Electric Vehicles, Batteries and Climate Change: A perspective on sustainability

Dr. Avi Bhangaonkar
Lecturer, School of Engineering
University of Leicester
The economics of biodiversity: The Dasgupta Review

• Our economies, livelihoods and well-being all depend on our most precious asset: Nature.

• We have collectively failed to engage with Nature sustainably, to the extent that our demands far exceed its capacity to supply us with the goods and services we all rely on.

• Our unsustainable engagement with Nature is endangering the prosperity of current and future generations.

• At the heart of the problem lies deep-rooted, widespread institutional failure.

• The solution starts with understanding and accepting a simple truth: our economies are embedded within Nature, not external to it.

• We need to change how we think, act and measure success.
  • Ensure that our demands on Nature do not exceed its supply, and that we increase Nature’s supply relative to its current level.
  • Change our measures of economic success to guide us on a more sustainable path.
  • Transform our institutions and systems – in particular our finance and education systems – to enable these changes and sustain them for future generations.
All the engineering we do happens here…
(although we do sometimes send some of it elsewhere)

As engineering fundamentally involves change, we have to do it very carefully…
The context in which Engineering takes place

• Anthropogenic climate change:
  • Global warming due to CO₂ and other ‘greenhouse gases’
  • Build up of waste and deterioration of local environments

• World population growth:
  • Projected growth from 7.7 to 9.7 billion from 2019 to 2050 (+26%)¹
  • Consumption of resources already exceeds rate at which planet replenishes them

• Increasing variety of resource use, due to increasing complexity and demand on products

• Availability of resources challenged by socio-economic-(geo)political factors

• Cost of change seen as a barrier despite massive opportunity cost

Anthropogenic climate change – temperature

- Commonly simplified as ‘global warming’
- Since about 100 years ago, global temperatures have risen at an unprecedented rate
- Scientific consensus: it’s our fault!
Anthropogenic climate change – Greenhouse gases

• ‘Greenhouse gases’ (GHGs) play a significant role
• Due to human activity, these are at unprecedented levels
• CO₂ most abundant but CH₄, NOₓ and F-gases also important
World energy consumption

- World energy consumption projected to rise by 50% by 2050 to approx. 264,000 TWh
- Share generated by renewables and other low carbon sources (e.g. nuclear) projected to rise from 20% to 32%
- Use of natural gas also projected to increase, while coal and petroleum will remain in significant use
Global resource usage

- Models have been produced to indicate how much we are overusing the Earth’s resources
- Since 1970 we have used more resources than are replenished each year
- 2020 is the only year when Earth Overshoot Day has been significantly pushed back #silverLinings…!

Source: National Footprint and Biocapacity Accounts 2023 Edition
Data from footprintnetwork.org

Global resource usage

- Countries consume resources at widely varying rates
- Advanced economies tend to reach the overshoot day early
- However, virtually all large countries must reduce their resource requirements – notable exception?

Number crunching…

- We consume 170% of Earth’s annual resources each year
- Global population is projected to increase by 26% between now and 2050

**Question:** By how much must we reduce our rate of consumption to become sustainable (i.e. only use 100% of Earth’s annual resources each year) by 2050?

Note: These figures are not likely to be accurate. They are intended to give a general sense of scale.
Circular Economy model – Inter/national context

Learn more about the Circular Economy and how it may be achieved: https://www.ellenmacarthurfoundation.org/explore/the-circular-economy-in-detail

4 RE principles:
- Reuse
- Repair
- Re-manufacture
- Recycle
The Triple Bottom Line – Organisational context

The ‘bottom line’ refers to the profit made by a company – the ‘triple bottom line’ refers to the total cost of doing business.

Economic theory that advocates balancing social, environmental and economic concerns.

Social and environmental aspects may be difficult to measure but can be promoted by taking a ‘sustainability first’ approach.

There’s a great series of illustrated videos about sustainability on YouTube, including this one about the Triple Bottom Line: https://www.youtube.com/watch?v=2f5m-jBf81Q
Comparison of energy storage rate (power)

**Determination of efficiency and power level during refilling fuel tank using fossil fuel**

Flowrate of the pump: 38 l/min with 42 MJ/kg, 0,83 kg/dm³, \( P_{eq} = 22 \text{ MW} \)

Power consumption of the pump: 0,5 kW

Efficiency \( \eta = (22\text{MW}-0,5\text{kW})/22\text{MW} = 0.99997 \)

**Design of electrical charging system at the same power level and efficiency as fuel pump**

<table>
<thead>
<tr>
<th>Voltage U (V)</th>
<th>100 kV</th>
<th>10 kV</th>
<th>1 kV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current I (A)</td>
<td>220 A</td>
<td>2,2 kA</td>
<td>22 kA</td>
</tr>
<tr>
<td>Resistance of cable (( \Omega ))</td>
<td>10 m( \Omega )</td>
<td>100 ( \mu \Omega )</td>
<td>1 ( \mu \Omega )</td>
</tr>
<tr>
<td>Assumed length of copper cable used for charging (( l_{Cu} ))</td>
<td>10 m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mass of copper (( M_{Cu} )) (kg)</td>
<td>1,4</td>
<td>142</td>
<td>14'200</td>
</tr>
</tbody>
</table>

\( \eta = 0.99997 \)

Voltage at which the charging system operates

Mass of the copper cable needed!
Over 26 million electric cars were on the road in 2022, up 60% relative to 2021 and more than 5 times the stock in 2018.

Electric car markets are seeing exponential growth as sales exceeded 10 million in 2022.

A total of 14% of all new cars sold were electric in 2022, up from around 9% in 2021 and less than 5% in 2020.

Electric car sales are expected to continue strongly through 2023.

Over 2.3 million electric cars were sold in the first quarter, about 25% more than in the same period last year.
Public charging points

Figure 1.13 Installed publicly accessible light-duty vehicle charging points by power rating and region, 2015-2022
Battery value chain - vision

A circular battery value chain as a major driver to meet the Paris Agreement target

- A circular battery value chain that is a major driver to achieve the Paris Agreement target to stay below the 2°C scenario
- Transformation of the economy in the value chain, creating new jobs and additional value
- An industry safeguarding human rights, supporting a just energy transition and fostering economic development, in line with the UN SDGs

Enable 30% of the required emission reductions in transport and power sector.
Create 10m jobs, and
Provide 600m of economic value in a responsible and just value chain

Source: World Economic Forum, Global Battery Alliance
Battery value chain - Challenges

3 challenges to scale up the battery value chain

- Battery production has a significant GHG footprint
- Raw material supply has significant social and environmental risks
- The viability of battery-enabled applications is uncertain
Battery demand – region and application

Global battery demand by application
GWh in 2030, base case

- Electric mobility: 2,623 GWh (26% CAGR)
- Energy storage: 971 GWh (38% CAGR)
- Consumer electronics: 221 GWh (5% CAGR)

Global battery demand by region
GWh in 2030, base case

- China: 1,122 GWh (20% CAGR)
- EU: 443 GWh (29% CAGR)
- USA: 357 GWh (26% CAGR)
- RoW: 702 GWh (38% CAGR)

Global Battery Alliance, World Economic Forum - A Vision for a Sustainable Battery Value Chain in 2030 (Insight report – September 2019) License CC BY-NC-ND 4.0
Road transportation

The road transport sector accounts for ~11% of global GHG emissions¹...

Percent

With 5.8 GtCO₂e, the road transport sector accounts for ~11% of global GHG emissions¹.

¹ Excluding land-use, land-use-change and forestry

...although the total number of vehicles globally is expected to grow, electrification...

Total number of vehicles globally, billion

ICE

HEV

PHEV

BEV

2017 20 25 2030

2.2% p.a.

1.4 1.5 1.6 1.8

12%

1 13 33 36

...will help decouple road transport emissions² from growth by 2030.

CO₂ emissions of new passenger cars sold globally, gCO₂

-3.0% p.a.

2017 2030

146.1 97.8
Battery production – Footprint

Battery production with significant CO₂ footprint, mainly driven by active materials and other components as well as cell production in China

Greenhouse gas emissions by value chain step, Mt CO₂e per annum (2030)

-8

~24 Mt CO₂e (2018)

~5 ~4 ~7 ~6 ~2<1

~11 ~20 ~70 ~62 ~20 ~2

~182 Mt CO₂e (2030)

Percentage of total GHG emissions

- China
- EU
- US
- Rest of the world

Raw material mining
Raw material refining
Active materials and other components
Cell production
Pack production
Recycling
EV Emission benefits compared to ICE

**EV emission benefit compared to ICE by vehicle size and geography, base case 2030**

- **Small vehicles (A/B)**
  - EU: -60%
  - USA: -35%
  - China: -26%

- **Medium vehicles (C/D)**
  - EU: -48%
  - USA: -26%
  - China: -21%

- **Large vehicles (E/F)**
  - EU: -55%
  - USA: -22%
  - China: -19%

**Life cycle GHG emissions for Chinese medium-sized vehicles, base case 2030**

- **ICE**: 202 gCO₂e/km
  - Use: 150
  - Chassis: 50
  - Powertrain: 32
  - Recycling: 2
  - Pack: 0
  - Cell: 0
  - Active materials: 0
  - Raw materials (refining): 0
  - Raw materials (mining): 0

- **EV**: 160 gCO₂e/km
  - Use: 100
  - Chassis: 50
  - Powertrain: 32
  - Recycling: 2
  - Pack: 0
  - Cell: 0
  - Active materials: 0
  - Raw materials (refining): 0
  - Raw materials (mining): 0

- **-21%**
Opportunity

Scaling battery production by a factor of 19 is a major opportunity for every step of the value chain.

- **Raw material mining**: 5-40x
- **Raw material refining**: 14x
- **Active materials**: 15x
- **Cell production**: 19x
- **Recycling**: 15x

The mining industry needs to extract a volume equivalent to >300 Great Pyramids of Giza per year in 2030.

A weight equivalent to >110K Boeing 787s (Dreamliners) is refined per year in 2030.

Active materials produced in 2030 are enough to produce >800B battery cells (AA type).

~120 additional Giga Factories (today’s largest) must be operational in 2030.

An equivalent of >10B mobile phone batteries are expected to reach end-of-life in 2030.
Coupling transport and energy sectors
EV emissions – circular economy levers
Circular Economy Levers – Batteries

Increase from 60% to 80%

Global Battery Alliance, World Economic Forum - A Vision for a Sustainable Battery Value Chain in 2030 (Insight report – September 2019) License CC BY-NC-ND 4.0
What professionals say?

Battery remanufacturing is difficult because of following factors.

- Different Battery size
- Different Battery shape
- Different Battery Chemical Composition
- Huge Initial Investment
- Safety Concerns
## Ranking of barriers for EV remanufacturing

<table>
<thead>
<tr>
<th>Criteria Nomenclature</th>
<th>Description</th>
<th>Grouping Criteria</th>
<th>Weightage</th>
<th>Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>C11</td>
<td>Market Size of Remanufacturing</td>
<td>Economic</td>
<td>0.711</td>
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<tr>
<td>C3</td>
<td>Different Battery Size</td>
<td>Technical</td>
<td>0.676</td>
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<td>C1</td>
<td>Huge industrial Setup</td>
<td>Operational</td>
<td>0.28</td>
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<td>C4</td>
<td>Different Battery Shape</td>
<td>Technical</td>
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<td>C14</td>
<td>Sourcing Vehicles for Remanufacturing</td>
<td>Operational</td>
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<td>C2</td>
<td>Skilled labour</td>
<td>Economic</td>
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<td>C10</td>
<td>Performance of Products</td>
<td>Operational</td>
<td>0.18</td>
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<td>C8</td>
<td>Recovery Rate of Remanufacture Products</td>
<td>Operational</td>
<td>0.18</td>
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<tr>
<td>C6</td>
<td>Huge Initial Investment</td>
<td>Capital</td>
<td>0.159</td>
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<td>C15</td>
<td>Legislation Restrictions</td>
<td>Legislation</td>
<td>0.127</td>
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<td>C9</td>
<td>Number of Parts in vehicle</td>
<td>Operational</td>
<td>0.12</td>
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<tr>
<td>C13</td>
<td>Manpower Cost</td>
<td>Economic</td>
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<td>C5</td>
<td>Different Battery Chemical Composition</td>
<td>Technical</td>
<td>0.076</td>
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<td>C7</td>
<td>Safety Concern</td>
<td>Safety</td>
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<tr>
<td>C12</td>
<td>Testing Equipment’s For remanufacturing</td>
<td>Operational</td>
<td>0.04</td>
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<td>Barriers</td>
<td>Rankings</td>
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<tr>
<td>Uncertainty of materials used</td>
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<td>Unorganised relation between Stakeholders</td>
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<td>Supply chain transparency</td>
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<tr>
<td>Poor Waste management regulations</td>
<td>16</td>
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<tr>
<td>Low quality perception of recycled goods</td>
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<td>Lack of standardization on EoL processes for EVBs</td>
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<tr>
<td>Lack of safety standards for (collect, storage, dismantle)</td>
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<td>Lack of focused financing from Gov</td>
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<td>Lack of EVB design considering EoL</td>
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<tr>
<td>Lack of enforcement and compliance</td>
<td>23</td>
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<tr>
<td>Lack of clear regulatory framework</td>
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<tr>
<td>High investment Risks</td>
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<tr>
<td>High costs for transporting, handling and storage</td>
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<tr>
<td>Hazardous emissions and Energy consumption</td>
<td>19</td>
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<tr>
<td>EoL EVBs have little economic value</td>
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<tr>
<td>Limited availability of sustainable materials</td>
<td>21</td>
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<tr>
<td>Slow-Developing technology infrastructure</td>
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<tr>
<td>Low recycling efficiency</td>
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<td>Lack of profits</td>
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<tr>
<td>Lack of efficient recycling infrastructure</td>
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<td>Lack of customer awareness and ignorance</td>
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<tr>
<td>Inefficient government policy</td>
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<td>High labour costs</td>
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</table>
Key takeaways

• Stakeholder engagement
• New metrics
• Circular economy
• Regulatory support
Transformative change is possible – we and our descendants deserve nothing less!