ELECTRIC VEHICLES: CLEAN SOLUTION OR CREATION OF NEW PROBLEMS?
<table>
<thead>
<tr>
<th>Mode</th>
<th>Image Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automobile</td>
<td>Image of a street filled with cars.</td>
</tr>
<tr>
<td>Bicycle</td>
<td>Image of a street filled with bicycle riders.</td>
</tr>
<tr>
<td>Bus</td>
<td>Image of a street with a bus in it.</td>
</tr>
</tbody>
</table>
Electric vehicles reduce local pollution!
Electricity mix (2016)

From mix to margin!
Environmental assessment

The chart compares the gCO₂/km emissions for different countries in three categories: WTT fuel, TTW car, and TTW fuel. The countries included are US, UK, TR, SE, NO, NL, IT, FR, DK, DE, CN, BE, and AT. The y-axis represents different countries, and the x-axis shows the gCO₂/km emissions. The chart uses bars to represent emissions for each category, with the length indicating the amount of emissions.
The problems of the battery

Where do the materials come from?

• New dependancies? From south America ...

• Children work in Congo to mine scarce materials ...
SOME CONCLUSIONS

• EVs can provide important contribution but we will not solve the transport problems just by changing the technology;

• It is important to conduct a comprehensive assessment from graddle to grave;

• Currently electricity mainly from fossil plants → marginal generation → need for certified green electricity!

• Fair trade for Electric vehicles’ batteries?
Sustainable energy systems with focus on personal transport electrification

Multi-criteria analysis of sustainability criteria

Aleksandar Janjić
What is the Smart Grid?

EC Smart Grid Task Force

• Increased sustainability;
• Adequate capacity of transmission and distribution grids for ‘collecting’ and bringing electricity to the consumers;
• Adequate grid connection and access for all kinds of grid users;
• Satisfactory levels of security and quality of supply;
• Enhanced efficiency and better service in electricity supply and grid operation;
• Effective support of transnational electricity markets by load flow control to alleviate loop flows and increased interconnection capacities;
• Coordinated grid development through common European, regional and local grid planning to optimise transmission grid infrastructure;
• Enhanced consumer awareness and participation in the market by new players;
• Enable consumers to make informed decisions related to their energy to meet the EU Energy Efficiency targets;
• Create a market mechanism for new energy services such as energy efficiency or energy consulting for customers;
• Consumer bills are either reduced or upward pressure on them is mitigated.
Existing parking system

![Bar chart showing time spent in parking](chart.png)

*Amount of space required to transport the same number of passengers by car, bus or bicycle. (Poster in city of Muenster Planning Office, August 2001)*

SDEWES 2018, Novi Sad Serbia
Multi Criteria Decision Making

- **Goal**
  - Technology
  - Cost reduction
  - Customer satisfaction
  - Environmental impact reduction

- **Criteria level**
  - Qualitative
    - KP 1
  - Quantitative
    - KP m - 1

- **Subcriteria level**
  - KP 1
  - KP n + 1

- **Alternatives level**
  - Project 1
  - Project 2
  - Project n

SDEWES 2018, Novi Sad Serbia
Charger location methodologies

Criteria: construction cost and running cost, traffic status, impact on power grid, impacts on ecology and urban development, user’s comfort

• Multiple Objective Decision Making
• Multiple Criteria Decision Making

Existing studies, which are based on the application of MODM methodology, for the selection of optimal locations use models such as:
• Linear/ nonlinear programming
• Mixed integer programming
• Stochastic programming
• Genetic algorithm (GA)
• Particle Swarm optimization (PSO)
V2G scheduling
City of Niš Case Study
“Impacts of transport sector digitalization and electrification on medium and long term energy planning”

doc. dr. sc. Goran Krajačić, dipl. ing.

Sustainable energy systems with focus on personal transport electrification
3rd SEE SDEWES Conference
Novi Sad, Serbia
01/07/2018
ENERGY TRANSITION

Decentralization

Digitalization

Decoupling

Decarbonization

Diversification

Deregulation

Democratization
Decarbonization pathways
European economy

EU electrification and decarbonization scenario modelling
Synthesis of key findings
May 2018

The 3 scenarios deliver unprecedented but necessary reductions in CO2 emissions

<table>
<thead>
<tr>
<th>Total GHG emissions, EU1</th>
<th>2050 scenarios</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Scenario 1</td>
</tr>
<tr>
<td></td>
<td>5.7</td>
</tr>
<tr>
<td></td>
<td>-1% p.a.</td>
</tr>
<tr>
<td>1990</td>
<td>15</td>
</tr>
</tbody>
</table>

Direct electrification results by scenario

- Total EU economy: Decrease of 22% in 2015 Baseline to 38% in 2050 Scenario 1, 48% in 2050 Scenario 2, and 60% in 2050 Scenario 3.
- Total transport: Decrease of 1% to 29%.
- Total buildings: Decrease of 34% to 45%.
- Total industries: Decrease of 33% to 44%.


Sources: Energy Insights, a McKinsey Solution - Global Energy Perspectives
Share of battery electric vehicles (BEVs) in new sales in the EU

Percent

- **Scenario 1**: Current fleet
- **Scenario 2**: Macro-economic drivers: GDP, population growth
- **Scenario 3**: Scrap rates, especially of internal-combustion-engine (ICE) vehicles
- **TCO of BEVs relative to other competing technologies, driven by decreasing battery cost**
- **Demand for shared mobility and autonomous driving**
- **Infrastructure deployment and innovation (i.e. wireless charging)**
- **Non-economic drivers for BEV acquisition (i.e. regulation, environmental awareness)**

- **Shift in electricity economics accelerates TCO\(^1\) parity**
- **BEV TCO\(^1\) parity (scenarios 1-2)**
- **Accelerated infrastructure rollout in sc2**
- **Various bans on ICE vehicles**

Zero ICE vehicles among new cars sold after 2035-37

Source: eurelectric
million cars per year

source: Bloomberg New Energy Finance
Electrification of transport?
Source: Robert Sansom (Imperial College), Winter Peak Heat Demand
100% RES electricity supply?

Izvor: Eurostat
Digitalization – market capitalization

**Key message:** Digital technology companies have become global leaders by market capitalisation, though energy companies still lead in revenues.

Notes: Rankings are for publicly traded companies; market capitalisations calculated at the end of Q2; circle sizes are relative to market capitalisation.

**Key message:** Technology cost reduction is a key driver enhancing connectivity throughout the electricity sector.

Sources: IEA analysis based on Bloomberg New Energy Finance (2017); Holdsworth et al. (2015); IEA (2017a; 2017b; 2017c); Navigant Research (2017).

**Key message:** Digitalization is set to greatly enhance demand flexibility, the integration of variable renewables, smart charging for EVs and distributed generation.

Sources: Analysis based IEA (2016; 2017d).
Market response to solarization

California Independent System Operator average hourly day-ahead energy market prices
January through June average dollars per megawatthour

Source: U.S. Energy Information Administration, based on ABB Energy Velocity
Note: Prices are simple averages of CAISO trading hubs ZP26, NP15, and SP15 from January 1 through June 30 of each year.
Energy storage?

Source: Energy Storage and Smart Energy Systems
Henrik Lund, Poul Alberg Østergaard, David Connolly, Iva Ridjan, Brian Vad Mathiesen, Frede Hvelplund, Jakob Zinck Thellufsen, Peter Sorknæs
BNEF EV lithium-ion battery pack price survey results

<table>
<thead>
<tr>
<th>Battery pack price ($/kWh)</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>$/kWh</td>
<td>1,000</td>
<td>800</td>
<td>642</td>
<td>599</td>
<td>540</td>
<td>350</td>
<td>273</td>
<td>209</td>
</tr>
<tr>
<td>2018</td>
<td>167</td>
<td>134</td>
<td>107</td>
<td>86</td>
<td>68</td>
<td>55</td>
<td>44</td>
<td>35</td>
</tr>
<tr>
<td>2019</td>
<td>0.06</td>
<td>0.05</td>
<td>0.04</td>
<td>0.03</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Source: Bloomberg New Energy Finance. Pack level pricing, Weighted average of BEV and PHEV packs
CLEAN ENERGY FOR ALL EUROPEANS
THANK YOU FOR YOUR ATTENTION!

goran.krajacic@fsb.hr

• Energy Technology Perspectives 2012, 2014, 2015, 2016, 2017 IEA
• Digitalization and Energy 2017, IEA, 2017
• Harnessing Variable Renewables, IEA, 2011
The development of the power transmission system of electric vehicles.

Huseyin Ayhan Yavasoglu, Ph.D.
Electric Vehicles

Why EV?

- To reduce petroleum dependency.
- Environmental concerns.
- To have more efficient and quiet transportation.

PEV Market Share

- U.S. PHEV Sales
- U.S. BEV Sales
- Plug-in Vehicle Market Share

PEV Market share in EU is: 0.8% PEV and 0.64%BEV with total 1.44%

http://www.anl.gov/

http://www.eafo.eu/eu
## Degrees of Electrification

<table>
<thead>
<tr>
<th></th>
<th>Engine</th>
<th>Motor</th>
<th>“Battery”</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Conventional</strong></td>
<td>100kW</td>
<td>Starter motor</td>
<td>12V 3kW, 1kWh</td>
</tr>
<tr>
<td></td>
<td>Full transient</td>
<td>Stop/start</td>
<td></td>
</tr>
<tr>
<td><strong>Mild Hybrid</strong></td>
<td>90-100kW</td>
<td>3-13kW</td>
<td>12-48V 5-15kW, 1kWh</td>
</tr>
<tr>
<td></td>
<td>Full transient</td>
<td>Torque boost / re-gen</td>
<td></td>
</tr>
<tr>
<td><strong>Full Hybrid</strong></td>
<td>60-80kW</td>
<td>20-40kW</td>
<td>100-300V 20-40kW, 2kWh</td>
</tr>
<tr>
<td></td>
<td>Less transient</td>
<td>Limited EV mode</td>
<td></td>
</tr>
<tr>
<td><strong>PHEV</strong></td>
<td>40-60kW</td>
<td>40-60kW</td>
<td>300-600V 40-60kW, 5-20kWh</td>
</tr>
<tr>
<td></td>
<td>Less transient</td>
<td>Stronger EV mode</td>
<td></td>
</tr>
<tr>
<td><strong>REEV</strong></td>
<td>30-50kW</td>
<td>100kW</td>
<td>300-600V 100kW, 10-30kWh</td>
</tr>
<tr>
<td></td>
<td>No transient</td>
<td>Full EV mode</td>
<td></td>
</tr>
<tr>
<td><strong>EV</strong></td>
<td>No Engine</td>
<td>100kW</td>
<td>300-600V 100kW, 20-60kWh</td>
</tr>
<tr>
<td></td>
<td>Full EV mode</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Announcements from major auto makers

• 400 models and estimated global sales of 25 million by 2025.

• Porsche aims at making 50% of its cars electric by 2023.

• JLR has announced it will shift entirely towards electric and hybrid vehicles by 2020.

• General Motors, Toyota and Volvo have all declared a target of 1 million in EV sales by 2025.

• By 2030, Aston Martin expects that EVs will account for 25% of its sales, with the rest of its line up comprising hybrids.

• By 2025, BMW has stated it will offer 25 electrified vehicles, of which 12 will be fully electric.

• The Renault Nissan & Mitsubishi alliance intends to offer 12 new EVs by 2022.

BEV Range Comparison

2018 US BEV Models

Rated Ranges

- Smart Electric Drive: 93km
- Fiat 500e: 135km
- Mercedes B Class ED: 140km
- Honda Clarity Electric: 143km
- Kia Soul EV: 179km
- BMW i3: 184km
- Ford Focus Electric: 185km
- Hyundai Ionic Electric: 200km
- Volkswagen e-Golf: 201km
- Nissan Leaf: 243km
- Tesla Model 3: 354km
- Tesla Model X: 381km
- Chevrolet Bolt: 383km
- Tesla Model S: 507km

$23.800

$135.000

https://www.fleetcarma.com
By year-end 2017, a total of **6,475** hydrogen fuel cell vehicles have been sold globally since 2013 when the vehicles first became available commercially.


**Production FCV**

- 2007 - Honda FCX Clarity
- 2010 - Mercedes-Benz F-Cell
- 2014 - Hyundai Tucson FCEV[2]
- 2015 - Toyota Mirai
- 2016 - Riversimple Rasa
- 2016 - Honda Clarity Fuel Cell
- 2018 - Hyundai NEXO
Battery Electric Vehicles

Almost 40% of the Cost is battery!

http://teslararti.com
### Current BEVs

<table>
<thead>
<tr>
<th>Brand</th>
<th>Model</th>
<th>Region</th>
<th>Price</th>
<th>Range [km]</th>
<th>Battery [kWh]</th>
<th>Powertrain</th>
<th>Year</th>
<th>Motor Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>BMW i3</td>
<td>EU &amp; US</td>
<td>$44,450</td>
<td>183</td>
<td>33</td>
<td>RWD</td>
<td>2018</td>
<td>AC induction</td>
</tr>
<tr>
<td>2</td>
<td>Chevrolet Bolt</td>
<td>US</td>
<td>$36,620</td>
<td>383</td>
<td>60</td>
<td>FWD</td>
<td>2017</td>
<td>AC PMSM</td>
</tr>
<tr>
<td>3</td>
<td>Fiat 500e</td>
<td>US</td>
<td>$32,995</td>
<td>135</td>
<td>24</td>
<td>FWD</td>
<td>2017</td>
<td>AC induction</td>
</tr>
<tr>
<td>4</td>
<td>Ford Focus E</td>
<td>EU &amp; US</td>
<td>$29,120</td>
<td>185</td>
<td>33.5</td>
<td>FWD</td>
<td>2018</td>
<td>AC PMSM</td>
</tr>
<tr>
<td>5</td>
<td>Honda Clarity E</td>
<td>US</td>
<td>$37,510</td>
<td>143</td>
<td>25.5</td>
<td>FWD</td>
<td>2018</td>
<td>AC PMSM</td>
</tr>
<tr>
<td>6</td>
<td>Hyundai Ioniq E</td>
<td>EU &amp; US</td>
<td>$29,500</td>
<td>200</td>
<td>28</td>
<td>FWD</td>
<td>2018</td>
<td>AC PMSM</td>
</tr>
<tr>
<td>7</td>
<td>Jaguar I-Pace</td>
<td>EU &amp; US</td>
<td>$76,500</td>
<td>386</td>
<td>90</td>
<td>FRWD</td>
<td>2018</td>
<td>AC PMSM</td>
</tr>
<tr>
<td>8</td>
<td>Kia Soul EV</td>
<td>EU &amp; US</td>
<td>$33,950</td>
<td>179</td>
<td>30</td>
<td>FWD</td>
<td>2018</td>
<td>AC PMSM</td>
</tr>
<tr>
<td>9</td>
<td>Mitsubishi MiEV</td>
<td>US</td>
<td>$22,995</td>
<td>160</td>
<td>16</td>
<td>FWD</td>
<td>2017</td>
<td>AC PMSM</td>
</tr>
<tr>
<td>10</td>
<td>Nissan Leaf (2nd Gen)</td>
<td>EU &amp; US</td>
<td>$29,900</td>
<td>243</td>
<td>40</td>
<td>FWD</td>
<td>2018</td>
<td>AC PMSM</td>
</tr>
<tr>
<td>11</td>
<td>Renault Zoe</td>
<td>EU</td>
<td>$31,000</td>
<td>299</td>
<td>41</td>
<td>FWD</td>
<td>2017</td>
<td>AC PMSM</td>
</tr>
<tr>
<td>12</td>
<td>Smart ED</td>
<td>EU &amp; US</td>
<td>$23,800</td>
<td>161</td>
<td>17.6</td>
<td>FWD</td>
<td>2017</td>
<td>AC SM</td>
</tr>
<tr>
<td>13</td>
<td>Tesla Model 3 (Long Range)</td>
<td>EU &amp; US</td>
<td>$50,000</td>
<td>499</td>
<td>75</td>
<td>RWD</td>
<td>2018</td>
<td>AC PMSM</td>
</tr>
<tr>
<td>14</td>
<td>Tesla Model S 100D</td>
<td>EU &amp; US</td>
<td>$94,000</td>
<td>539</td>
<td>100</td>
<td>FRWD</td>
<td>2017</td>
<td>AC induction</td>
</tr>
<tr>
<td>15</td>
<td>Tesla Model S 75D</td>
<td>EU &amp; US</td>
<td>$74,500</td>
<td>417</td>
<td>75</td>
<td>FRWD</td>
<td>2017</td>
<td>AC induction</td>
</tr>
<tr>
<td>16</td>
<td>Tesla Model S P100D</td>
<td>EU &amp; US</td>
<td>$135,000</td>
<td>507</td>
<td>100</td>
<td>FRWD</td>
<td>2017</td>
<td>AC induction</td>
</tr>
<tr>
<td>17</td>
<td>Tesla Model X 100D</td>
<td>EU &amp; US</td>
<td>$96,000</td>
<td>475</td>
<td>100</td>
<td>FRWD</td>
<td>2017</td>
<td>AC induction</td>
</tr>
<tr>
<td>18</td>
<td>Tesla Model X 75D</td>
<td>EU &amp; US</td>
<td>$79,500</td>
<td>381</td>
<td>75</td>
<td>FRWD</td>
<td>2017</td>
<td>AC induction</td>
</tr>
<tr>
<td>19</td>
<td>Tesla Model X P100D</td>
<td>EU &amp; US</td>
<td>$140,000</td>
<td>465</td>
<td>100</td>
<td>FRWD</td>
<td>2017</td>
<td>AC induction</td>
</tr>
<tr>
<td>20</td>
<td>Volkswagen e-Golf</td>
<td>EU &amp; US</td>
<td>$30,495</td>
<td>192</td>
<td>35.8</td>
<td>FWD</td>
<td>2017</td>
<td>AC PMSM</td>
</tr>
<tr>
<td>21</td>
<td>Volkswagen e-Up!</td>
<td>EU</td>
<td>$30,495</td>
<td>159</td>
<td>35.8</td>
<td>FWD</td>
<td>2017</td>
<td>AC PMSM</td>
</tr>
</tbody>
</table>

### Upcoming BEVs

<table>
<thead>
<tr>
<th>Brand</th>
<th>Model</th>
<th>Region</th>
<th>Range [km]</th>
<th>Battery [kWh]</th>
<th>Powertrain</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Audi e-tron Quattro</td>
<td>SUV</td>
<td>426</td>
<td>95</td>
<td>FRWD</td>
<td>2018</td>
</tr>
<tr>
<td>2</td>
<td>Hyundai Kona E</td>
<td>crossover</td>
<td>402</td>
<td>64</td>
<td>FWD</td>
<td>2018</td>
</tr>
<tr>
<td>3</td>
<td>Kia Niro EV</td>
<td>crossover</td>
<td>380</td>
<td>64</td>
<td>FWD</td>
<td>2018</td>
</tr>
<tr>
<td>4</td>
<td>Mercedes-Benz EQC</td>
<td>SUV</td>
<td>410</td>
<td>70</td>
<td>FRWD</td>
<td>2019</td>
</tr>
<tr>
<td>5</td>
<td>Nissan Leaf (Long Range)</td>
<td>hatchback</td>
<td>362</td>
<td>64</td>
<td>FWD</td>
<td>2019</td>
</tr>
<tr>
<td>6</td>
<td>Porsche Taycan</td>
<td>hatchback</td>
<td>418</td>
<td>90</td>
<td>FRWD</td>
<td>2019</td>
</tr>
<tr>
<td>7</td>
<td>WV ID</td>
<td>hatchback</td>
<td>370</td>
<td>60</td>
<td>RWD</td>
<td>2019</td>
</tr>
</tbody>
</table>
The load power could be effectively split between the two propulsion machines to obtain the highest powertrain efficiency.

The powertrain efficiency could be improved up to 10%.

Utilizing two propulsion Machines

Only one propulsion machine

- Simple
- Limited high efficient operation map

Two propulsion machines

- Powertrain efficiency could be improved
- More complicated

Tesla.com

Tesla.com
IDENTICAL MOTORS

THE WORLD’S FIRST STREET LEGAL ELECTRIC CAR TO EXCEED 350KM/H

330 km/h (205.6 mph)

354 km/h (220 mph)

https://genovationcars.com
Utilizing two propulsion Machines

Remy Electric Motor Efficiency Map

Torque [Nm]
Efficiency

Speed [RPM]

Remy Inc., 2010
Utilizing two propulsion Machines

For Low Speeds

\[ \eta_{\text{Two}} > \eta_{\text{Single}} \]

800 rpm

For High Speeds

\[ \eta_{\text{Two}} < \eta_{\text{Single}} \]

6800 rpm

IDENTICAL MOTORS
Utilizing two propulsion Machines

The properties of this two permanent magnet propulsion machines are provided by Argonne National Laboratory (ANL)'s Autonomie software library and detailed specifications are given in.

Efficiency map of Complementary motor couple

Upcoming high capacity BEVs

- Audi e-tron Quattro SUV (95kWh)
- Mercedes- Benz EQC SUV (70kWh)
- Porsche Taycan (90kWh)

Potential of having better powertrain efficiency

The properties of this two permanent magnet propulsion machines are provided by Argonne National Laboratory (ANL)'s Autonomie software library and detailed specifications are given in.
Conclusion

• Currently PEV are the goal for CO2 regulations, Zero-emission vehicles would be mandatory wish upcoming regulations.

• Powertrain of the EVs is still improving.

• Li-ion batteries are major ESS unit currently, Technological improvement and cost reduction are required.

• What kind of new propulsion technologies are likely to make sense?
  * PMSM is the major propulsion machine for the BEVs. Tesla is also going to use PMSM in 4WD Model 3
  * Current and upcoming almost all EVs with +65kWh battery capacity utilizes two propulsion machines.
  * Using two complementary propulsion machines instead of double identical or single large one make more sense in terms of placing and efficiency.
Thank You!

TUBITAK
ENERGY INSTITUTE
Automotive Center for Excellence
June 2017