Integration of renewable energies in the development of modern transport infrastructure

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Structure

1 The project “behind“
   1.1 Motivation
   1.2 Targets

2 Energy consumption
   2.1 Sample route
   2.2 Selection of sample vehicles
   2.3 First result for the energy consumption

3 Production of energy along the highway
   3.1 Opportunities of integrating renewable energies
   3.2 Szenarios
   3.3 First results for the energy production

4 summary
1 The project “behind“

- part of the feasibility study: “Intelligent infrastructure systems – basis for road-oriented e-mobility“

Reference: Prof. Dr.-Ing. habil. W. Kühn

- promoted by: Sächsischen Staatsministerium für Wissenschaft und Kultur (SMWK)
1.1 Motivation

- extensive development in e-mobility sector
  → german car industry announced to launch electric vehicles with a pure electric drive in the next years

- present infrastructure is not conform to the requirements of e-mobility
  → usage of the electric vehicles is limited
1.2 Targets

• Adaption of the existing and newly constructed roads to the new requirements

Developing a lane-attended energy providing system

1. energy consumption → driving drag: speed, route, type of the vehicle

2. energy providing system

renewable energies along the highway

on board: • exchange of energy storage

external: • loading lane
• filling station

12.06.2012 1 The project “behind“
2 Energy consumption

2.1 Sample route

- highway with 3 lanes and 1 hard shoulder for each direction
- distance: about 10 km

Reference: RAA 2008

- simplified structure and limited conditions for the theoretical calculation

Sample route 1: gradient: 0
Sample route 2a: gradient: 4
Sample route 2b: gradient: -4
Sample route 3: gradient: 0, 2, -2, 4, -4
### 2.2 Selection of sample vehicles

- only passenger cars

<table>
<thead>
<tr>
<th>drive</th>
<th>conventional (diesel)</th>
<th>electric</th>
</tr>
</thead>
<tbody>
<tr>
<td>minicar</td>
<td></td>
<td>Twike</td>
</tr>
<tr>
<td>small car</td>
<td>VW Polo</td>
<td>Mitsubishi iMiev</td>
</tr>
<tr>
<td>Compact car</td>
<td>VW-Golf</td>
<td>VW E-Golf</td>
</tr>
<tr>
<td>mid-range car</td>
<td>VW Passat</td>
<td></td>
</tr>
<tr>
<td>top-of-the-range car</td>
<td>Porsche Panamera</td>
<td></td>
</tr>
</tbody>
</table>

Reference: www.importrpm.com/all-electric-mitsubishi-i-miev-heads-to-the-u-s, 06/2012
2.3 First results for the energy consumption

Energy consumption\(^1\) by the average of all sample vehicles
(10 km, 130 km/h, one direction)

- **present:**
  - cars with conventional drive and few cars with electric drive\(^2\)
  
- **e-mobility:**
  - 100% electric cars

\(\eta_{\text{conventional}}: 0,28\)
\(\eta_{\text{e-car}}: 0,84\)

\(^1\) only to get over the driving drag
\(^2\) for calculation: only VW E-Golf

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3 Production of energy along the highway

3.1 Opportunities of integrating renewable energies

vertical wind turbine
horizontal wind turbine
photovoltaic on the median strip
photovoltaic on the bank

Reference: Prof. Dr.-Ing. habil. W. Kühn
3.2 Szenarios

**usable area around the highway**
- on/above the highway
- next to the highway

roadway  median strip  open space  noise barrier

**variant A1:**
- (small wind turbine) + photovoltaic

**variant A2:**
- solar road (small wind turbine) + photovoltaic

**variant A3:**
- roof with photovoltaic

**variant B1:**
- photovoltaic, (small wind turbine) + additional or integrated photovoltaic

**variant B2:**
- large wind turbine, (small wind turbine) + additional or integrated photovoltaic

**variant B3:**
- photovoltaic, large wind turbine, (small wind turbine) + additional or integrated photovoltaic

12.06.2012  3 Production of energy along the highway
2.3 First results for the energy production

a) Wind energy

Energy yield\(^1\) by the large wind turbines (height:120 m)

<table>
<thead>
<tr>
<th>Energy yield [GWh]</th>
<th>Vestas V112</th>
<th>Gamesa G10X-136</th>
</tr>
</thead>
<tbody>
<tr>
<td>year</td>
<td>300</td>
<td>150</td>
</tr>
<tr>
<td>winter</td>
<td>250</td>
<td>125</td>
</tr>
<tr>
<td>autumn</td>
<td>200</td>
<td>100</td>
</tr>
<tr>
<td>summer</td>
<td>150</td>
<td>75</td>
</tr>
<tr>
<td>spring</td>
<td>50</td>
<td>25</td>
</tr>
</tbody>
</table>

\(^1\) without consideration the land use plan for the area next to the highway, e.g.: development, agriculture

12.06.2012 3 Production of energy along the highway
b) Solar energy

Energie yield¹ by photovoltaic

<table>
<thead>
<tr>
<th>Area [m²]</th>
<th>Tilt [°]</th>
<th>Usable part [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>road</td>
<td>290.000</td>
<td>0</td>
</tr>
<tr>
<td>roof</td>
<td>330.000</td>
<td>0</td>
</tr>
<tr>
<td>median strip</td>
<td>20.000</td>
<td>35</td>
</tr>
<tr>
<td>open space²</td>
<td>652.400</td>
<td>35</td>
</tr>
<tr>
<td>noise barrier³</td>
<td>6.500</td>
<td>90</td>
</tr>
<tr>
<td>noise protection wall</td>
<td>4.410</td>
<td>35</td>
</tr>
</tbody>
</table>

η_{System}: 10 %

1 without consideration the land use plan for the area next to the highway, e.g.: development, agriculture
2 open space is the area next to the highway (40 m) minus the area of traffic security, tunnels, bridges and noise protection dams
3 only one side of the noise barrier is provided for the photovoltaic utilization,
c) The energy consumption vs. the energy production by renewable energies

Energy yield vs. energy consumption (10 km, 130 km/h, both directions)

- **Photovoltaic**
  - (best case)
  - (realistic case)

- **Wind Energy**
  - (best case)
  - (realistic case)

- **Energy Consumption**

### Table: Energy Production

<table>
<thead>
<tr>
<th>Scenario</th>
<th>On/above the Highway</th>
<th>Next to the Highway</th>
</tr>
</thead>
<tbody>
<tr>
<td>Best case</td>
<td>Roof with photovoltaic</td>
<td>Large wind turbines + photovoltaic + noise barrier with photovoltaic</td>
</tr>
<tr>
<td>Realistic case</td>
<td>Not provided</td>
<td>20% large wind turbines + 50% photovoltaic + noise barrier with photovoltaic</td>
</tr>
</tbody>
</table>

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3 Production of energy along the highway
4 Summary

- the energy consumption of present days is about 600 MWh/a for 10 km with a speed of 130 km/h

- at 100% e-mobility the energy consumption can be reduced to 1/3

- the maximum energy yield of renewable energies along the highway (10 km) is about 350 GWh/a

- realistical there might be only provided ca. 27% by the average of the energy consumption of e-cars

- the main part (71%) of produced energy is supplied by the wind turbines
Thank you for your attention!