<td>11%</td>
<td></td>
</tr>
</tbody>
</table>

I. II. III. IV. V.
IV. Results: Material production

**CO₂ emissions for material**

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

- 33%
- 26%
- 10%

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

IV. Results: Material production

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

- 33%
- 26%
- 10%

- Limestone
- Binder course
- Antifreeze layer
- Base course
- Riding course
IV. Results: job-site processes

Machine efficiency: lower fuel consumption

Reduction:

- 23%
- 18%
- 36%

- Common rail injection
- Ecomode
- Management System

I. Past
II. Present
III. Future

- CO2
- CO2e

- Earthmoving
- Pavement

Machine efficiency: lower fuel consumption

Amount [t]

Riding course
Binder course
Base course
Antifreeze layer
Ground level
Overburden

- Reduction:
  - CO2: 23%
  - CO2e: 36%
  - CO2: 18%

- Common rail injection
- Ecomode
- Management System
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 interdigitation
     - 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](image)

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

Amount [t]

- 13 %
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
...
IV. Results: Influences of the 4 pillar approach

- Only process efficiency (not material)

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

- + 1 material feeder
- - 2 rollers

![Chart showing CO2 and CO2e amounts for Present and Future scenarios](chart)

- **Present**
  - CO2
  - CO2e

- **Future**
  - CO2
  - CO2e

**Amount [t]**

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

-0.2% decrease
V. Conclusion

- **Summary**
  - Elaboration of the method
  - Application on a new road construction of type BK10
  - Identification of the **material & processes & machines**
  - CO$_2$ quantification & CO$_2$ attained and potential reduction

<table>
<thead>
<tr>
<th>Machine efficiency</th>
<th>Attained CO$_2$ reduction 1990-2013</th>
<th>Potential CO$_2$ reduction 1990-2020</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