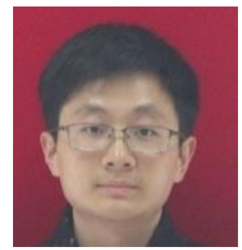
Sustainable Solid Waste Management Lessons from COVID-19 Pandemics



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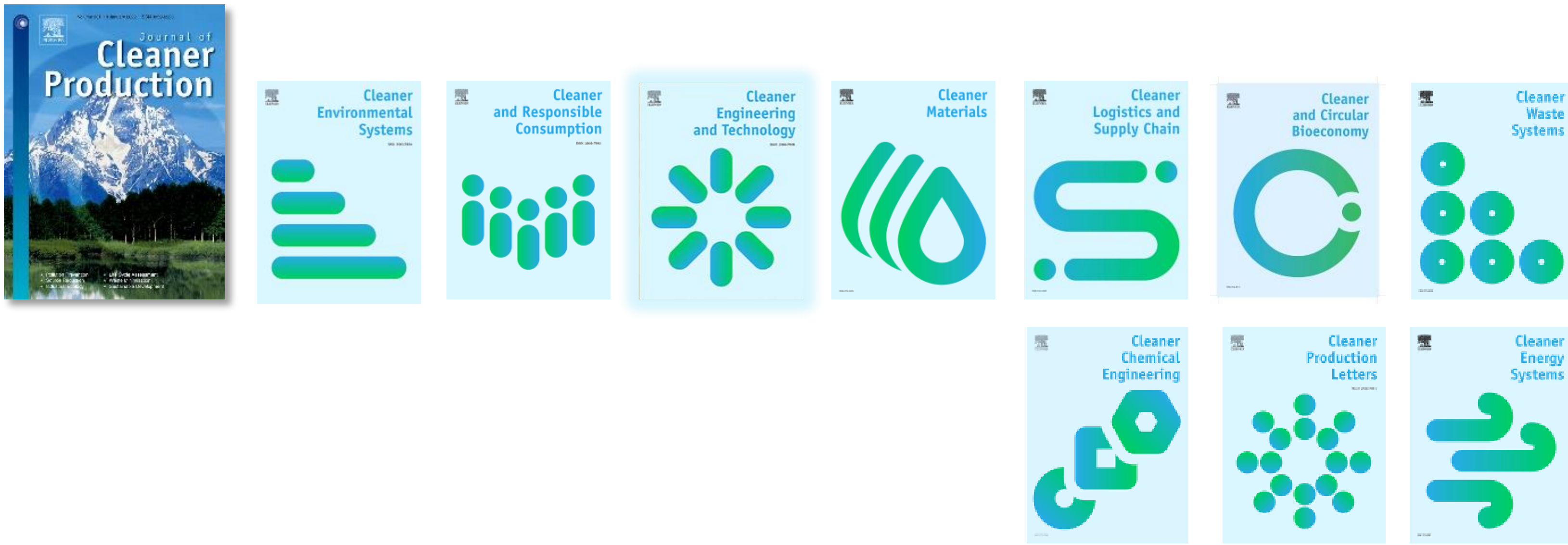

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Old Issues Recent Concern

Nearly 50 years ago

“Increasing production of plastics, combined with present waste-disposal practices, will undoubtedly lead to increases in the concentration of these particles.” (Carpenter and Smith, 1972)

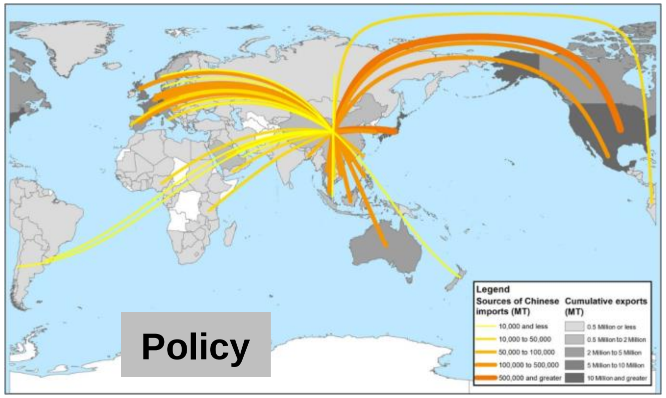
Why?

Plastic Tide

Media

Harm to Wildlife - Ingestion, Entanglement

Plastic Export Ban, Circular Economy



Policy

Carpenter, E. J.,Smith, K. L., 1972. Plastics on the Sargasso Sea surface. Science, 175(4027), 1240-1241.
www.theguardian.com/environment/2018/nov/13/the-plastic-backlash-whats-behind-our-sudden-rage-and-will-it-make-a-difference
Brooks AL, Wang S, Jambeck JR, 2018. The Chinese import ban and its impact on global plastic waste trade. Science Advances, 4(6), eaat0131.

Plastic Footprint

A **Plastic Footprint** is the total amount of plastic used and discarded by a single individual.

Boucher, J., Dubois, C. Kounina, A., Puydarrieux, P., 2019. Review of plastic footprint methodologies: Laying the foundation for the development of a standardised plastic footprint measurement tool, Gland, Switzerland

- Out of 19 methodologies 10 does not consider microplastics and lacking in several ways
- To date, no operational methodology to quantify the plastic impact for ecosystems and biodiversity

Marine Plastic Footprint focus on leakage

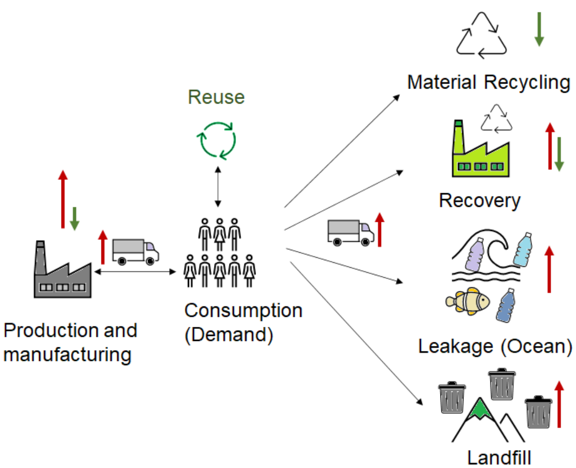
- Glass bottle has a higher marine plastic footprint than a plastic bottle due to footprint arises from tyre dust in transporting
- Existing Plastic Footprint frameworks have been particularly focussing on leakage where the other footprints and Circular Economy Rs is not fully integrated.

Boucher, J. , G.Billard, E.Simeone, J.Sousa 2020. The marine plastic footprint. Accessed July 12 2020. portals.iucn.org/library/sites/library/files/documents/2020-001-en.pdf.

Plastic Waste Footprint

- The **Plastic Waste Footprint** is defined as the net externalities cost (NEC) as a result of fulfilling the plastic demand at a place.
- NEC is used as the representative indicator integrate different impacts including the marine pollution

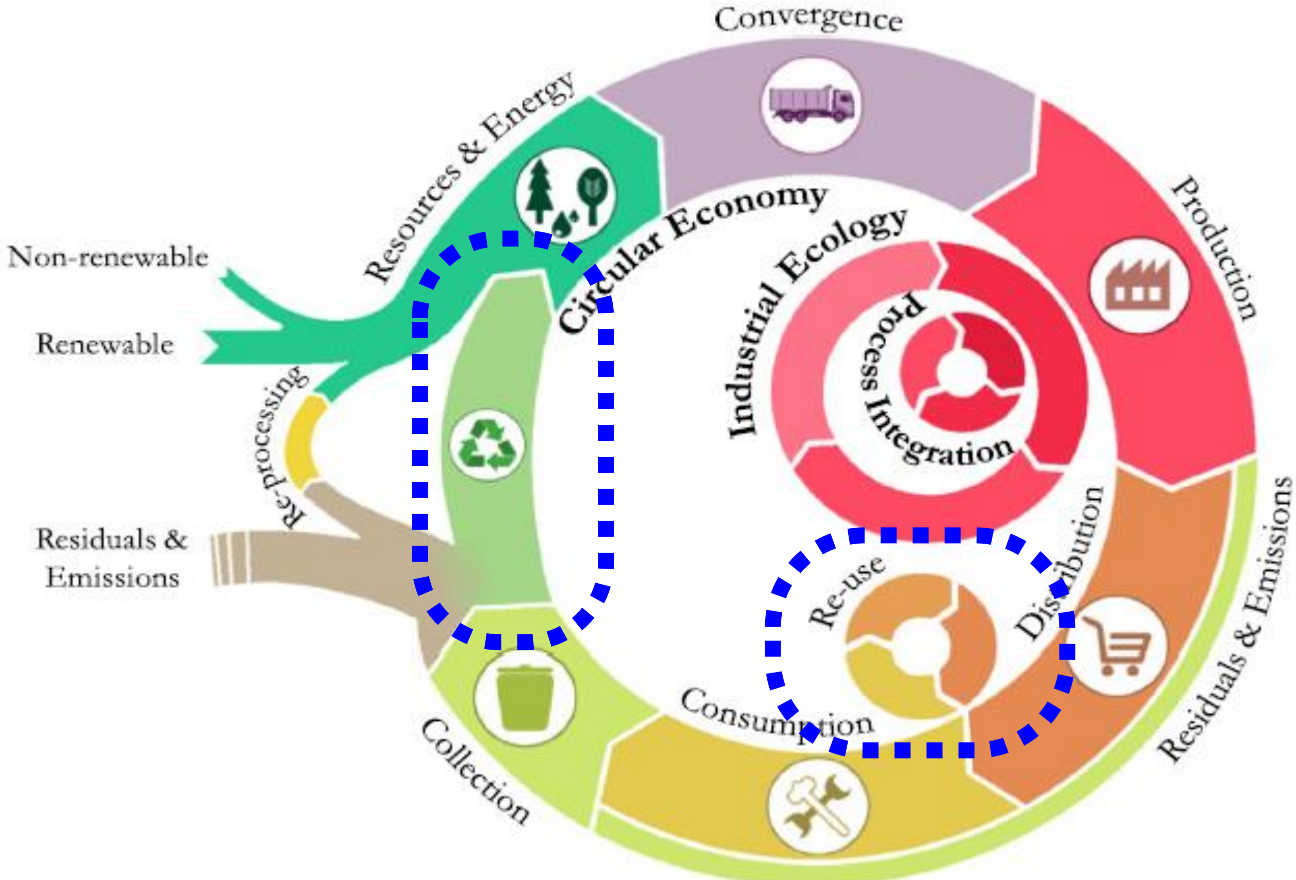
$$PWF = (TA - RA_{reuse} - RAr_n) \times ECp + \sum_n (ECr_n \times RAr_n) + (ECe_n \times RA_n) + (DA \times EC_L) + (LA \times EC_M)$$



TA is the total amount of plastic demand (t).
RA_{reuse} is the plastic (t) being reused in reducing the demand.
RAr is the amount of plastic being processed as a part of the circular economy strategies (t),
n is the type of treatment approaches
ECp is the total externalities cost to produce plastic products (EUR/t).
ECr is the externalities cost in recycling (EUR/t).
ECe is the net externalities cost in implementing the recovery approaches (EUR/t)
RA is the amount of plastic being recovered and converted to the other form of resources (t).
DA is the amount of plastic being disposed of (t).
EC_L is the externalities cost when the waste ended in the landfill (EUR/t).
LA is the leakage amount to the marine
EC_M is the externalities cost when the waste ended in the marine.

Klemeš, J. J., Fan, Y. V., Jiang, P., 2021. Plastics: friends or foes? The circularity and plastic waste footprint. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 43(13), 1549-1565.

Circular Economy: Closing the Loop



A set of paths closing the loops. Each path can involve:

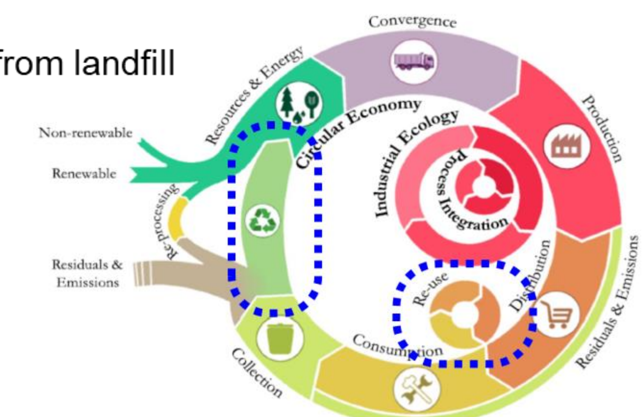
- Delivery of the secondary resources to demand locations
- Processing of the secondary resources
- Combinations of those two options are also possible

Walmsley T. G., Ong B. H., Klemeš J. J., Tan R. R., Varbanov P. S., 2019. Circular Integration of processes, industries, and economies. Renewable and Sustainable Energy Reviews, 107, 507-515

Circular Economy Hierarchy (10Rs)

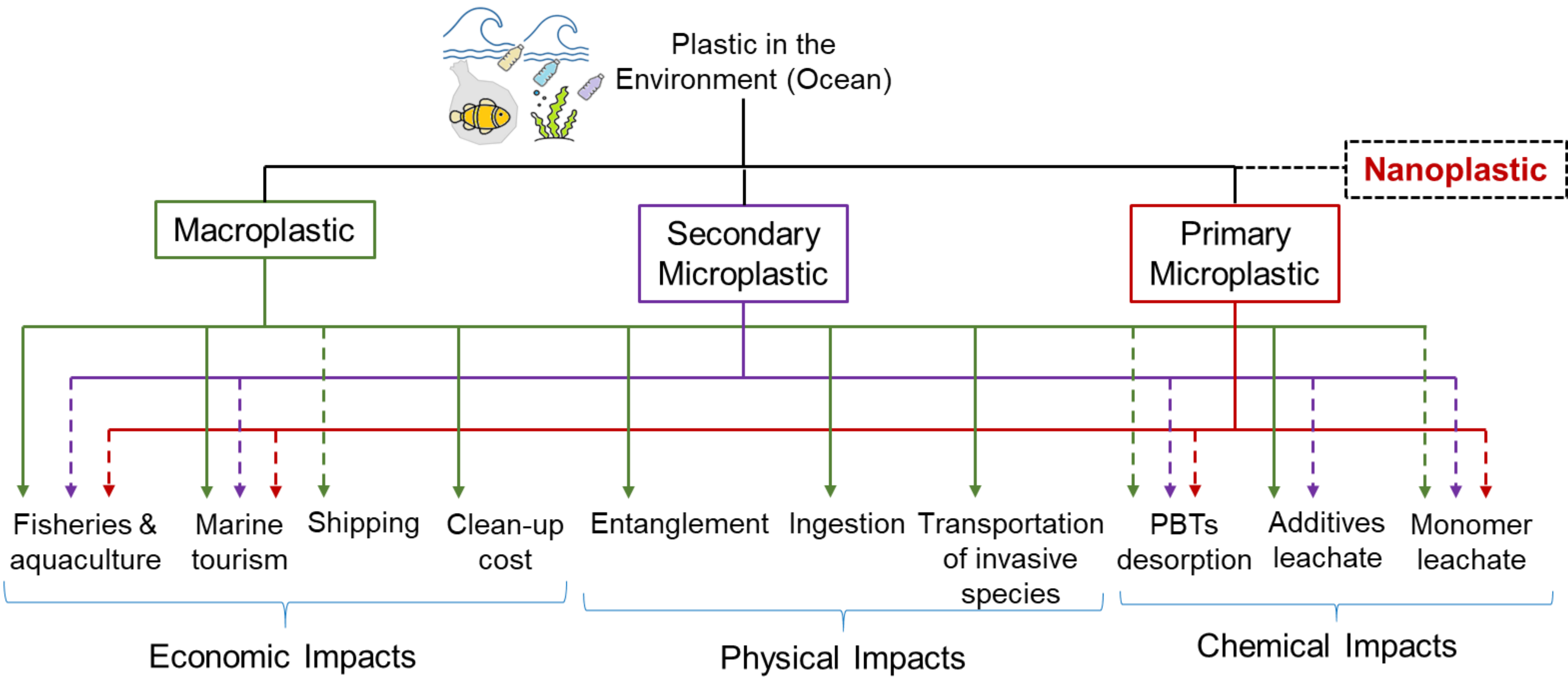
Most Preferred → Least Preferred

Waste Management Hierarchy	Circular Economy (CE) Hierarchy (10Rs)	
Reduction and Reuse	**R**efrain (Refuse)	Avoid the use of resources
	Redesign & Reduce	Decrease the use of resources
	Reuse	Repeat to use an item
With additional footprints compared to the above	**R**epair	Maintain and repair
	Refurbish	Improve product
	Remanufacture	Create new product from second hand
	Repurpose	Reuse product for different purpose
Recycling and Composting	**R**ecycle	Reuse raw materials of product
Energy Recovery	**R**ecover	Recover energy from waste
	Remine	Retrieval of material from landfill
Treatment/ Disposal		



Fan YV, Jiang, P., Klemeš, J. J., Liew, P. Y., Lee, C. T., 2020. Integrated regional waste management to minimise the environmental footprints in circular economy transition. Resources, Conservation and Recycling, 105292.

Impact Pathway of Plastics



Dotted lines are the impacts less consider in existing valuation models

Klemeš, J. J., Fan, Y. V., Jiang, P., 2021. Plastics: friends or foes? The circularity and plastic waste footprint. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 43(13), 1549-1565.

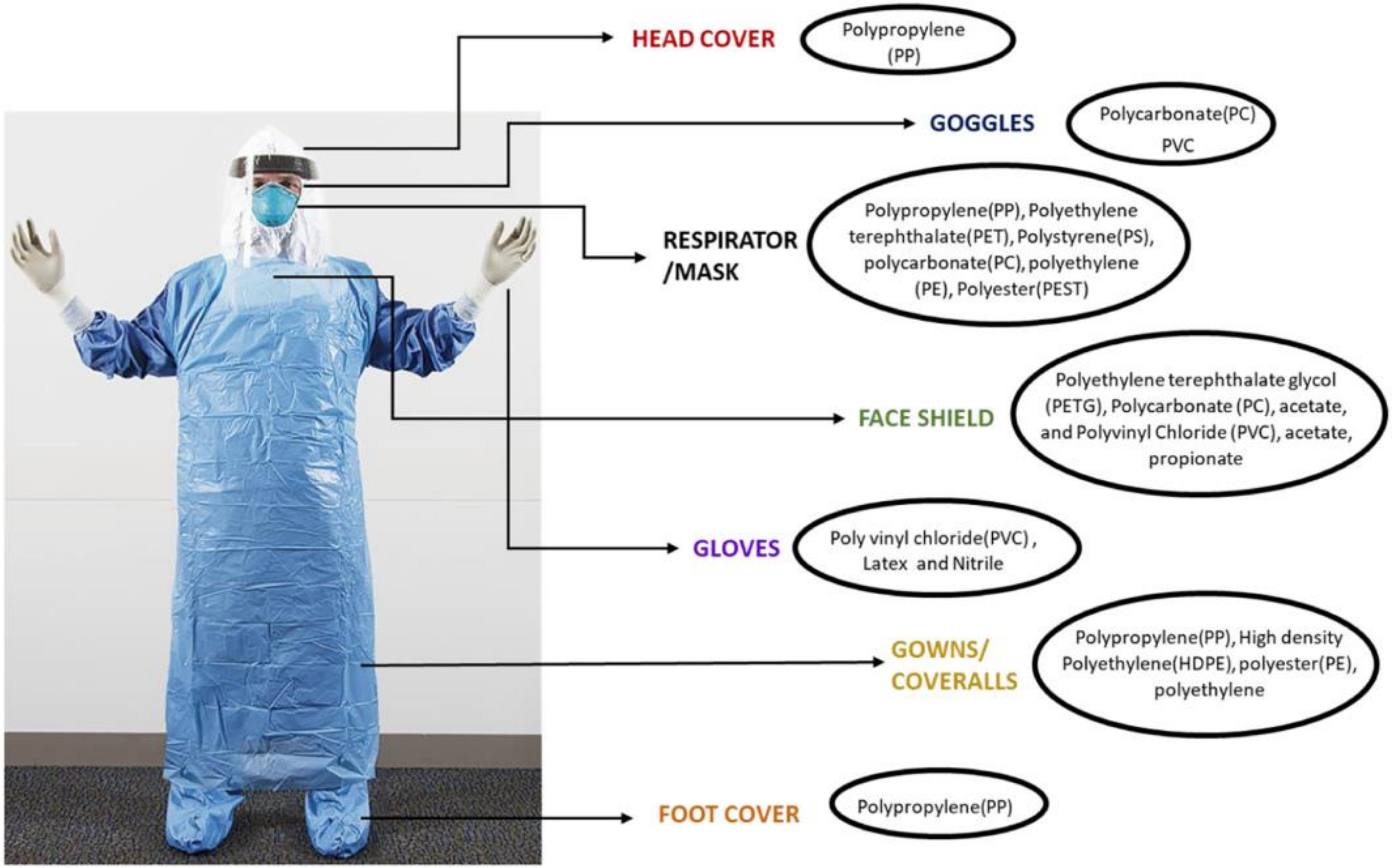
LCA Comparison of Face Masks

Mask type	Image	Material	Weight [g]
M1. 3D printed M1		PP – Polypropylene (filter)	0,50
		PE – Polyester (filter)	0,50
		PLA (mask)	30,00
		Synthetic rubber (bands)	3,00
M2. Surgical M2		PP – Polypropylene (filter)	1,28
		PE – Polyester (filter)	1,28
		Aluminum (nose adapter)	0,44
		Cotton (bands)	0,02
M3. FFP2 with valve M3		Synthetic rubber (bands)	3,00
		PP – Polypropylene (filter)	5,00
		Aluminum (nose adapter)	0,95
		Polyurethane foam (nose protection)	0,05
		PP (valve)	5,00
M4. FFP2 without valve M4		Synthetic rubber (bands)	3,00
		PP – Polypropylene (filter)	5,00
		Aluminum (nose adapter)	0,95
M5. Reusable M5		PP – Polypropylene (filter)	2,70
		PE – Polyester (filter)	2,70
		Cotton (bands)	1,00

- Manufacturing, use and end-of-life (landfill) phases considered
- Highest environmental burden for masks that are discarded after use (M3 > M4 > M2). Significantly lower burden for reusable masks (M1 > M5)
- Eco-design ideas:
  - Production of masks with lower amount of plastics (FFP2 with less PP, reduction of the filtering area)
  - Adoption of more sustainable manufacturing processes
  - Design to easy disassemble and separate materials

Rodríguez, N.B., Formentini, G., Favi, C., Marconi, M., 2021. Environmental implication of personal protection equipment in the pandemic era: LCA comparison of face masks typologies. Procedia CIRP 98, 306-311.

Polymers Present in Medical PPEs

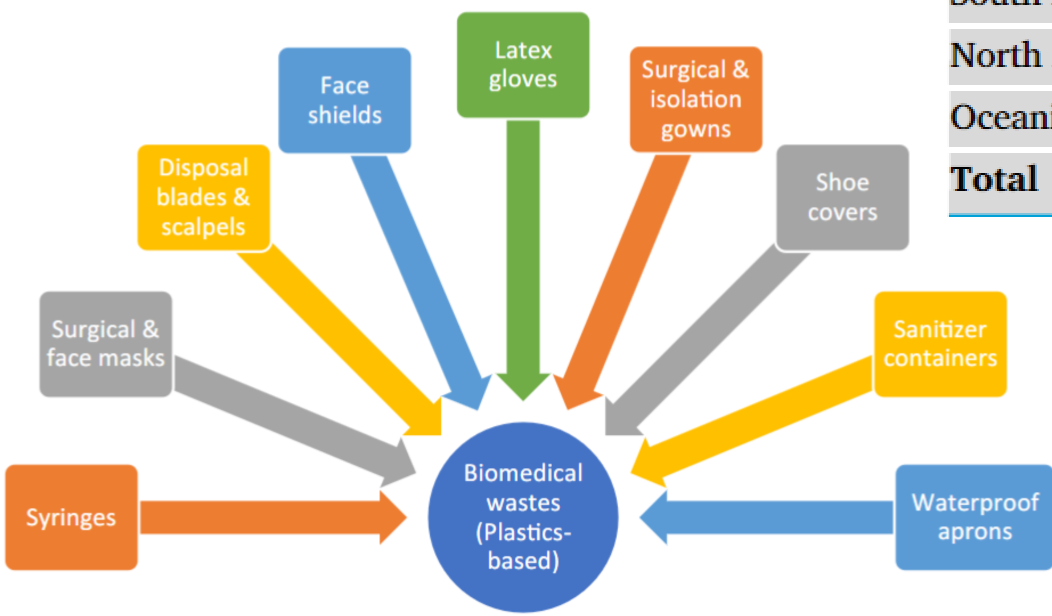


Abhilash, Inamdar, I., 2022. Recycling of plastic wastes generated from COVID-19: A comprehensive illustration of type and properties of plastics with remedial options. Science of The Total Environment 838, 155895.

Impact of COVID-19 on Plastic Waste Footprint

Most of healthcare waste are made of plastic materials

Types of plastic based biomedical waste from COVID-19

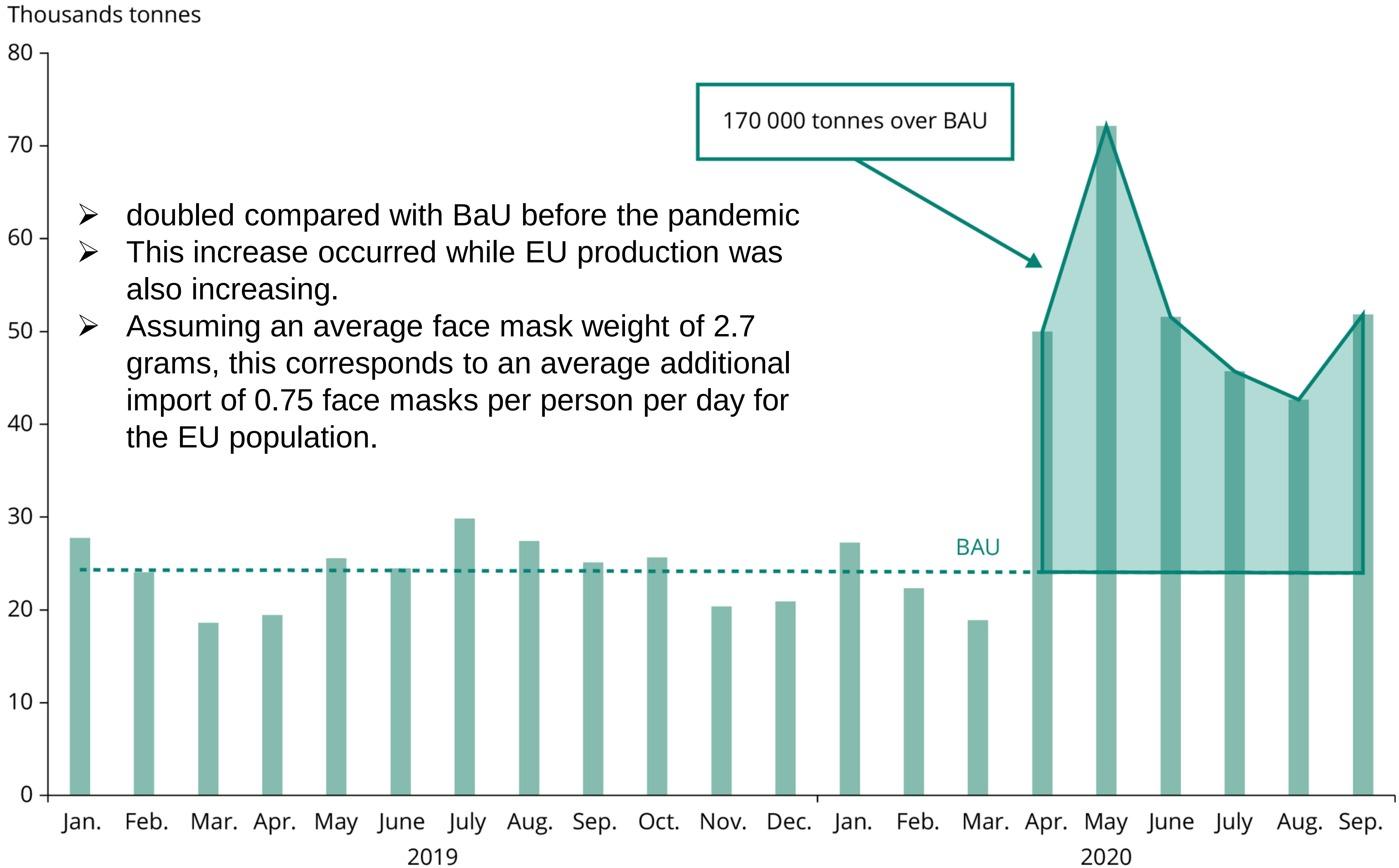


Region	Estimated daily facemask disposed	Estimated plastic waste generated per day (Tonnes)
Africa	411,814,854	275,465
Asia	1,875,181,681	953,641
Europe	445,022,934	153,623
South America	380,414,703	134,373
North America	244,335,150	75,795
Oceania	21,682,379	8,769
Total	**3,378,451,702**	**1,601,666**

Estimated plastic waste generation by region as a result of COVID-19

Benson, N. U., Bassey, D. E., Palanisami, T., 2021. COVID pollution: impact of COVID-19 pandemic on global plastic waste footprint. Heliyon, 7(2), e06343.

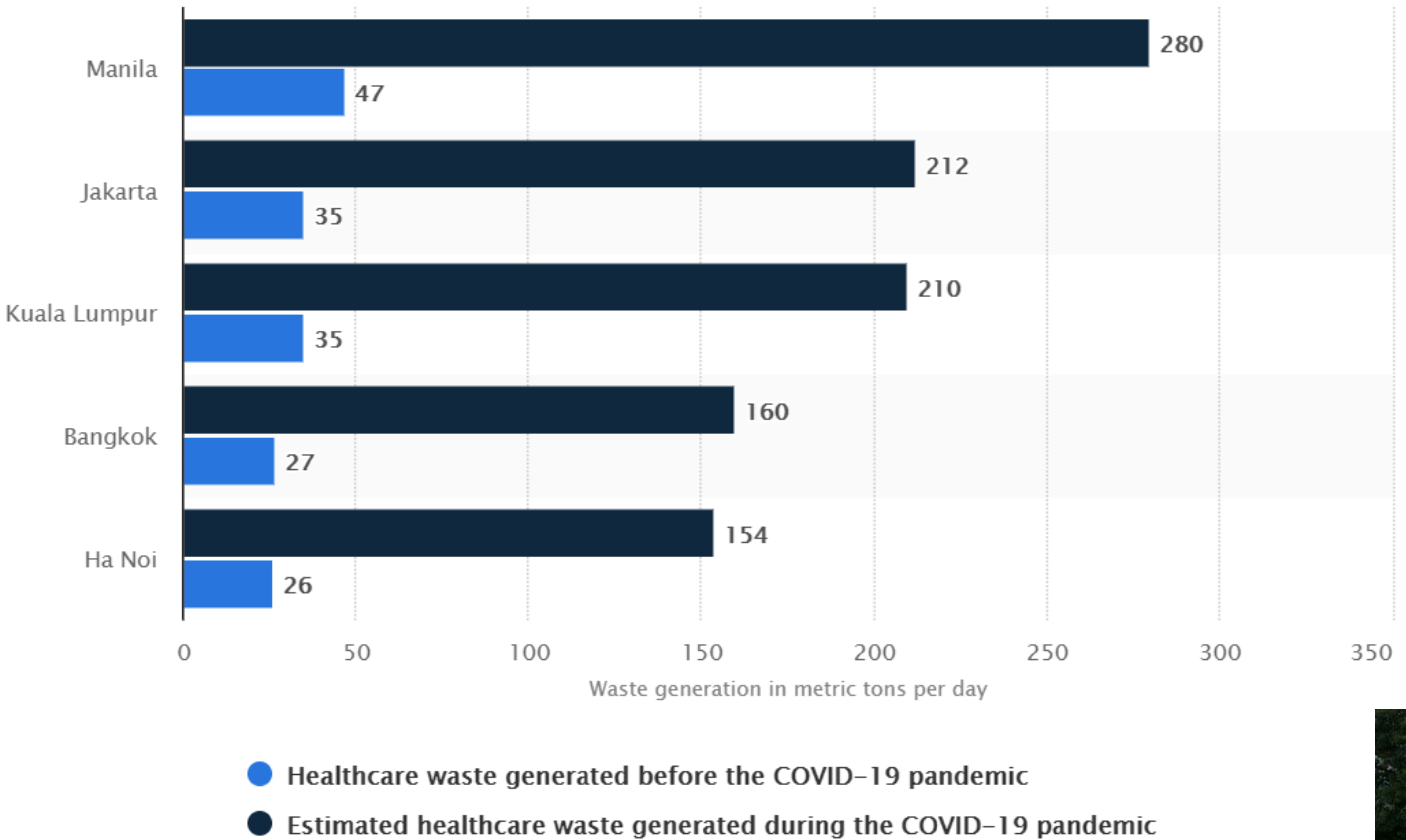
Face Mask Imports to EU-27 from Rest of the World



- doubled compared with BaU before the pandemic
- This increase occurred while EU production was also increasing.
- Assuming an average face mask weight of 2.7 grams, this corresponds to an average additional import of 0.75 face masks per person per day for the EU population.

https://www.eea.europa.eu/publications/impacts-of-covid-19-on

Estimated Healthcare Waste



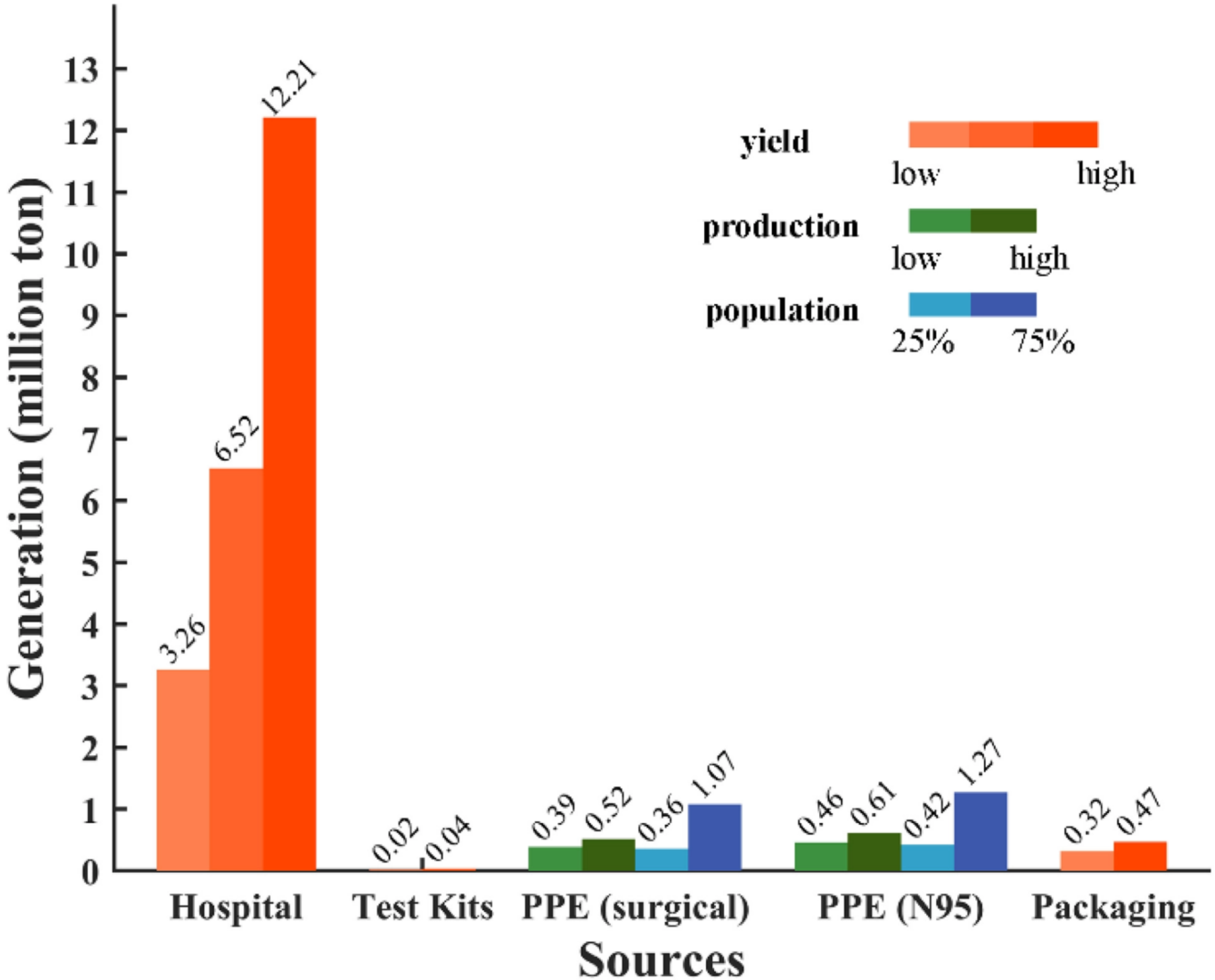
A whopping increase of 370 % in Hubei, China and 350 % in Catalonia, Spain.

Over 35% of medical waste was not treated properly in Brazil.

Pictures from open-source internet

<www.statista.com/statistics/1167512/healthcare-waste-generation-before-during-covid-19-asia-by-city/>

Global Generation of Mismanaged Plastics Attributable to Covid-19



Peng, Y., Wu, P., Schartup, A. T., Zhang, Y. (2021). Plastic waste release caused by COVID-19 and its fate in the global ocean. Proceedings of the National Academy of Sciences, 118(47), e2111530118

Vaccine Solid Waste

Waste Type	Safe & Compliant Disposal Guidance	Energy Required/ Potential Energy Recovered
Syringes	Used syringes shall be captured in sharps containers and disposed of as RMW.	• Pyrolysis = 239 kWh/t and 9.9 kg/t of diesel • Chemical Disinfection = 420 kWh/t • Steam Sterilisation = 775 kWh/t and 48.1 kg/t of diesel • Incineration = 0.4-8.4 kg/t • Autoclave = 13.3 kWh/ month = ~0.44 kWh/t Potential recovered energy = ~ 41.3 MJ/kg
Vaccine Packaging	Can be disposed of as RMW. Follow manufacturer's instructions (e.g. returning)	
Empty Vials	All vial waste to be captured in sharps containers to mitigate potential diversion and illicit intent. Once placed in a sharps container, the container should be managed as RMW.	
Full or Partial Vials	Once placed in a sharps container, these items should be managed as RMW or as NHPW.	
Other Medical Waste	Gloves, gauze, cotton balls, bandages, and the like should not be placed in SDS. Either the regular waste or if potentially infectious material, disposed of as RMW.	
Leftover Vaccine	Local autoclaving/incineration (most common approach)	
Dry ice	Please refer to CDC guidance for the disposal of dry ice.	0.14 kWh/kg

Klemeš, J. J., Jiang, P., Fan, Y. V., Bokhari, A., Wang, X. C., 2021. COVID-19 pandemics Stage II–Energy and environmental impacts of vaccination. Renewable and Sustainable Energy Reviews, 150, 111400.




Pictures from open-source internet

Plastic Waste Related to COVID-19

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Renewable and Sustainable Energy Reviews

Volume 127, July 2020, 109883

Minimising the present and future plastic waste, energy and environmental footprints related to COVID-19

Jiří Jaromír Klemeš [a], Yee Van Fan [a], Raymond R. Tan [b], Peng Jiang [c]

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https://doi.org/10.1016/j.rser.2020.109883

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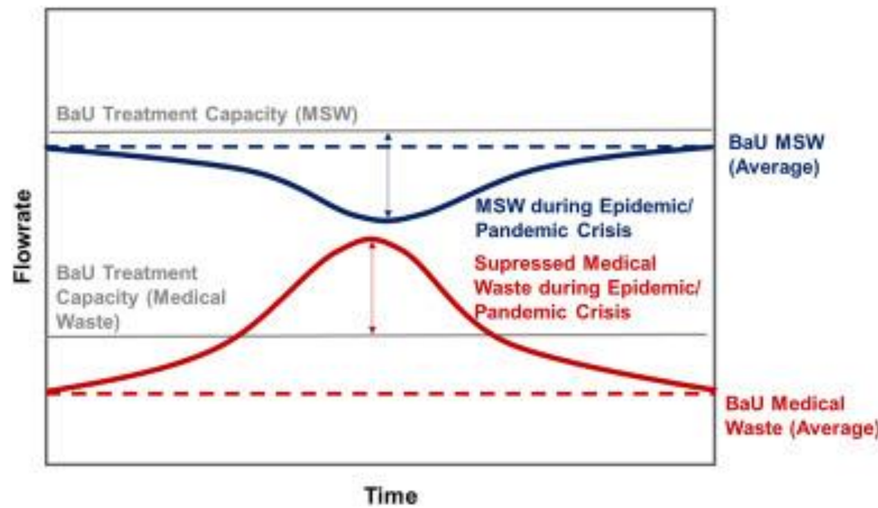
Highlights

- Expert insight for dealing with COVID-19 plastic use and waste.
- Minimising plastic waste during and after the pandemic.
- Introduction and benefits of Plastic Waste Footprint.
- Considering and reducing Environmental, including GHG, Footprints.



Klemeš, J. J., Fan, Y. V., Tan, R. R., Jiang, P., 2020. Minimising the present and future plastic waste, energy and environmental footprints related to COVID-19. Renewable and Sustainable Energy Reviews, 127, 109883.

Energy and Environmental Footprint - PPE

Energy
Volume 211, 15 November 2020, 118701

The energy and environmental footprints of COVID-19 fighting measures – PPE, disinfection, supply chains

Jiří Jaromír Klemeš [a], Yee Van Fan [a], Peng Jiang [b]

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https://doi.org/10.1016/j.energy.2020.118701

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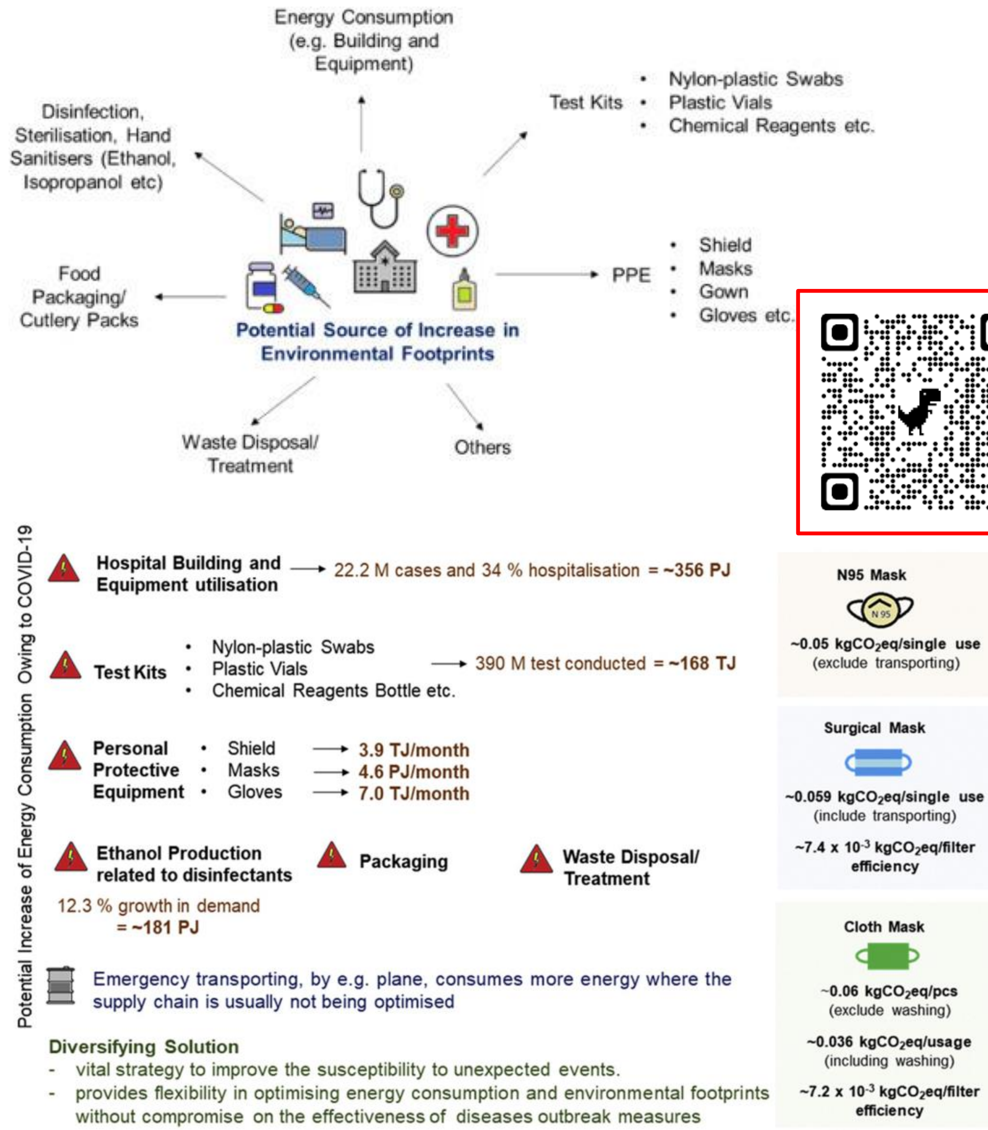
Highlights

- COVID-19 pandemic impacts on energy structure, energy requirements and related emissions.
- Overview of the invested energy sources and environmental footprints increased.
- Required energy and resources consumption of Personal Protection Equipment (PPE) and testing kits.
- An assessment of intensive energy consumption for aseptic and disinfection.
- The outcomes emphasised that diversifying solutions are a vital strategy needed.



Klemeš, J. J., Fan, Y.V., Jiang, P., 2020. The energy and environmental footprints of COVID-19 fighting measures–PPE, disinfection, supply chains. Energy, 211, 118701.

Influence of COVID 19 on Waste Management

ELSEVIER

Science of The Total Environment

Volume 754, 1 February 2021, 142014

An update of COVID-19 influence on waste management

Yee Van Fan [a], Peng Jiang [b], Milan Hemzal [a], Jiří Jaromír Klemeš [a]

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https://doi.org/10.1016/j.scitotenv.2020.142014

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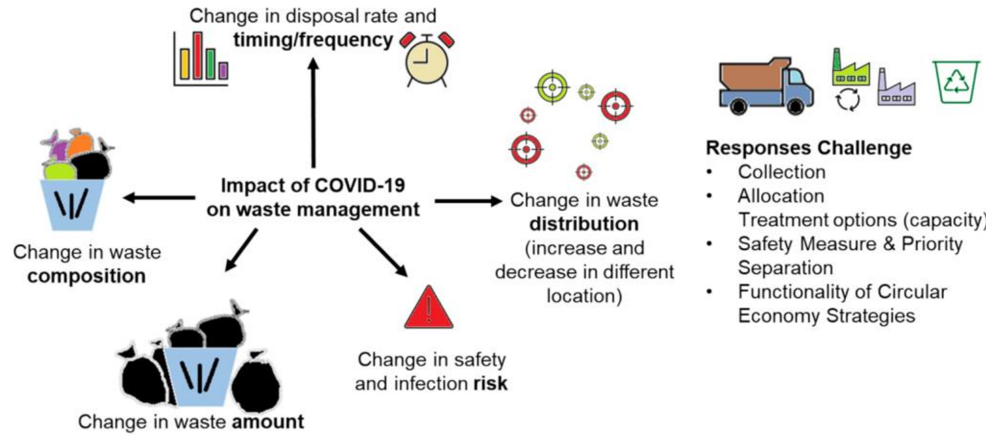
Highlights

- The influence of COVID-19 on waste management is summarised.
- Manual sorting and recycling are restricted due to the potential risk of infection.
- Shanghai shows a 23% reduction in MSW and 3% increase in Singapore.
- Brno demonstrates 1% increase for MSW from household and small business, 40% decrease for business and industrial.
- The impacts of COVID-19 can be diverse depending on the geographical and sociological factors.

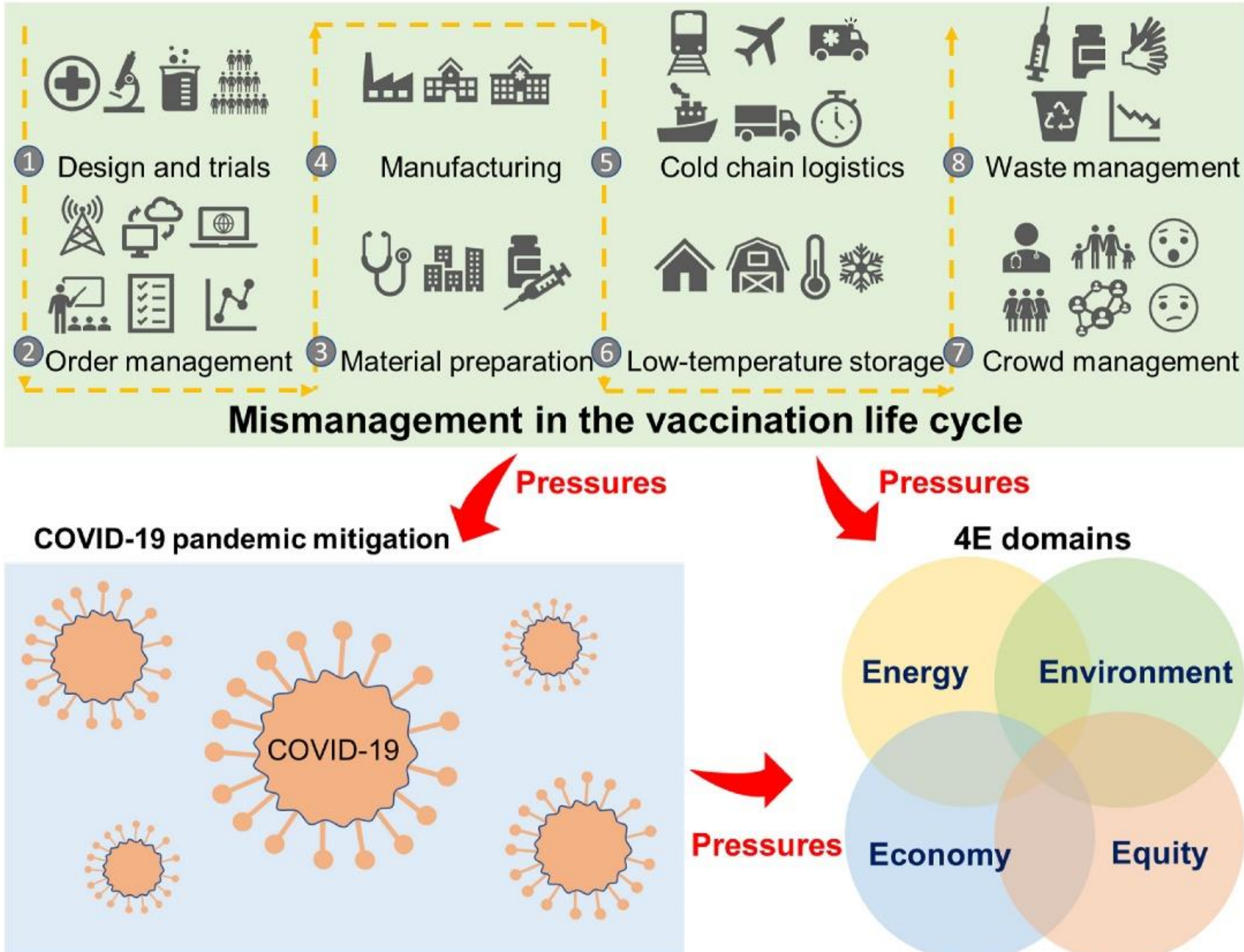


Municipal Solid Waste (MSW) during and before the influence of COVID-19

- Singapore: 3 % increased
- Shanghai 23 % reduced
- Brno: 1 % increased (ZEVO SAKO - household and small business), 40 % decrease (Kaiser servis, Brno - business and industrial)

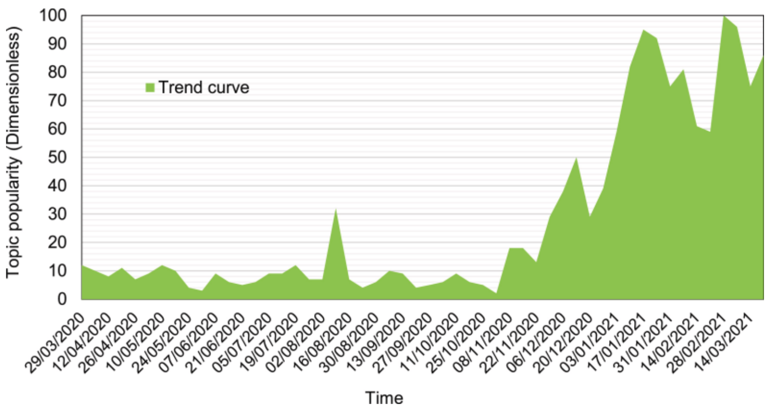
Fan, Y. V., Jiang, P., Hemzal, M., Klemeš, J. J., 2021. An update of COVID-19 influence on waste management. Science of the Total Environment, 754, 142014.

4E Pressures of Vaccination

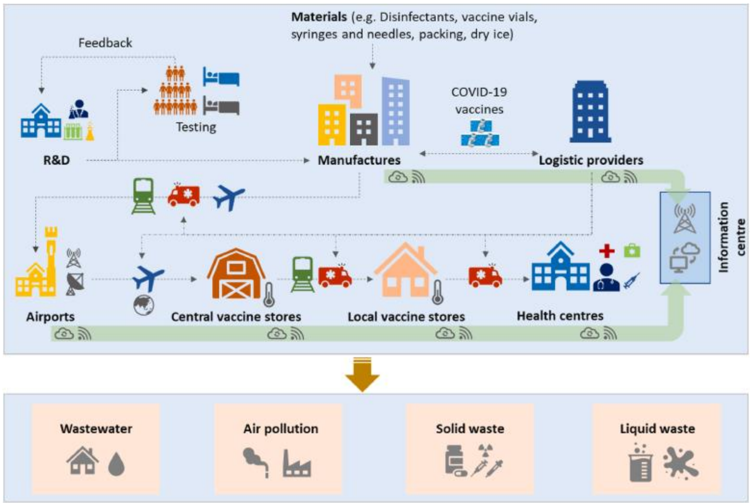


Jiang, P., Klemeš, J. J., Fan, Y. V., Fu, X., Tan, R. R., You, S., Foley, A. M. (2021). Energy, environmental, economic and social equity (4E) pressures of COVID-19 vaccination mismanagement: A global perspective. Energy, 235, 121315.

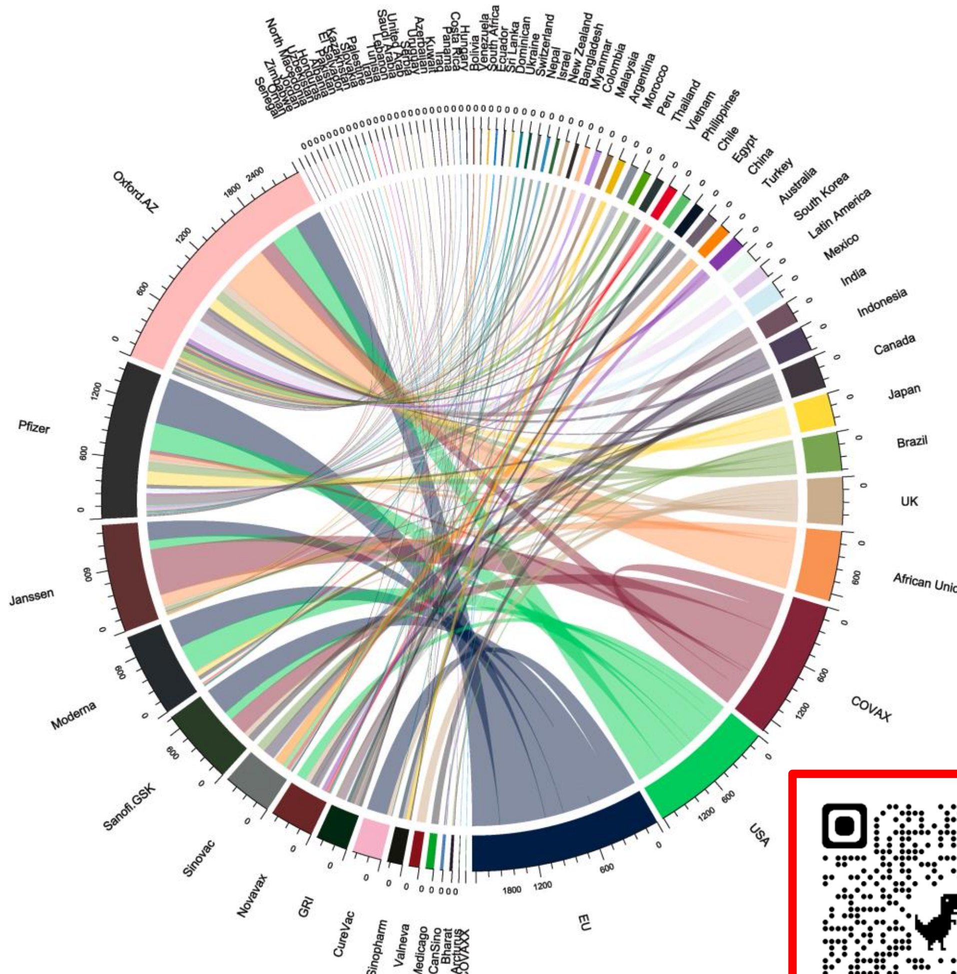
Energy and Environmental Impacts of Vaccination



The trend of “vaccine for COVID-19” over time.



The diagram of a vaccination process



Global flows of COVID-19 vaccines

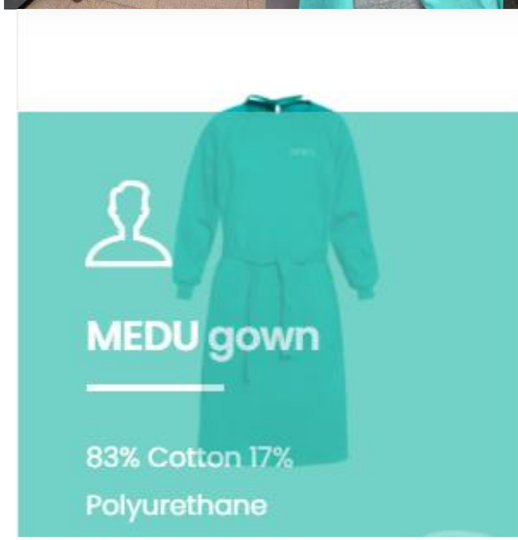
Klemeš, J. J., Jiang, P., Fan, Y. V., Bokhari, A., Wang, X. C., 2021. COVID-19 pandemics Stage II–Energy and environmental impacts of vaccination. Renewable and Sustainable Energy Reviews, 150, 111400.

New Opportunities and Emerging Developments

1. Spread out of distance meeting and learning
2. Massive home office
3. The growing popularity of e-shopping
4. Raise in e-socialising
5. Related to this intensifying the data transmissions as 5G and even starting 6G
6. Urban and sanitary reforms
7. Remote and robotic health monitoring and even treatment
8. Related preference to shortening the commuting
9. Intelligent traffic control, strengthening to favour self-driving autonomous vehicles
10. Advanced digital manufacturing. Advanced and possible person-less waste management collection and treatment.
11. Applications of novel ways for deliveries
12. Promotion of renewable energy
13. Setting up a post-COVID-19 supply chain
14. Industrial Internet of Things (IIoT)

Innovation – Reusable PPE Suit

- MEDU Gown
- Embedded with QR technology
- 50 wears (machine wash/chlorine friendly)
- Second life after 50 wears: Return for disinfect and converts into cotton scrubs and bags for packaging its products
- Could slash hospital PPE spending by 90 %



https://meduprotection.com/
https://news.trust.org/item/20210726093612-t7ghr/

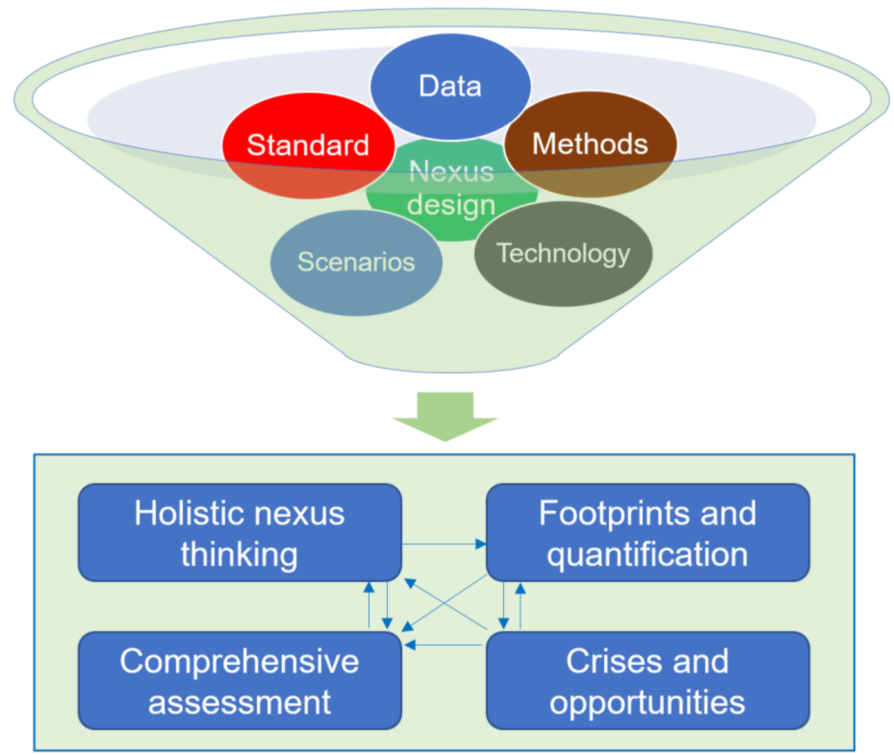
Innovation – Masks into Bricks

- Melt down hospital gowns, masks, hairnets, tray wraps and ward curtains into plastic bricks
- Used to manufacture anything from school chairs to 3D printer filament and yarn for clothing
- 300°C, killing COVID-19 and other pathogen
- 6,500 kg of CO_2 emissions are saved for every 10,000 kg of material processed
- Takes what's designated as a single-use product and actually turns it into a multi-use product

https://news.trust.org/item/20210726093612-t7ghr/
https://www.tcgsolutions.co.uk/

Nexus Thinking to Address Challenges

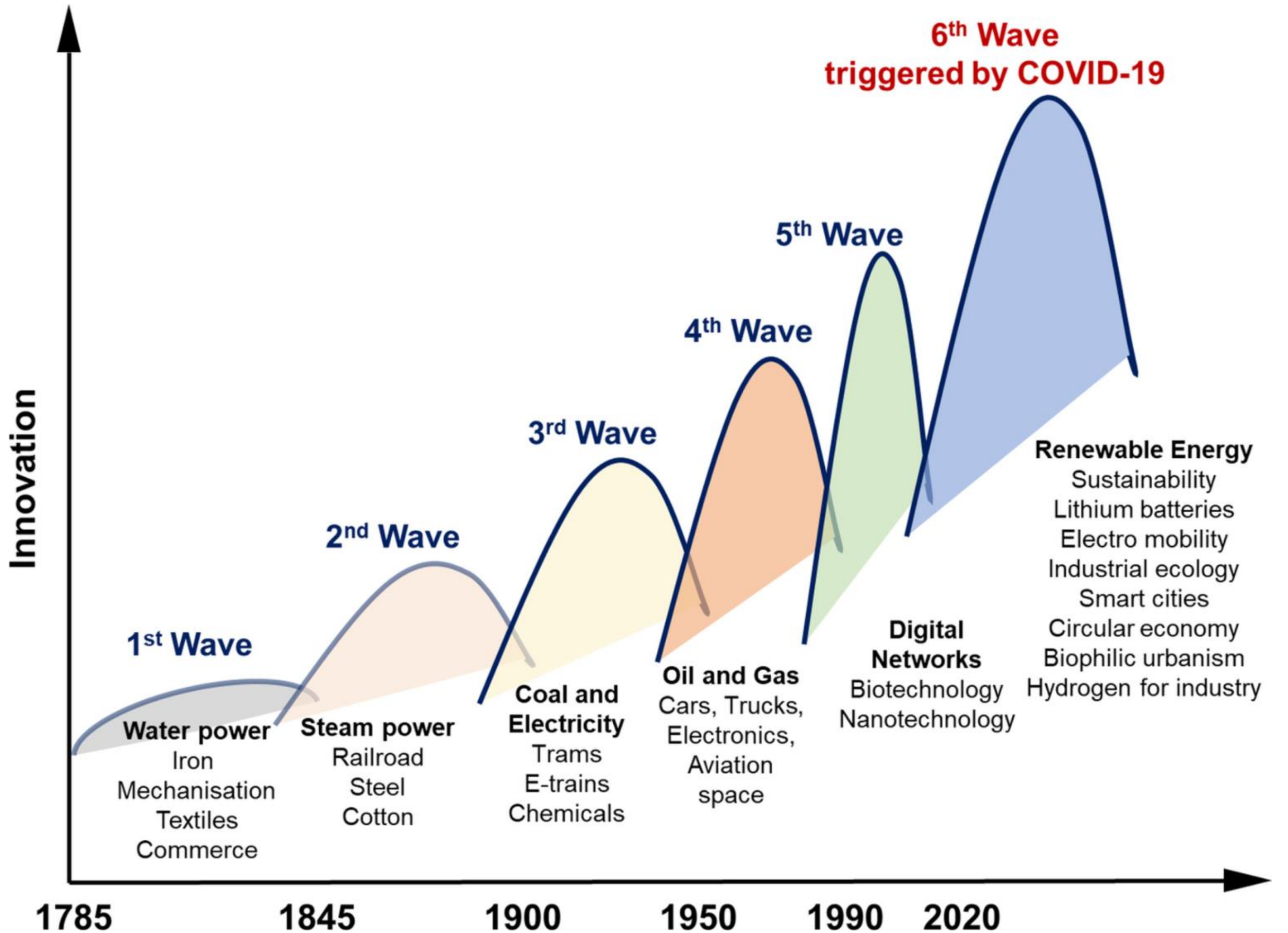
Linking WE-extended nexus, CE and SDGs



Water-energy extended nexuses framework for future development and application towards SGDs.

Wang, X. C., Jiang, P., Yang, L., Fan, Y.V., Klemeš, J. J., Wang, Y., 2021. Extended water-energy nexus contribution to environmentally-related sustainable development goals. Renewable and Sustainable Energy Reviews, 150, 111485.

Waves of Innovation



Klemeš, J. J., Fan, Y.V., Jiang, P., 2020. COVID-19 pandemic facilitating energy transition opportunities. International Journal of Energy Research. DOI:10.1002/er.6007

Conclusions

- COVID -19 Pandemic created **world-wide crisis**
- It has **severe impac**t in many fields
- It brought a **need for investing in PPE and medical resources**
- However, **pandemic initiated** and facilitated a new innovation step: **creative destruction**.
- After major crisis follow **strong growth**
- This has to be exploited for **promoting the innovations**
- The **high-tech business and science should lead** the innovations into the right direction
- Utilising **social media resources** and platforms – **waste reduction**

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