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PROGRESS TOWARDS THE RESOURCE REVOLUTION

Christian Ludwig and Sonia Valdivia (Eds.)

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Foreword

Since their first edition in 2009 World Resources Forum (WRF) conferences have served as a global platform for scientific exchange and helped to advancing international agendas by building on sound science contributions from the participants published in WRF conferences scientific reports.

During the WRF 2017 conference, about 150 scientific presentations were part of the program which generated interesting and lively discussions. Highest-quality contributions went through an international peer review process supported by the WRF Scientific Committee which concluded with the selection of 26 papers. An exclusive subchapter on sustainable resources management containing six contributions from the private sector complements this book.

Based on the key outputs of the WRF 2017 conference and the work performed during and after the review process in 2018 we are proud to announce this book entitled '*Progress Towards the Resource Revolution*' which presents innovations and approaches that support solutions required by the Paris Agreement on Climate Change as well as the Sustainable Development Goals (SDGs). In line with the international developments, the focus of this book is set on:

- Policy, governance, and education for sustainable development
- Methods, indicators, and design for resource efficiency and sufficiency
- Water and regional aspects
- Metals, minerals, and materials
- Sustainable resource management with personal views and insights from the private sector

Policy conditions provide the umbrella for discussing the transition to circular economy and set the tone of the discussions towards the resource revolution. This includes roadmaps and incentives at regional and international levels. Assessments, metrics used, solutions and communication approaches are also broadly exposed through various national and international cases.

Along the policies and tools described the focus is given to climate change as well as on sustainable energy, resources and materials, food and water management related topics. Contributions on secondary resources management such as waste electrical and electronic equipment (WEEE) stand out in this book which offer opportunities for generating value and job creation but also poses huge risks if mismanaged as this is the case in the least developed regions of the world. The book further highlights work related to mobility which has growing influence on our lifestyles and great potential to reduce impacts on climate change.

Looking forward, this book demonstrates numerous examples from different countries around the world of increasing resource efficiency in various areas, impact categories and value chains and provides recommendations for mitigating climate change (Paris Agreement and SDG 13), making cities more sustainable (SDG 11), improving the accessibility of clean energy (SDG 7) and industrial innovation and infrastructure (SDG 9), making consumption and production more sustainable (SDG 12), and protecting marine environment (SDG 14) and land (SDG 15) environments.

We would like to thank the Scientific Committee for their valuable support at the WRF 2017 Conference and for the review of selected contributions. Our special thanks go also to Dr. Cecilia Matasci and Jordan Prieto who provided professional technical assistance during the development of this book.

We wish you an inspiring reading that reaffirms your commitment to protect the planet and to make this a better world.

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Villigen PSI and St. Gallen, Switzerland, January 2019

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Part I

Policy, Governance, and Education for Sustainable Development

1. Raw Materials and Sustainable Development Goals: the EU Policy Contribution

Lucia Mancini ✉, Serenella Sala, Dominic Wittmer, David Pennington

Abstract

Many of the Sustainable Development Goals (SDGs) set by the United Nations for 2030 (UN General Assembly 2015) could not be reached without the contribution of raw materials. Raw materials are fuelling the manufacturing sector and creating jobs and value added along the supply chains. At the same time, the provision of raw materials can generate negative environmental and social impacts, constraining the achievement of other development goals.

At European level, policy initiatives dedicated to raw materials have focused both on resource availability and efficiency issues (EC 2011), but also on security of supply concerns (EC 2008) and circular economy (EC 2015). Moreover, a regulation has been issued on the responsible sourcing of minerals from conflict affected areas (EU 2017). For combining efforts in this field, the stakeholder platform Raw Materials European Innovation Partnership (RM EIP) was created in order to spur innovation and research in the field (EC 2012).

In order to support the EU raw materials policy, the European Commission (EC) Joint Research Centre (JRC) is developing the EC Raw Materials Information System[1] and issued the 2016 Raw Materials Scoreboard (EC 2016).

This paper investigates the links between raw materials sectors and the SDGs, based on an in-depth analysis of the literature (on social impacts of the mining sector) and the result of the RM EIP monitoring 2016 (EC 2017). Challenges for the sustainability of the mining sector regards, in particular, health and safety for workers and local communities and land use conflicts. Results also show that the highest potential of the raw materials policy in terms of contribution to the SDGs concerns the goals on economic growth (8), innovation (9) and peace (16). Additional indirect contributions of the RM sectors to other goals (e.g. green energy, zero hunger and good health) are also highlighted.

Keywords: Sustainable Development Goals, Raw Materials, EU Policy.

Introduction

Strategically important for the competitiveness of the industrial sector and essential for populations' wellbeing and economic development, raw materials are at the basis of societies. Many of the Sustainable Development Goals (SDGs) set by the United Nations for 2030 (UN General Assembly 2015) could not be reached without the contribution of raw materials, that are fuelling the manufacturing sector and creating jobs and value added along the supply chains. At the same time, the provision of raw materials can generate negative environmental and social impacts, constraining the achievement of other development goals (like, e.g. climate action, good health, clean water).

This twofold role in human societies, joined to the resource scarcity concerns driven by increasing world population and security of supply considerations, have amplified the policy relevance of raw materials in the last decades. At European level, policy initiatives dedicated to natural resources have focused both on resource availability, scarcity and efficiency issues (EC 2011) but also on security of supply concerns, through the Raw Materials Initiative (RMI) (EC 2008) and circular economy (EC 2015). The European Innovation Partnership on Raw Materials (RM EIP) is a stakeholder platform that brings together representatives from industry,

[1] http://rmis.jrc.ec.europa.eu/

public services, academia and NGOs. Its mission is to provide high-level guidance to the EC, EU Member States and private actors on innovative approaches to the challenges related to RM.

From a trade perspective, the import of minerals from conflict-affected areas is an issue of concern for policy and downstream operators trying to sustain legitimate trade. Recent policy initiatives have tackled the challenge of conflict-free sourcing of Tin, Tungsten, Tantalum and Gold both in US with the Dodd-Frank Act (US Congress 2010) and in the EU with the Conflict Minerals Regulation (EU 2017).

In order to support the EU policy on RM, JRC is developing the EC Raw Materials Information System (RMIS), which is a European reference web-based knowledge platform for non-energy, non-agricultural materials from primary and secondary sources. The RMIS includes information on trade, social and environmental considerations. This is complemented by the biennual Raw Materials Scoreboard (EC 2016), presenting a wide overview of considerations related to raw materials, including, e.g., the environmental and social sustainability, trade, conflict minerals, material flows and circular economy (EC 2016). The Scoreboard's purpose is to provide quantitative data on the EIP's general objectives and on the raw materials policy context.

The potential contribution of the mining sector in the SDG achievement has been discussed in a report by the Columbia Center on Sustainable Investment, Word Economic Forum and United Nations (CCSI et al. 2016). The report shows how mining companies could integrate into core business actions and objectives that contribute to the achievement of SDG.

The objective of the paper is to investigate the main challenges and potentials of RM sectors with respect to the achievement of the SDGs. The methodology followed in this paper uses two different approaches:

- An analysis of the literature on the social impacts of the mining sector, which results in a list of typical positive and negative impacts of the sector.
- An analysis of the contribution of the RM EIP's activities to the SDGs, through the monitoring of EIP Commitments, addressing the UN SDGs. These commitments are joint undertakings by several partners, who commit themselves to carrying out activities that contribute to the EIP's actions and targets.

Methodology

The literature review performed in this study aimed at having a representative sample of studies from the literature, describing the most frequent social impacts occurring in the mining sectors. The search was conducted through both the generalist web research engines, and the academic interdisciplinary databases Scopus and Google Scholar. The key words used in the search were "social impacts mining" in the timeframe 2000-2017. In order to gather sustainability issues in a broader sense, we complemented this with thematic searches, in which other keywords were added to the original anchor title: econom*, employment, environment*, health, safety, human rights, land use, demograph*, migration. From the results, we selected the most cited studies. The aim was not to comprehensively cover the literature in the field, but to obtain a list of most common social impacts characterizing the activities of the sector. Subsequently, we matched the SDGs with the impacts detected in literature.

Concerning the analysis of the RM EIP, the Annual Monitoring Report provides an overview on the state-of-play of the Commitments, based on indicators that measure the commitment's inputs and outputs (EC 2017). The data used come from the information provided during the Calls for Commitments and from the annual monitoring surveys, which are mandatory for active commitments.

Results

Literature review

From the literature review we gathered a list of 28 social impacts characterizing the mining industry, concerning the following six thematic areas: Economy, income and security; Employment and education; Land use and territorial aspects; Demography; Environment, health and safety; Human rights.

Table 1-1 matches some of these impacts with corresponding SDGs. The second column of the table includes the potential direct and indirect contribution (both positive and negative) of the RM sectors to the SDG, identified by the authors. For instance, indirect contributions of the RM sectors concern the "zero hunger" goal (through the provision of fertilizers); the "good health" goal (through the provision of materials used in medical devices) and the "clean energy" goal (through materials used in low-carbon energy technologies).

Moreover, the table shows the EU policies on RM contributing to each goal. The most addressed goals are those on "decent work and economic growth"; "affordable and clean energy"; "industry, innovation and infrastructure"; "sustainable production and consumption"; "peace, justice and strong institutions".

The results of the literature review highlight that the main challenges for the social sustainability of the sectors concern the health and safety of workers and local communities (often deriving from environmental impacts and competition for resource use) and land use competition.

UN Sustainable Development Goals	**Direct and indirect contribution (both positive or negative) of the RM industries to the SDG (examples – non-exaustive list)**	**Correspondent impacts detected in literature on social impacts of mining**	**EU policies related to RM**
1. No poverty	Taxes from mining revenues	Contribution to local income; increase in export and GDP; poverty alleviation	
	Employment creation	Creation of employment (direct and indirect to community and national economy)	
2. Zero hunger	Fertilizers production		
	Land competition	Limited access to land and consequent impact on livelihood, food insecurity, and loss of protected areas	
3. Good health and well-being	Negative health effects for workers and local mining communities	Negative health and safety impacts in mining communities; social impacts linked to boom-bust cycles	
	Materials in medical devices		
4. Quality education	Employees skills and education	Employees skills development and further education	
5. Gender equality	Equal opportunities for women; ensuring gender parity	Unequal opportunities and discrimination (e.g. gender based)	
6. Clean water and sanitation	Pollution of water bodies	Environmental impacts affecting social conditions and health	
	Water use competition	Reduced water supplies or water contamination, competition with other uses (e.g. agriculture) and increased water scarcity	
	Provision of sanitation and water supplies	Improved access to health and education	

7. Affordable and clean energy	Supply of metals used in low carbon energy technologies		List of Critical Raw Materials (COM(2017) 490 final)
8. Decent work and economic growth	Contribution to economic growth and employment	Contribution local income; Increase in export and GDP Business and employment opportunities in other sectors due to revitalized economy and markets	Raw Materials Initiative (COM(2008) 699 final) European Innovation Partnership on Raw Materials (COM(2012) 082 final) Action Plan for a competitive and sustainable steel industry in Europe (COM/2013/0407 final)
	Poor working conditions	Poor working conditions and low wages; heath impacts for workers, fatalities and work related accidents	
	Child and forced labour	Child labour, forced and compulsory labour	
9. Industry, innovation and infrastructure	Provision of inputs for manufacturing industries and services	Improved infrastructures (telecommunications, road network, power and water supplies)	European Innovation Partnership on Raw Materials (COM(2012) 082 final)
10. Reduce inequalities	Inclusion of stakeholders and marginalized communities	Lack of stakeholder inclusion and non- involvement of indigenous communities; Lack of informed consensus and social acceptability Unequal opportunities and discrimination	
11. Sustainable cities and communities	Provision of materials for the construction sector		
12. Responsible consumption and production	Material stewardship		The EU Action Plan for Circular Economy (COM(2015) 614 final) European Innovation Partnership on Raw Materials (COM(2012) 082 final)
13. Climate action	Emissions to air due to operations	Environmental impacts affecting social conditions and health	
	Supply of metals used in low carbon technologies		
14. Life below water	Water contamination	Environmental impacts affecting social conditions and health	
15. Life on land	Land competition with other uses (including protected areas)	Expropriation, population displacement and resettlement; forceful acquisition of land. Limited access to land and consequent impact on livelihood, food insecurity, and loss of protected areas	

16. Peace, justice and strong institutions	Conflict minerals	Conflicts and social tensions due to the inequitable distribution of benefits and costs with communities or to limited access to resources; Conflicts between companies and illegal miners; politically motivated killings of anti-mining activists	EU Conflict Minerals Regulation (2017/821)
	Illegal trade of raw materials (e.g. timber)		EU Timber Regulation (2010/995)
17. Partnership for the goals	Transparency on resource's revenues		

Table 1-1: *Raw Materials and SDGs: mapping the links between SDGs, raw materials sectors, mining and EU policies.*

EIP commitments

Figure 1-1 shows, for each of the 17 SDG, how many individual Commitments address the related targets, providing an indication about the contribution of the RM sector to the UN SDG. First, more than 200 linkages were identified by the respondents of the survey. While all SDGs are addressed by at least three Commitments, almost half of the linkages (49%) are concentrated on three SDGs (SDG8, SDG9, SDG12) outstanding from the remainders. SDG12 is addressed by almost two out of three respondents (65%) (EC 2017). Within the three dominating SDGs, the following observations are made:

- SDG12 Ensure sustainable consumption and production patterns: the key addressed targets relate to the sustainable management of natural resources, waste reduction and environmentally sound management of chemicals and wastes.
- SDG8 Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all: increasing economic productivity and improve resource efficiency.
- SDG9 Industry, innovation and infrastructure: enhancing the scientific research and technological capabilities.

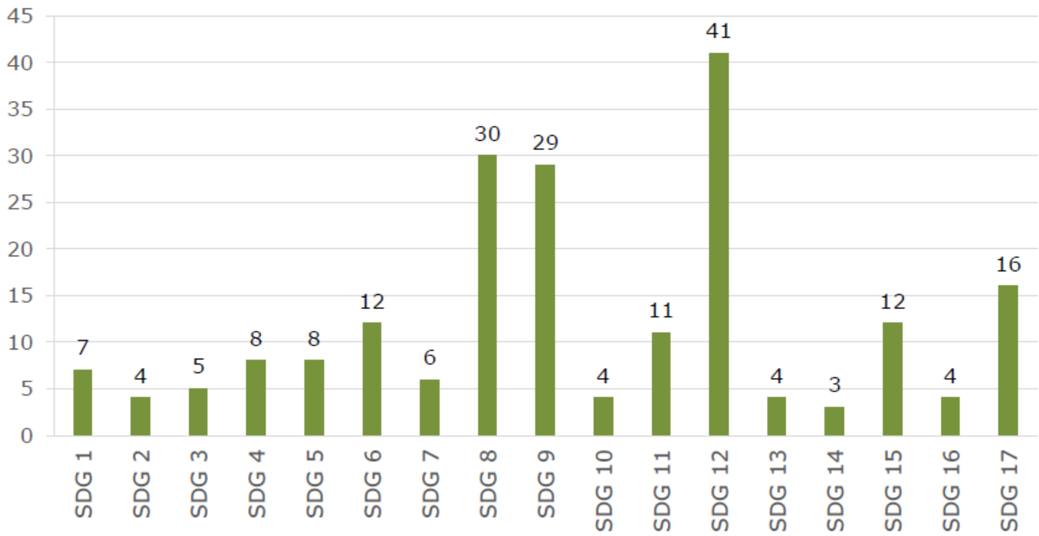

Figure 1-1: *EIP Commitments addressing the UN Sustainable Development Goals.*

Conclusions

The literature review performed in this study resulted in a list of 28 social impacts, grouped in six impact categories, characterizing the mining sector. Even though not comprehensive, this list of impacts is assumed to be representative of the literature on the topic. This list has been compared against the Sustainable Development Goals scheme, in order to identify the contribution of the RM sectors to the UN initiative. In this study, we also pinpointed some examples of positive and negative contribution of the RM sectors to the Goals (both directly and indirectly). From the literature review the main potential and challenges faced by the mining sector in terms of sustainability emerged.

The contribution of the EU RM policies to address the SDG was also analysed by matching them with the Goals they are supposed to contribute. This was complemented by the results of the annual monitoring of the RM EIP Commitments. The results of our analysis show that the EU RM policy is prominently contributing to Goal 8 on “decent work and economic growth”; Goal 9 on “industry, innovation and infrastructure”; Goal 12 on “responsible consumption and production”; Goal 16 on “peace, justice and strong institutions”, for what concerns the Conflict Minerals Regulation.

2. The Role of Research and Innovation for the Transition to a Circular Economy in Europe. Evidence from the Community Innovation Survey 2014

Jesús Alquézar Sabadie ✉, Claire Kwiatkowski

Abstract

The signature of international commitments such as the Sustainable Development Goals (SDGs) and the COP21 Paris Agreement in 2015 demonstrates a current favourable policy context to address environmental issues. These engagements have been endorsed by the European Union (EU) which also launched complementary strategies such as the one on Circular Economy. Doing so, the EU promotes a transition towards a sustainable, low carbon and circular economy where innovation plays a key role.

To monitor progress towards such models, the paper proposes an analysis of the 2014 edition of Eurostat's Community Innovation Survey (CIS) and more precisely its module on "innovations with environmental benefits". The dataset allows to understand the performance of companies in eco-innovation and to identify the factors leading to innovation with environmental benefits.

The CIS data shows that environmental concerns are becoming a significant component of innovation *at large* in enterprises' strategies. It also demonstrates that a significant number of European firms (almost 25%) have introduced new products, processes, marketing or organisational innovations with environmental benefits between 2012 and 2014.The main factors leading to such eco-innovations include enterprise's reputation, reducing costs of inputs, and environmental regulation, while surprisingly a factor like market demand is not statistically significant.

The paper defends that circular models generate an environmental, economic and social value for companies and the entire society. But it also suggests that enterprises are followers in the transition towards a sustainable economy, the process being led by other actors like public authorities and an active part of the civil society.

Despite some caveats, the CIS' microeconomic data allow identifying the most efficient policy instruments to promote the transition towards a sustainable, circular and low-carbon economy and society.

Keywords: Sustainability, Circular Economy, Eco-innovation, Community Innovation Survey.

Introduction

In the last years, environmental and climate change issues are at the top of international and European political agendas. The year 2015 was marked by two very important international commitments: the Sustainable Development Goals (SDGs) and the COP21[2] Paris Agreement. The European Union (EU) played a crucial role in their negotiation and has endorsed them. The EU commits to mainstream SDGs into EU policies and initiatives[3] and to encourage the transition towards a low-carbon, resource-efficient economy – which is seen as an opportunity for growth and jobs[4].

The EU's engagement with the SDGs and the COP21 is consistent with other strategies launched at almost the same time. This is the case of the "Circular Economy Action Plan"

[2] 21st Conference of the Parties of the Convention on Climate Change.

[3] European Commission Communication "Next Steps for a Sustainable European Future", COM(2016)739 final.

[4] European Commission Communication "The Road from Paris", COM(2016)110 final.

which aims is to push businesses and consumers to make the transition to a more circular model where resources are used, re-used and recycled in a sustainable way, producing benefits for both environment and the economy[5].

Those international and European strategies raise the importance of innovation as a pre-requisite for the transition towards a greener economy and society. They also include or announce monitoring systems, mainly based on indicators. In this prospect, one element to be analysed is eco-innovation, which provides solutions to environmental issues and is key to achieve the desired transition. This paper analyses data from the Eurostat's Community Innovation Survey (CIS), and more specifically its module on "innovation with environmental benefits" (here generically called "eco-innovation") published in 2008 and 2014.

The CIS provides harmonised data on enterprises' innovation activities and results by sector, size of company, type of innovation and the various stages of the innovation process: objectives, sources of information, investments, public funding, etc. Its eco-innovation module provides tailored information on business activities and performance in this specific area, allowing a sound understanding of drivers and barriers to innovation with environmental benefits.

Results of the analysis of the CIS data

Eco-innovation as an integrated component of innovation

Table 2-1 shows that the percentage of companies having introduced innovations with environmental benefits has significantly decreased between 2008 and 2014. This challenging trend appears in all countries where data are available. It may be explained by the decline in cleantech investments which peaked globally and in Europe in 2012 after been constantly increasing since early 2000s[6].

CIS edition	No. of respondents of the whole CIS (N) and No. of respondents of the eco-innovation module (N_{eco})	Firms that have introduced at least one innovation with environmental benefits (ECOTOT)	Countries covered by the eco-innovation module
2008	N= 168,875 N_{eco}= 121,395	41,211 33.9%	20: BG, CY, *CZ*, DE, EE, *ES*, FI, FR, HU, *IE*, IT, LT, LU, LV, MT, *NL*, PT, RO, SE, SK
2014	N=154,221 N_{eco}= 112,923	26,070 23.1%	18: BG, CY, DE, EE, *EL*, FI, FR, *HR*, HU, IT, LT, LU, LV, MT, PT, RO, SE, SK

***Note**: In italic, countries that are not included in both surveys.*

***Table 2-1:** Enterprises having introduced at least one innovation with environmental benefits, CIS 2008 and 2014.*

These figures (and trend) may look disappointing, but they are not negligible. Between 2012 and 2014, almost one quarter (23.1%) of enterprises introduced eco-innovations while 44.8% of European firms declared having introduced at least one innovation *at large*. This comparison shows that innovation with environmental benefits represents a high proportion of all innovation

[5] European Commission Communication "Closing the loop – An EU Action Plan for the Circular Economy", COM(2015)614 final.

[6] See the figure on Cleantech investment in main world regions (2000-2015) in https://ec.europa.eu/environment/ecoap/indicators/inputs_en. Original source: Cleantech.com

activities and demonstrates that environmental concerns are already integrated in innovation strategies of a significant number of European firms.

Benefits of eco-innovation

The main purposes of enterprises when introducing an innovation with environmental benefits are reducing energy use or CO_2 footprint (59.7%), recycling waste or water for own use or sale (47.8%), and reducing pollution (45.4%) as well as material or water use (43.5%). Those benefits apply within the companies, not to the end-users. Surprisingly, replacing fossil fuel energy by renewables does not appear as a widespread solution to address environmental issues (and their costs) within the companies surveyed (18.8%)[7].

Instead, benefits for end-users are generally considered as secondary objectives of eco-innovation, with the exception of those aiming at reducing energy use or CO_2 footprint (45.2%). Actions like extending products' end of life or facilitating recycling after sale are mentioned by almost one-third of companies, which still remains a significant proportion.

Those figures demonstrate a gradual transformation of business strategies towards circular models. They also demonstrate that the main objective of firms when they introduce eco-innovations is not only environmental but also economic. The purpose of reducing energy, materials or water use, or recycling for own use or sale, allows to save production costs generating higher profits. Eco-innovation is not only about limiting pollution, but also a solution to business problems like the cost of energy or raw materials.

Drivers of eco-innovation

Figure 2-1 shows that the main eco-innovation driver is to improve enterprise's reputation. In contrast, the current or expected market demand is only evoked by 28.5% of eco-innovative enterprises. This paradox indicates that firms do not perceive strong market signals to implement greener innovations. They see eco-innovation more as an opportunity to communicate on their environmental responsibility and improve their image. Reputation is a highly relevant component of business strategic management as it can be translated into a comparative advantage. Environment is becoming a strong social value for companies' stakeholders (investors, clients, etc.) and it is consequently used by firms as a marketing argument to attract investment or to benefit from customers' preferences.

The high cost of energy, water or materials appears as the second main motivation of eco-innovation (38.9%), closely followed by existing environmental regulations (38.5%). These data show that eco-innovations are also introduced to reduce internal costs and to comply with environmental regulations, the former confirming the Porter hypothesis (Porter 1991, Porter and van der Linde 1995, Ambec 2011).

Government grants, subsidies and other financial incentives for environmental innovations (20.2%) and public procurement requirements (20.8%) are instead the less quoted factors driving eco-innovation. The latter could be explained by the facts that the green public procurement market in Europe is still relatively small (CEPS and College of Europe 2012) and not all enterprises deal with public markets.

[7] An hypothesis to explain this finding could be the (perceived) costs of renewable energy investments during the CIS 2014 reference period (2012-2014). The costs of renewable energy are decreasing very fast, but they still require investments, difficult to achieve in such a period. Confirming this hypothesis goes beyond the scope of this analysis.

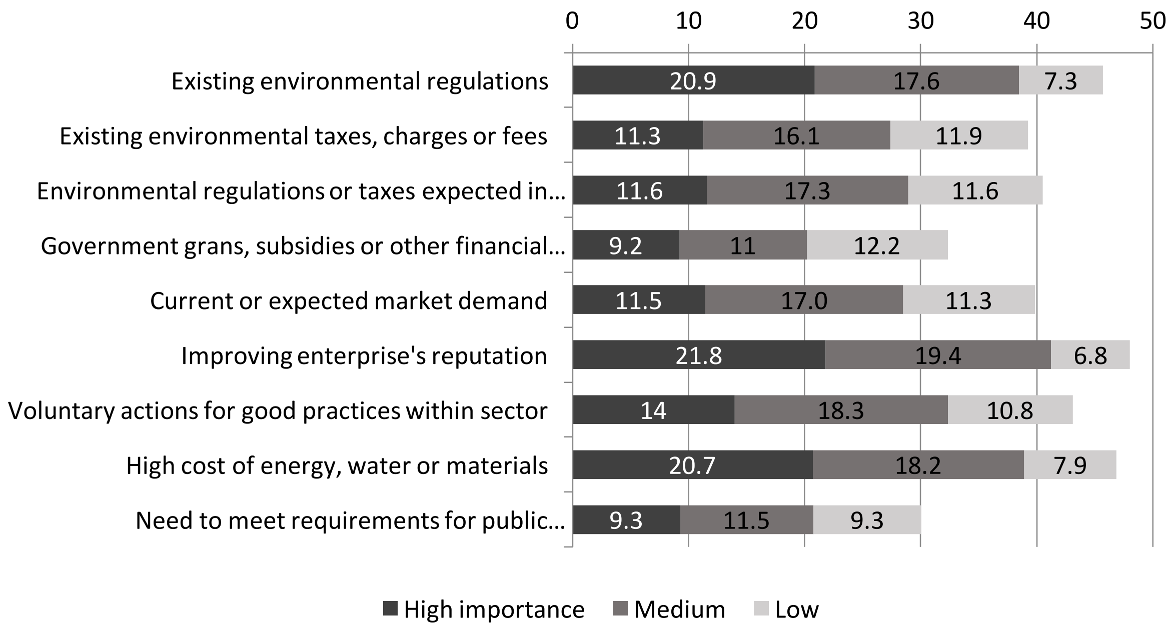

Figure 2-1: *During 2012 to 2014, how important were the following factors in driving your enterprise's decisions to introduce innovations with environmental benefits?; source: CIS 2014.*

Existing environmental taxation is also surprisingly not considered as a relevant factor. It could be explained by the fact that environmental taxation is very specific and punctual. Instead, regulations or taxes expected in the future are quoted slightly more frequently (28.9%), meaning that companies are starting to anticipate future trends and to integrate them in their strategic management.

Environmental procedures in place in companies

Enterprises with procedures in place to regularly identify and reduce environmental impacts such as environmental audits or ISO certification are significantly more eco-innovative than those without (43.2% and 13.5% respectively). Those procedures invite companies to integrate environmental issues in their strategic management allowing a better evaluation of the associated risks and opportunities as well as the design of appropriate solutions. The CIS data shows that corporate procedures stimulate eco-innovation.

Multivariate analysis

This descriptive analysis needs to be completed by a multivariate model. The authors propose a logistic regression where the dependent variable is the binomial ECOTOT, i.e. enterprises that have introduced at least one sort of innovation with environmental benefits (value 1) against those not having done so (value 0). The logit model informs about which variables have a statistically significant effect on ECOTOT, while holding other predictors constant. We can observe differences in the findings from the bivariate and the multivariate analysis.

The results of the logistic regression show that the statistically significant factors leading to innovation with environmental benefits are:

- Environmental regulation,
- Grants, subsidies or financial incentives for environmental innovation,
- Enterprise's reputation,
- Sectoral voluntary actions or initiatives for good practices,
- Cost of energy, water or materials,

- The number of tertiary education employees of the company, and the fact of having applied for patents. These indicators can be considered as proxies of the knowledge and innovation capacities of the firm.
- The country of the firm. This is not surprising, since some Member States have a more favorable context and conditions for (eco-)innovation than others.

Instead, other indicators about innovation inputs and outputs of enterprises, such as their expenditure and capacities in R&D, their newly exploited products and processes or the funding they have actually received for innovation *at large*, are not statistically significant. Innovation with environmental benefits looks a very particular kind of innovation, with its own specific logic. For instance, grants, subsidies or financial incentives are significant factors when addressing specifically environmental innovation, while European, national or sub-national schemes for innovation in general are not. This finding confirms empirical literature that indicates that the determinants of eco-innovation differ from those of other innovation activities. In particular, the impact of regulation and cost savings is more important for innovations with environmental benefits (Horbach et al. 2011).

The importance of enterprise's reputation contrasts with the fact that the variable "demand for environmental innovations" is not significant statistically. This confirms that European companies do not perceive a strong market push for eco-innovations yet, but they observe social pressures to be considered "green" or socially/environmentally responsible. This paradox can lead to both positive (increasing attention for environment in business strategies) and negative ("greenwashing"; Lyon 2015, Watson 2016) consequences.

Neither current taxation, nor expected future regulations and taxes are statistically significant determinants of innovation with environmental benefits. The former may be due to the relatively small importance of environmental taxation in European countries: only 6.3% of all total revenues from taxes and social contributions, excluding imputed social contributions, or 2.4% of the GDP, in 2015[8].

These findings correspond to the aggregation of all countries that provide data from the CIS 2014's eco-innovation module. The fact that the variable "country" is statistically significant indicates that there are relevant differences between Member States

Conclusions

Policy makers consider that innovation is a critical factor to ensure the transition towards a sustainable, low-carbon and circular economy and society. The current political context, favorable to sustainability, coincides with increasing citizens' awareness about climate and environmental issues (Schauber 2017), which leads to preferences towards green growth. There are positive social signals, like the growing demand for well-being activities and life-styles, such as health, education and training, "bio" goods and services, or recycling and other climate and resource-related actions (Pérez et al. 2016). Citizens also prefer greener infrastructures and lifestyles in cities and consider that natural features lead to better quality of life – as demonstrated by Eurobarometer surveys[9].

The CIS 2014 allows to understand how those trends affect eco-innovation. The survey shows the determinants of eco-innovation in companies. This information is useful to identify the most efficient combination of instruments and actions ("policy-mix") to promote the transition towards a circular economy and society. The analysis provides some interesting conclusions. First, it shows that innovation with environmental benefits represents a relatively high proportion of all innovation activities, showing that environmental concerns are already integrated in the innovation strategies of a significant number of European firms. This integration process is just starting and it is fragile: the percentage of companies having

[8] Source: Eurostat (env_ac_tax).

[9] Special Eurobarometer EB 444.

introduced innovations with environmental benefits has decreased between 2008 and 2014 – in line with the negative trend in cleantech investments since 2012.

Secondly, environmental regulations, reduction of internal costs and enterprise's reputation are amongst the most significant determinants of eco-innovation. The case of regulation has been object of a large literature on the empirical demonstration of the Porter Hypothesis. Since the 1970s, Europe has developed an environmental legislation considered amongst most advanced in the world. Although its implementation is considered still insufficient in different areas and/or in different parts of the EU[10], it has an impact on companies' decisions to introduce eco-innovations.

Surprisingly, enterprises do not perceive a significant market demand for eco-innovations, but they are very concerned about their "green reputation". European firms feel social and political pressures to *look* green and to appear as socially and environmentally responsible. This paradox can lead to both positive (increasing attention for environment in business strategies) and less positive ("greenwashing") consequences.

The CIS 2014 indicates that, currently, EU enterprises are hardly leading the transition towards a circular economy. They are followers of a process led by an active part of the civil society and supported by public authorities. However, companies that have introduced eco-innovations generate an environmental value (e.g. less pollution), but also – and especially – an economic return derived from cost savings. This becomes a motivation to introduce innovations with environmental benefits, creating a virtuous circle of practices where environmental, social and economic values work in synergy and allow companies to perceive environment as a business opportunity.

The paper suggests that some policy instruments are more effective than others to promote a circular economy. "Soft" instruments clearly linked to companies' reputation such as eco-labels look efficient measures to integrate sustainability in enterprises' strategies. Clear and transparent information on the sustainability of products empowers consumers and therefore push enterprises to implement solutions with environmental benefits – including for end users, now often neglected. Procedures in place to reduce environmental impacts influence also positively eco-innovations.

The public administration has still a key role to play to promote eco-innovation, being pro-active, taking risks and creating markets (Mazzucato 2013), through the exploitation of a consistent combination of "hard" and "soft" instruments, such as enforced regulation, eco-labels or research and innovation funding focused specifically on the circular economy.

Disclaimer:

This paper is based on data from Eurostat's Community Innovation Survey, editions 2008 and 2014. It reflects the views only of the authors; neither the European Commission nor any person acting on behalf of the Commission is responsible for the use which might be made of the following information. The responsibility for all conclusions drawn from the data lies entirely with the authors.

Acknowledgments:

The authors would like to thank Geneviève Villette (Eurostat) for her valuable support, as well as the different persons who read, reviewed and commented the paper.

[10] European Commission Communication "Delivering the benefits of EU environmental policies through a regular Environmental Implementation Review", COM (2016)316 final, quoting IMPEL (2015).

3. Analysis of Resource Productivity and Decoupling in Nepal and Bangladesh

Bishal Baniya ✉, Scott Kelly, Damien Giurco

Abstract

Developing Asian countries such as Nepal and Bangladesh have been doing well in recent years in terms of achieving improved economic growth and environmental performance. This study makes an inventory of historical data on energy and material use/intensities, GDP, and CO_2 intensity to analyse the changes in environmental and economic efficiency using Data Envelopment Analysis (DEA) in a time-varying context. In the last 25 years, the Gross Domestic Product (GDP) has increased by almost seven-fold for Nepal and nine-fold for Bangladesh, and whilst the absolute amount of energy and material use have substantially increased, energy and material intensity has fallen by almost 30 per cent for Nepal and 10 per cent for Bangladesh. The research analysis indicates the rate of increase of GDP is much higher than the rise in CO_2 intensity per energy use, as there have been efforts to achieve technical efficiency by setting favorable policy instruments, and because of changing levels of activity in contributing economic sectors. If the progress made recently can continue, particularly regarding energy and material intensity improvements, there is further potential to reduce resource use and CO_2 emissions with similar or higher GDP growth.

Keywords: Resource Productivity, Decoupling, Policies, Climate Resilience, Economic Sectors.

Introduction

Like many regions around the world, economic growth in South Asia is progressing, mostly led by India's significant growth rate. The average Gross Domestic Product (GDP) growth rate of South Asia is 7.4% per year, while that of whole world is 2.7% as of 2015. To date, the economic progress has demanded additional use of resources and associated emissions in South Asia. There has been a similar trend for Bangladesh and Nepal; however, the growth rate is much lower than that of India. The economic growth is characterised by a rapid expansion in industrialisation, construction, urbanisation, and population growth. In future, further increased resource use and CO_2 emissions can be expected if recent growth trends continue. In 2015, the annual GDP growth rate for Bangladesh was 6.6% and that of Nepal was 2.7%. Nepal's GDP growth rate was 5.9% in 2014 until the massive earthquake in early 2015 triggered a severe economic downturn, but it is likely to improve as the recovery progresses. In the last 25 years, GDP has increased by almost seven-fold for Nepal to 21 bn USD in 2015 and nine-fold for Bangladesh to 195bn USD (WB 2017). Whilst the absolute figures of energy and material use has substantially increased, energy intensity has fallen by 30 per cent for Nepal and 10 per cent for Bangladesh respectively. Similar reductions have been achieved for material intensity. In the same period, the absolute CO_2 emissions have increased by almost fourteen-fold for Nepal and five-fold for Bangladesh even though the population has risen by only 55 per cent, however, the CO_2 intensity per energy use have increased by about six-fold for Nepal and doubled for Bangladesh. This suggests that the economic progress in these countries is contributing to the massive share of growth in energy and material use and CO_2 emissions, but the rate of growth of energy and material use/intensities and CO_2 intensity per energy use is less than the growth of GDP in last 25 years, and particularly in last decade (WB 2017). Therefore, it appears that they are being able to do relative decoupling of resource use and CO_2 emissions from economic growth, but the question is how did it happen and what were the contributing factors?

Methodology

This study investigates the dynamic relationship between capital and labor productivities, energy and material intensities, GDP and CO_2 intensity per energy use. The inter-relationships between these variables were investigated for the period 1990-2014 for Nepal and Bangladesh. A linear programming approach – Data Envelopment Analysis (DEA) was used to assess, analyze and compare the efficiencies of Decision Making Units (DMUs) that has multiple inputs and outputs. In context of this study, DMUs are the historical years for which environmental and economic efficiency scores were calculated by assigning optimal weights to all input and output variables.

Data and variables

Data on GDP, energy and material intensity and CO_2 intensity per energy use were collected mainly from the World Development Indicator (WDI) database and from the Asian Development Bank (ADB) database. Capital and Labour productivity data were mostly collected from Asian Productivity Organization (APO) annual data reports. For the years where data was not available in the database and in reports, missing data were interpolated. To estimate the relative efficiency through DEA, capital and labour productivities, energy and material intensities were used as inputs, and GDP and CO_2 intensity were used as outputs. Table 3-1 shows the descriptive statistics for input and output variables. Mean, standard deviation, minimum and maximum values of variables data from 1990 to 2014 are the estimates obtained from DEA estimator with variable return to scale model. In addition to data with relative metrics in Table 3-1, absolute resource use and emission data are shown in Table 3-2 for later discussion.

Nepal		**Mean**	**Std. Dev.**	**Minimum**	**Maximum**
Inputs	**Capital Productivity** (GDP per USD)	2.19	0.47	1.5	3.05
	Labour productivity (GDP (in thousand USD) per worker)	4.24	0.51	3.4	5.1
	Energy Intensity (MJ per USD)	72.22	16.7	50.7	100.7
	Material Intensity (kg per USD)	12.53	1.99	9.32	16.36
Outputs	**GDP** (billion USD)	8.79	5.68	3.4	19.82
	CO_2 intensity (ton per ton of oil eq. energy use)	0.35	0.13	0.11	0.68
Bangladesh		**Mean**	**Std. Dev.**	**Minimum**	**Maximum**
Inputs	**Capital Productivity** (GDP per USD)	1.97	0.43	1.35	2.74
	Labour productivity (GDP (in thousand USD) per worker)	5.06	1.22	3.5	7.4
	Energy Intensity (MJ per USD)	40.36	27.06	14.6	88.4
	Material Intensity (kg per USD)	9.45	4.55	4.21	16.26
Outputs	**GDP** (billion USD)	72.21	40.1	30.96	172.88
	CO_2 intensity (ton per ton of oil eq. energy use)	1.63	0.27	0.21	2.06

***Table 3-1**: Descriptive statistics for inputs and output variables.*

	Year	Energy use	Material use[11]	CO_2 emission	Labour force
		million tonnes of oil eq.	million tonnes	million tonnes	million
Nepal	**1990**	5.79	48.42	0.64	9.2
	2014	11.66	87	8	15.8
Bangladesh	**1990**	12.74	157.8	15.53	34.5
	2014	35.42	350	73.2	63.2

***Table 3-2**: Absolute amount of resource use, CO_2 emission and labour force.*

Selection of DEA model

This study used an applied empirical DEA model with output-oriented variable return to scale (VRS). The VRS assumption was developed by Banker et al. (1984) for a system that is not operating at an optimal scale. In this model, the DEA frontier is seeking to maximise desirable output (Coelli et al. 2005), in this case GDP. Below is the general VRS equation that has been developed further as per the scope of the study, and is shown by following equations to below.

$\text{Max}\ \theta_k = (u_{1y1k} + u_{2y2k} \dots \dots \dots + u_{sysk})/(v_{1x1k} + v_{2x2k} \dots \dots \dots + v_{mxmk})$
Subject to: $0 \leq (u_{1y1k} + u_{2y2k} \dots \dots \dots + u_{sysk})/(v_{1x1k} + v_{2x2k} \dots \dots \dots + v_{mxmk}) \leq 1$; (k=1,……,n)
$v_1, v_2, \dots \dots \dots, v_m \geq 0,\ u_1, u_2, \dots \dots \dots, u_s \geq 0$………..equation (1)

As the selected DEA model aims to identify years that appears in an envelopment surface against other comparable year, it assumes that outputs should be maximized. However, the selection of output variable for this study is such that an undesirable output, CO_2 intensity (ton per ton of oil equivalent of energy use), should be minimized. This situation of having simultaneous desirable and undesirable outputs was flagged by Koopmans (1951), and followed by Fare et al. (1989) who introduced a non-linear programming model to analyse the efficiency of DMUs with one undesirable output. Usually in the case of environmental and/or eco-efficiency evaluation of a production system where pollution and waste are generated along with the desirable output, this has been the preferred method. Seiford and Zhu (1998) has developed a DEA model that estimates the efficiency score of a production system by increasing the desirable outputs and reducing undesirable outputs. This study uses a similar model to estimate the environmental and economic efficiency score. Additionally, since the equation (1) above does not consider slacks[12] in the estimation of the efficiency score, this has been computed by using an output-oriented slack model as defined by Agarwal et al., 2011.

Results and discussion

Environmental and economic efficiency

The environmental efficiency scores of Nepal and Bangladesh from 1990-2014 are shown in Figure 3-1, and is computed using a DEA model with GDP as a desirable output and CO_2 intensity as an undesirable output. Similarly, the economic efficiency scores are shown in Figure 3-2. The score indicates that for any year, gains in GDP and slower rate of increase of CO_2 intensity have been achieved with relatively less energy and materials. The closer the value of the efficiency score to unity, more efficient is the country in terms of utilizing its resources such as energy and material, and minimizing CO_2 intensity. The efficiency score of unity (maximum score) denotes the most efficient year relative to other years under study. For both Nepal and Bangladesh, environmental efficiency has been gradually increasing since

[11] Data taken from Dittrich (2014): Global Material Flows Database. Available at www.materialflows.net. Material use data for 2014 is an estimated data from trendline of 1990 to 2010 data.

[12] Slack is the surplus input or output deficit of an inefficient system.

1990 and approached its maximum score after 2010. Until 2002, the environmental efficiency of Nepal was higher than that of Bangladesh, however since 2002, the environmental efficiency score for Bangladesh has dramatically risen to achieve its maximum score in 2011. One potential explanation for this is because Bangladesh started to adopt two-fold strategy for combating climate change, (i) mitigation and (ii) improving resilience (e.g. adaptation). Both strategies were implemented well before Nepal as policy makers felt the socio-economic gain achieved in last 30 years is jeopardised by present and future impacts of climate change (INDC 2015). Nepal achieved its maximum score in 2014.

A correlation between absolute energy use and CO_2 intensity shows the rate of increase of CO_2 intensity is higher than the rate of increase of energy use for Nepal, but the absolute value of CO_2 emission is much lower. This is exactly opposite for Bangladesh. This could be one reason as to why the environmental efficiency of Bangladesh is doing better than Nepal, particularly in recent years. Nepal's major energy source is biomass followed by fossil fuels. Almost 85 per cent[2] of total energy in Nepal is used for residential purposes, which is relatively less productive as a sector. For Bangladesh, almost 60 per cent[13] of total energy is used for non-residential purposes such as manufacturing, agriculture and service sectors. Energy for productive end uses (manufacturing, small-scale rural enterprises and agricultural production) and better energy intensity of Bangladesh could have contributed to a higher environmental efficiency.

The environmental efficiency score of Nepal was much higher than that of Bangladesh before 2003 because unlike Bangladesh where small and medium industries were thriving well before 2003, Nepal was generating GDP predominantly from the agriculture sector which is relatively less resource intensive. Figure 3-2 shows the change in economic efficiency. Here the efficiency score shows that the economic efficiency of Nepal was maximum initially which then decreased until 2003 and then started to increase again to reach maximum score at 2011. The efficiency score of Bangladesh was however minimum in the beginning and started to increase gradually to achieve maximum score at 2011. The efficiency score for both countries are high in later years which indicates that resource productivity has been enhanced in recent years.

The level of productivity and economic growth rate of Nepal is among the lowest in Asia. However, since 1990s, Nepal's economy has gradually grown and is moving towards becoming a remittance based economy, largely due to the remittance payments being made from emigrant workers located overseas. This sort of economy typically leads to decreased capital productivity – another reason why the economic efficiency started to show downward trend. The average economic growth rate of Nepal hovered around 4-6% throughout last decade because of internal political unrest that severely affected the small scale industries, but even amidst slow economic growth, the economic efficiency score has increased in recent years, largely due to improved labour productivity. Bangladesh on the other hand had satisfactory growth, and it was less affected by the global economic crisis. Bangladesh's economy performed far better after 2009/10. Labour and capital productivity figures frequently fluctuated, but maintained a steady progress in last decade.

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[13] International Energy Agency (IEA), Energy balance of Nepal and Bangladesh.

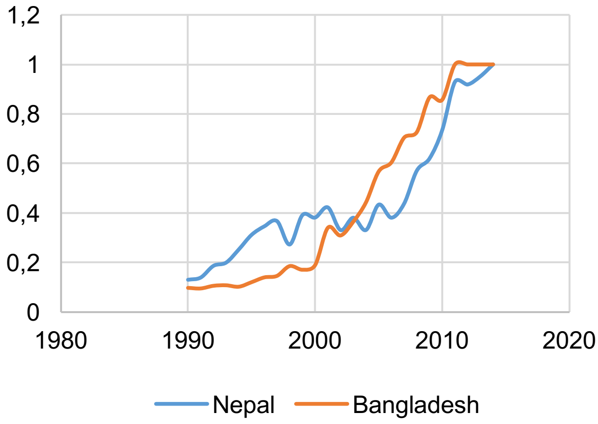

Figure 3-1: *Environmental Efficiency Score.*

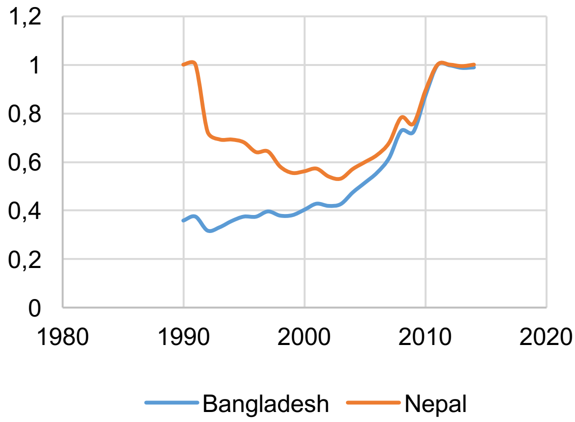

Figure 3-2: *Economic Efficiency Score.*

Relationship between GDP and energy/material intensities

Figure 3-3 and Figure 3-4 show the relationship between GDP and energy intensity, and GDP and material intensity respectively. Bangladesh has better utilized energy for economic output. In fact, the most efficient year of Bangladesh is three times better performing than that of Nepal. In terms of utilizing materials to produce GDP, again Bangladesh is doing far better than Nepal. The efficient year of Bangladesh is almost twice than that of Nepal, which means Bangladesh has almost doubled value out of material in comparison to Nepal. In addition, most of the years for Bangladesh have higher GDP value and lower intensity value relative to corresponding years of Nepal. This supports the fact that in most of the historical years, Bangladesh has done better than Nepal in terms of using materials and producing value out of it. The relationship between GDP and energy/material intensity shows both of these countries have managed steady economic growth through continuous reduction of energy and material. The GDP and energy/material intensities are far better in recent years in comparison to earlier years.

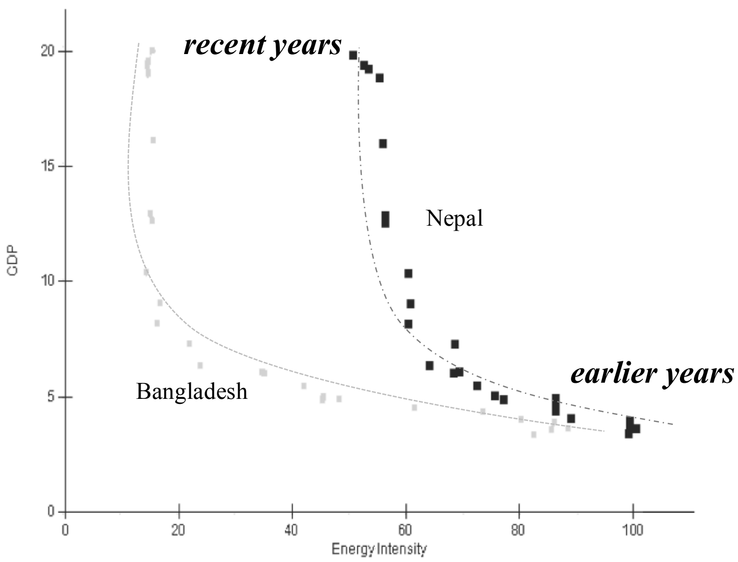

Figure 3-3: *GDP vs Energy Intensity.*

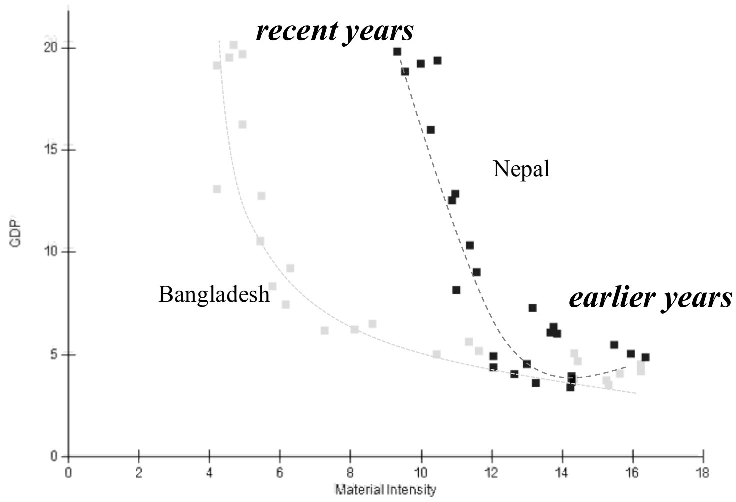

Figure 3-4: *GDP vs Material Intensity.*

The action of improving environmental efficiency by increasing the GDP whilst keeping total emissions constant would reduce the CO_2 intensity, however the country that uses energy sources like fossil fuels and biomass particularly for basic activities like livelihood and transport would still have to be subjected to CO_2 intensity associated with GDP output. Different authors using empirical research to investigate technical insights on the elements of eco-efficiency have simultaneously focused on environmental efficiency and economic efficiency, as the relationship between these two can underscore any trade-offs between economic growth and environmental impact (DeSimone and Pop off 2000). This has contributed in the development of sustainability related indicators useful to policy makers as these efficiencies are also linked with social data such as population, employment and labour.

UNEP (2015) infographic report shows a relationship between material footprint and material use for Bangladesh and Nepal. For both countries, material footprint is lower than the material use, which means some of the material use is a by-product of the export (UNEP 2015). Material footprint is 88% of material use for Bangladesh while that of Nepal is 68%. In Asia pacific region, most of the industrialised countries (Japan, NewZealand, Singapore, and Australia) have higher material footprint (>85%). Nepal and Bangladesh are both net importer of materials. Bangladesh accounts for almost 8 million tons of physical trade balance and Nepal accounts for 5 million tons (UNEP 2015). Almost half of the total material footprint comes from the manufacturing sector in each country. The manufacturing sector of Bangladesh contributes more to the GDP than that of Nepal, and given higher overall material footprint of Bangladesh, this could be one reason as to why Bangladesh is showing better progress in material efficiency in comparison to Nepal.

Historically in Nepal and Bangladesh, the concept of environmental sustainability, resource productivity and climate resilience came through international donor agencies and the programs and projects they implemented through Official Development Assistance (ODA). However as shown by Figure 3-5 the net ODA expressed in per cent of Gross National Income (GNI) has significantly decreased in both countries. This could potentially mean that the countries have started to take initiatives themselves through high level strategic planning/policy-making and implementing programs pertinent to sustainability. Additionally, the dynamics of contribution of various economic sectors has an impact on progress related to resource productivity and decoupling. Both Bangladesh and Nepal have now transitioned towards a service sector based economy. More than 50 per cent of GDP is now generated from service sector, which is relatively more resource efficient in comparison to agro and industry based economy.

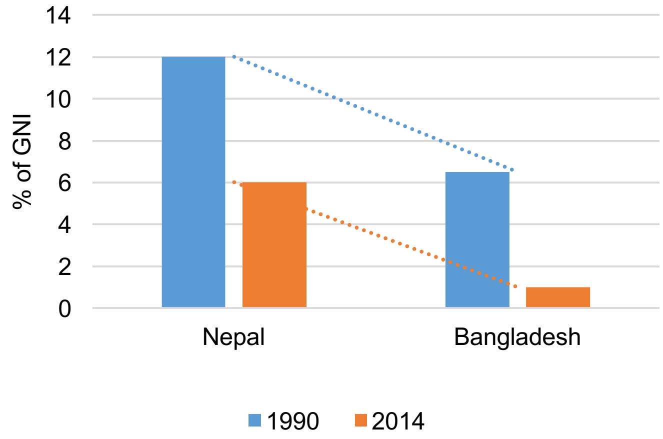

Figure 3-5: *Net official development assistance (% of GNI); source: The World Bank database.*

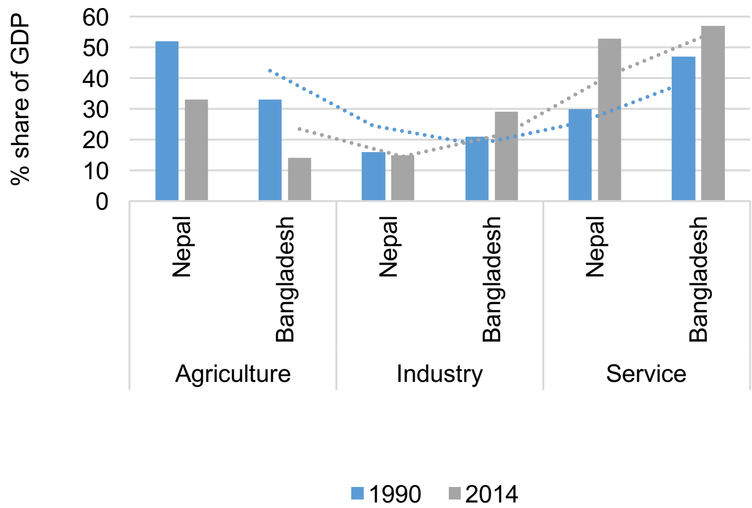

Figure 3-6: *Contribution of different economic sectors; source: The World Bank database.*

Slack analysis

Slack analysis of the years under study can help understand the extent of inefficiency aggregated for all historical years under consideration. In context of the study, slack can be defined as the deficient output produced with fixed inputs or an excess input with fixed outputs (Kortelainen and Kuosmanen 2005). Table 3-3 shows the values of slacks for each input and output variables. Bangladesh had more potential to reduce the value of inputs particularly the energy intensity. These values of slacks indicate that for every unit of energy intensity reduction for Bangladesh through efficiency improvement can add approximately 17 per cent to the GDP and 15 per cent of CO_2 intensity reduction. For Nepal, every unit of energy and material intensity reduction can add almost 25 per cent to GDP.

Slack Analysis						
	Capital productivity	Labor productivity	Energy Intensity	Material Intensity	GDP	CO_2 intensity
Nepal	0.01	0.3	4.07	3.98	1.32	0.04
Bangladesh	0.05	0.43	20.41	2.75	3.7	3.07

Table 3-3: *Slacks for input and output variables.*

Conclusions

Nepal and Bangladesh show they are on a pathway to achieve resource productivity and relative decoupling through strategies on reduction of resources/emissions and bolstering climate resilience. However, other non-technical factors such as the dynamics of various economic sectors and the change in their contribution to GDP has also helped enhance resource productivity and relative decoupling. Additionally, the domestic material consumption measured in terms of material footprint and change in the energy mix appear to have influenced material and energy intensity respectively. The progress on achieving relative decoupling is steady; however slack analysis shows further potential to achieve reduction of resource use and CO_2 emissions, but other social factors such as population growth rate and human development index needs to be considered.

Additionally, even with reduced foreign support – official development assistance – and being ranked as highly vulnerable countries pertinent to climate change, both of these countries have managed to improve environmental and economic efficiency scores. This indicates each country's ability and capability to achieve further relative decoupling of growth and environmental attributes in future.

Acknowledgements
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4. The Long View Exploring Product Lifetime Extension

C.A. Bakker , C.S.C. Schuit , Bettina Heller ✉ , Feng Wang, Ian Fenn, Madison McSweeney

Abstract[14]

Less than nine months into 2017, more resources than our planet produces over the whole year were consumed globally, marked by Earth Overshoot Day. Short use and fast replacement of products increasingly dictates consumption patterns in many regions. As fast turnover of consumption is detrimental for the environment, a transition to a more circular economy and to sustainable consumption and production practices is urgent to alleviate this situation. This research paper aims to provide policy recommendations on the opportunities available to consumers, the private sector and governments of development and developed economies to address product lifetime extension. This can reduce resource use and waste, while preserving the economic value embedded in products. The primary focus is on policy-making.

Keywords: Product Lifetime Extension, Circular Economy, Sustainable Consumption and Production, Hotspots, Life Cycle Assessment.

Introduction

Background: the need for product lifetime extension

On August 2, 2017, more had been used globally from nature than our planet can renew in the whole year. 'Earth Overshoot day'[15] comes earlier every year. A major reason for this is the economic model of industrialized economies, referred to as the 'throughput' economy, or a 'take-make-dispose' economy; an economy that relies on large quantities of cheap, easily accessible materials and energy, and that produces vast amounts of waste (Ellen MacArthur Foundation 2013). Alternatively, in many economies the average income is increasing, resulting in growing domestic consumption and generation of waste. According to the Organisation for Economic Cooperation and Development (OECD), sales of refrigerators, television sets, mobile phones, motors and automobiles have surged in virtually every African country in recent years. In Ghana, for instance, the possession of cars and motorcycles has increased by 81% since 2006 (Pezzini 2012).

With the expected doubling of the global middle class in the coming years, it is widely recognized that the linear economic model is reaching its physical and environmental limits, and a transition to a more circular economy and to more sustainable consumption and production practices will make sense for people and the planet. In a circular economy, the value of products is maintained for as long as possible, for instance by extending their useful lives (EU 2010). This article builds on a report[16] which explored how the useful lives of products can be extended and how product lifetime extension can inform consumers, insight policy and change consumption patterns towards a circular economy.

[14] This article builds on the UN Environment report 'The Long View – Exploring Product Lifetime Extension': http://www.scpclearinghouse.org/resource/long-view-exploring-product-lifetime-extension

[15] www.overshootday.org

[16]The Long View – Exploring Product Lifetime Extension http://www.scpclearinghouse.org/resource/long-view-exploring-product-lifetime-extension

Objectives and questions

The objective of the study was to provide recommendations on the opportunities available to consumers, private sector and governments of developed and developing economies, to address product lifetime extension. The study researched empirical evidence for decreasing product lifetimes in industrialized societies, looking specifically at when product lifetime extension make sense from an environmental life cycle perspective, product-specific policy measures and general opportunities and measures for product lifetimes extension, for governments, manufacturers and consumers globally.

Definitions

Product Lifetime and Product Lifetime Extensions

At some point in time, all products end their life and become obsolete. 'Obsolescence' simply means "the condition of no longer being used or useful."[17] This can be for objective reasons, for instance when the product physically breaks down and is beyond repair, or for subjective reasons, when the user does not like or want the product anymore (for instance because it no longer meets the user's needs, or because the perceived costs of maintenance or repair are too high). It happens regularly that perfectly functional products are discarded (Oswald and Relle 2011). Therefore product lifetime is defined as the duration of the period that starts at the moment a product is released for use after manufacture or recovery, and ends at the moment a product becomes obsolete.

Product lifetime extension seeks to go beyond the current lifetime by creating durable products that are used for a long time. In order to prolong or extend product lifetime, designers have three design approaches at their disposal (Hollander et al. 2017). The first approach focuses on long(er) use of a product (longer than the market average), the second on extended viability of a product (through maintenance and repair), and the third on product recovery (including its components).

Designers can design products with an intrinsically long life through creating emotionally and/or physically durable products. This is referred to as 'resisting obsolescence'. Designers can also keep a product from becoming obsolete ('postponing obsolescence'), for instance through designing for maintenance and upgrading. The third design approach is to return an obsolete product to a non-obsolete state (also called recovery, or 'reversing obsolescence'), for instance through design for repair or remanufacturing (Hollander et al. 2017). Thus product lifetime extensions are the postponement or reversal of the obsolescence of a product through deliberate intervention.

Methodology

A review of Life Cycle Assessment (LCA) studies was conducted on the optimal replacement moment of seven use-intensive product categories (washing machines, refrigerators, TVs, mobile phones, laptops, clothing and vacuum cleaners). This review was based on the collation of existing data, insights and a literature review. Expert interviews were conducted to uncover opportunities to address product lifetime extension and assessed examples of policies and private sector initiatives regarding product lifetime extension.

The investigation revealed product lifetime extension is not a widespread practice in developed economies. Rather, rapid replacement cycles have become the norm and consumers express feeling "locked-in" to wasteful consumption patterns. In developing and lower-income economies, the situation is different as informal repair markets are common and there seems to be a culture of keeping products in use for longer.

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[17] Definition retrieved from http://www.merriam-webster.com/dictionary/obsolete

Product lifetime extension opportunities

For developed economies, the report proposes two policy approaches towards product lifetime extension; the Open Source perspective aimed to empower consumers and the Closed Loop perspective aimed at unburdening consumers. A third policy perspective specifically for developing economies with a large informal repair market is also proposed.

The nature of these two perspectives are deliberately presented as two extremes, to show the range of options available for product lifetime extension. Both perspectives can co-exist (there is no one-size-fits-all) and all kinds of mixed or 'hybrid' perspectives are possible.

Open Source perspective

The 'Open Source' perspective is based on the idea that the lack of transparency (asymmetrical information between industry and consumers) is one of the causes of shorter product lives. If consumers have better information, they can make better consumption decisions. Open Source is therefore a policy perspective aimed to enable and empower consumers to extend the lifetime of products. It follows that consumers are not only given more power, but also more responsibility. The success of the Open Source policy perspective will depend on consumers taking action, supported by relevant policy measures, non-governmental organizations (NGOs) and industry initiatives. The report recommends the following short/medium-term policy measures:

The Dutch company Fairphone is an example of an Open Source solution. Fairphone aims to make mobile phones last at least 5 years through a modular design and by offering spare parts at an affordable price to stimulate self-repair.[18] Fairphone attempts to break the cycle of constant replacement of broken or out-of-date phones by setting up their own small parts supply chain.

[18] https://www.fairphone.com/en/about/about-us/?ref=footer

	Open Source perspective: enable and support consumers to extend the lifetime of their products
Law against planned obsolescence	Planned obsolescence was recently made punishable by law in France (through articles L441-2 and L454-6 of the Code de la Consommation). It is recommended to evaluate the implementation of the French law and, if effective, to consider EU-wide adoption and adoption in other countries/regions.
Minimum durability criteria	The European Ecodesign Directive already has minimum durability criteria for light bulbs and vacuum cleaners, and more measures are planned. The criteria in the European Ecodesign Directive could be extended and measurement standards, test standards and verification methods for durability and resource efficiency could be developed for a range of products.
Product lifetime labelling	A comprehensive study by the European Economic and Social Committee (2016) indicates that consumers respond positively to product lifetime labelling. More research and testing needs to be done to study the effectiveness of lifetime labels, and to develop standardized measurement procedures. If product lifetime standards are based on manufacturers' data, they have to be willing to participate, thus incentives need to be introduced.
Extended product warranty	France and Portugal have extended the period for the reversal of the burden of proof from 6 months to two years. It is recommended to evaluate the French and Portuguese measures and, if successful, to consider making this an EU-wide measure and introducing it in other countries/regions.
Right to Repair legislation	Repair needs to be affordable and accessible for consumers (for instance through publicly available repair manuals). A reduction of Value Added Tax on repair can further incentivize actions in this area. In France, manufacturers and retailers are obliged to inform consumers on spare part availability. It is recommended to evaluate the 2016 law (decree nr. 2014-1482) and, if effective, to consider adoption at EU level and introduction of similar legislation in other countries/regions.
Monitoring of trends in product lifetimes	Monitoring the trends in product lifetimes of a range of energy-use-intensive products consistently, over a number of years, can track the impact from different generations of products and provide up-to-date suggestions for lifetime extension.
Consumer education and information	The promotion of the development of (for instance) product buying/use guides, or consumer awareness/marketplace campaigns, can increase the understanding of product durability, induce a positive consumer attitude towards product maintenance and repair, and encourage consumers to hold companies to account.

Figure 4-1: *The Open Source perspective, UN Environment, 2017.*

Closed Loop perspective

The 'Closed Loop' perspective is based on the idea that product lifetime extension is a strategic business decision. Companies need to (be able to) maintain economic control over their resources and products, in order to close the loop, in line with Circular Economy thinking (Ellen MacArthur Foundation 2013). This perspective aims to enable and empower manufactures to extend the lifetime of product, whilst giving their customers a high-quality product experience. The companies will retain full responsibility over their products, and that alternative business models like 'lease' or 'pay-per-use' are an integral part of the Closed Loop perspective. This incentivizes the development of durable and reusable products. The success of this perspective will depend on the extent to which these alternative business models are accepted and embraced by both consumers and industry. The report recommends the following short/medium-term policy measures:

	Closed Loop perspective: enable manufacturers to retain full responsibility over their products in order to extend product lifetime
Individual Producer Responsibility	Individual Producer Responsibility (IPR) can be considered for selected product categories. It is recommended to evaluate the Japanese IPR regulation for air conditioners, TVs, refrigerators and washing machines, and to explore if a translation to other countries' contexts is feasible.
Removal of legal barriers for refurbishment and remanufacturing	The development of international standards for remanufacturing and the introduction of warranties and a tax reduction on remanufactured products can provide incentives. There is also a need to address trade barriers that prohibit the import of product parts that are to be remanufactured.
Alternative business models	Stimulating the acceptance of alternative business models (the shift from ' owning' to 'using' products) in the Business-to-Consumer market, includes addressing privacy and other liability issues pro-actively.

Figure 4-2: *The Closed Loop perspective, UN Environment, 2017.*

Access models is an example of the shift towards alternative business models whereby users pay for access instead of ownership. Vigga Baby Clothes is executing this circular economy approach by enabling parents to lease organic baby clothing.[19]

Recommendations for developing economies

Despite the absence of enforced legislation, product lifetime extension often occurs naturally in developing economies. Instead of a 'throw-away' culture, a repair culture exists in which consumers try to get the most out of their products by getting them fixed or giving them to relatives or staff with lower incomes (Hanafi personal communication, 8 August 2016).

In addition, many developing economies have large, informal secondary markets, facilitated by online sales platforms (equivalent of Ebay). The informal market, where repair is cheaper is condoned by the government as it creates employment. It follows that for developing economies where such informal second-hand and repair market is highly developed, the report recommends the following policy measures:

[19] https://vigga.us/in-english/

	Product lifetime extension in developing economies
Improvement of waste treatment infrastructure	In many economies a formal, environmentally sound and safe waste management system is needed. In order to make such a system function properly, public education on how and where to dispose products is required.
Recognition of the full potential of the informal sector	Informal economic sectors that revolve around trading, repairing and regaining materials from redundant products currently lack access to investment capital and information to make repairs energy efficient, safe and environmentally sound. It is recommended to recognize these professions and offer them social rights, official status, and training.
Stimulation of energy efficient repair and refurbishment of old appliances	Addressing the often prevailing lack of an institutional infrastructure to implement energy efficiency regulations, appliance efficiency in the used and rehabilitated appliance market can for instance be promoted and increased through training and the provision of energy efficiency repair manuals.
Consumer education and information	The introduction of energy efficiency labelling, other eco-labels and awareness campaigns can stimulate the more affluent households to invest in high-quality, longer lasting and/or energy efficient products.
Monitoring, verification and enforcement (MVE) measures	Developing monitoring, verification and enforcement (MVE) measures can help ensure that energy efficiency and product lifetime standards are met.

Figure 4-3: *Product lifetime extension in developing economies, UN Environment, 2017.*

Conclusion

Product lifetime extension is not yet a widespread practice in developed economies. Policies are needed to facilitate the solutions from the three policy perspectives put forward, and to enable consumers and industry to transition towards sustainable consumption and production and a circular economy. More research on existing activity around products' lifetime extension is needed to establish the business case and drive good practices to become the norm.[20]

[20] UN Environment is continuing work in this area with partners under the 10YFP Consumer Information Programme. To learn more, please visit http://www.scpclearinghouse.org/consumer-information-scp or contact Bettina.Heller@un.org.

5. Implications of the 1.5-Degree Target for Lifestyles

Michael Lettenmeier ✉, Mathis Wackernagel

Abstract

At current emission level, humanity would have used up their remaining carbon footprint budget from now to eternity within four years or less, when compared to the emissions compatible with keeping global warming within a limit of 1.5°C. Therefore, zero net carbon lifestyles (for all) should be achieved well before 2050. These lifestyles have also to manage within the budgets of natural resources provided by the planet, e.g. in terms of land area and material resources available. This paper looks at such lifestyles under the premises of the 1.5°C target and a sustainable level of resource use. "One-planet lifestyles" have been illustrated on relatively detailed level in studies on the Ecological Footprint and the Material Footprint. The paper illustrates the production and consumption features on the basis of the three footprint approaches. The paper discusses opportunities to achieve these one-planet lifestyles through measures related to production, infrastructure, and consumption. Opportunities in reducing the climate impact of food production and consumption are highlighted. Building new homes from wood instead of concrete to render buildings from carbon emitters to carbon sinks is another relevant option, or running public transport on low- or zero-carbon renewables. Pilot studies indicate that considerable reductions in households' footprints, particularly among high-income communities, are possible even in the short term and with increasing quality of life. A huge amount of solutions for decreasing footprints already exists. Investing in the right energy, transport, food and urban infrastructure, as well as addressing the size of humanity's population will therefore determine whether humanity will win or lose the race for sustainability.

Keywords: Carbon Footprint, Ecological Footprint, Material Footprint, Lifestyles.

What resource demand do 1.5 degrees allow and what are the implications for lifestyles?

If humanity wants to keep global warming within a limit of 1.5 °C, as identified by the Paris Climate Accord, less than 200 billion tonnes of CO_2 can be emitted from now on to eternity. In contrast, annual emissions now are about 40 billion tonnes of CO_2[21]. And this amount may not even include other GHGs, since the ppm limits in the 4th IPCC report refer to carbon equivalent, not carbon. This means that living up to this target would require net-zero carbon emissions within some years. In other words, zero net carbon lifestyles should be achieved already well before 2050. These lifestyles however have also to manage within the planet's resource budget. This paper is outlining what these physical constraints mean for people's resource availability and their ways of living. For this inquiry, the lenses of the Ecological Footprint and the Material Footprint are being applied. The focus on lifestyles does not mean that footprint improvements have to be achieved solely by means of personal lifestyles. In contrary, putting the lenses on lifestyles opens a new angle to innovations and business solutions which so far have focused too narrowly on the technology side.

Ecological Footprint accounting

The Ecological Footprint adds up all the biologically productive area needed to regenerate everything people demand from nature: fruits, vegetables, fish, timber, fibre, absorption of carbon dioxide, space for buildings and roads. This space is then compared to biological productive areas available – or biocapacity. Both Ecological Footprint and biocapacity are

[21] https://www.mcc-berlin.net/en/research/co2-budget.html

expressed in global hectares. These are biologically productive hectares with world average productivity.

Given the size of the planet and the human population, the planet currently makes available 1.7 gha of ecologically productive space per person. If we followed Wilson's (2016) proposition of sharing the planet's bounties 50%-50% between wild species and human activities (incl. its animals and crops), this would reduce the budget to 0.85 global hectares per person. With a population of 10 billion people this per person amount would be reduced to 0.62 global hectares. In contrast, humanity's present demand adds up to 2.7 global hectares per person, much larger than the amount available per person. Country-average Ecological Footprints in Europe hover between 4 and 7 gha/person.

Fossil fuel will be phased out –as anticipated in most imaginable scenarios, the question is only when– biocapacity will not only have to feed people. It also will have to help replace fossil fuel. If we want to comply with the Paris Agreement, humanity will have to phase out fossil fuel use well before 2050. If fossil fuel was phased out as consistent with the warming goal of the Paris Agreement, and if this was done in a way that no extra pressure was put on other ecosystems, the current per capita Ecological Footprint would be reduced from 2.7 to 1.6 global hectares. The reason is that currently 60% of the global Ecological Footprint is caused by carbon emissions from fossil fuel use.

Lifestyle Material Footprint

The Lifestyle Material Footprint (LMF) adds up all abiotic materials, biotic materials and erosion in agri- and silviculture as an aggregated measure for material use (Schmidt-Bleek 2009, Lettenmeier et al. 2009). It includes both the materials used by the human economy and the unused extraction (Aachener Stiftung 2011). Based on Bringezu's (2009) macro-economic considerations on sustainable resource use, Lettenmeier et al. (2014) suggested a sustainable LMF of 8 tonnes per person and year by 2050 for households. This is an average, as future lifestyles will be diverse and vary widely between different households (Leppänen et al. 2012, Kuittinen et al. 2013). Nevertheless, the eight tonnes vision can serve as a benchmark illustrating the production and consumption of goods, services and activities that fit into a sustainable lifestyle accessible to all humans on Earth (see e.g. Leppänen et al. 2012).

The LMF can help to identify critical activities in terms of material use during the transition to a net zero carbon economy within the biocapacity of one planet. A net zero carbon consumption pattern might still have notable impact on the environment because of its resource requirements. For example, electric cars could achieve zero carbon emissions if their production and consumption were based on sustainable renewable energy sources. However, their LMF might well be higher than that of present cars because of their (remaining) road infrastructure and (most likely increasing) metal requirements due to batteries and other equipment. The material footprint can thus serve as an additional check for ensuring the sustainability of net zero carbon lifestyles.

What would a one-planet lifestyle require?

Lifestyles that fit into the boundaries our only planet provides ("one-planet lifestyles") have been illustrated on relatively detailed level in terms of Ecological Footprint and Material Footprint. Using national ecological footprint data, Moore (2013) draws a one-planet lifestyle scenario with an Ecological Footprint of 1.8 gha/cap (the amount of biocapacity on the planet at the time of her study).

Lettenmeier et al. (2014) used micro-level Lifestyle Material Footprint (LMF) data to illustrate requirements in terms of production, infrastructure and consumption for a sustainable lifestyle of 8 annual tonnes per person. Achieving this level of LMF per person, a 20% of the Finnish average or 25% of the German average LMF of today (Buhl et al. 2016). Calculations for this paper show that a zero-carbon one-planet economy could be achieved in Germany with similar efforts. The consumption features in the different consumption components of all three approaches are listed in Table 5-1.

Consumption component	**One-planet consumption for Germany 2050, Global Footprint Network and Wuppertal Institute 2017 (for this paper)** **(EF= Ecological Footprint measured in gha per person, CF – Carbon Footprint measured in annual t of CO_2 per person)**	**One-planet consumption for Vancouver 2050, Moore (2013)** **(EF= Ecological Footprint measured in gha per person)**	**One-planet consumption for Finnish households 2050, Lettenmeier et al. (2014)** **(LMF = Lifestyle Material Footprint measured in annual t per person)**
Total footprint available	**1.0 gha EF, zero net CF** 19% of current 5.3 gha/cap	**1.8 gha EF** 43% of current EF	**8 tonnes LMF** 20% of current LMF
Nutrition	50% of current EF, Improving agriculture and food chain, eliminating food waste, moving to healthier, less meat-based diets Current: 0.87 gha/cap	52% of current EF, 26% smaller amount, 50% substitution of red meat and dairy, halving food waste	51% of current MF, 29% smaller amount, mostly vegetarian (14 kg meat), food waste mostly eliminated
Housing	10% of current EF, Mediterranean style cities, with highly efficient buildings. Current: operation 0.75 gha/cap, infrastructure 0.95 gha/cap	18% of current EF, Energy efficiency improved 40%, all buildings zero emission, life span increase by 50%	15% of current MF, $20m^2$, 1000 kWh, zero heating energy within present resource intensity per m^2
Goods, services, waste	20% of current EF, Consumer behaviour shifts with urban form, education, and incentives. Radical shift in energy production to renewables, especially solar. Current: goods 0.84, services 0.36 gha/cap.	67% of current EF, 50% of current paper consumption, 50% of current landfilled waste, better landfill gas capture etc.	22% of current MF, fewer consumption, less resource-intensive consumption and production, sharing solutions, longevity, etc.
Mobility	10% of current EF, Increased electric vehicle and public transportation use combined with transitions to renewable energy and walkable cities. Current: operation 0.97 gha/cap	20% of current EF, 86% of trips by walking, cycling and public transportation, private vehicle ownership –50%, private vehicles 100% zero emission, flying –50%	12% of current MF, 10,000 km by resource-efficient public transportation, car-ownership shifting to shared use of different vehicles

Table 5-1: *One-planet consumption specifications (the reduction is a combination of decarbonized energy system, infrastructure that is more conducive to low-resource intensive activities, and change in behavior).*

The three approaches show that one-planet lifestyles require notable changes in both production and consumption, thus opening huge potentials for innovation and business. Lettenmeier et al. (2014) estimate that roughly half of the required Lifestyle Material Footprint reduction could be achieved by production-related and half by consumption-related measures. However, the more rapid or disruptive technological innovation becomes, the smaller the need for lifestyle changes will remain. Still, it looks obvious that both approaches are required for achieving a sufficiently rapid transition. Tackling technologies and lifestyles simultaneously can help direct interventions in an optimal way.

Filling the sustainable lifestyle proposal of Lettenmeier et al. (2014) in two web-based CF calculators[22] resulted in CFs of around 1.5 annual tonnes CO_2e/cap under present conditions and if mobility excludes air travel. In both calculators, nutrition constitutes approximately 50% of the total CF and mobility and housing each make up roughly 20% of the results. 1.5 tonnes CO_2e are not sufficient to meet the 1.5°C target, additional changes should be achieved. The overall decarbonisation of the production system will affect the production of food, transportation services and buildings, as well as the provision of any goods and services. For instance, a study for London (Hersey et al. 2009) shows the huge potential of an overall decarbonisation if it is tackled under all components of consumption. The study still results in carbon footprints around one annual tonne of CO_2e /cap in 2050 but it was commissioned long before the Paris Agreement.

Especially food production plays a huge role. Note that the approximately annual 750 kg of CO_2e /cap in this scenario require a shift to vegan, not only vegetarian diets. This highlights the significance of adjusting the food system in regard to its climate impact, in addition to the need to switch food consumption to be closer to vegan. Plenty of alternatives to meat and milk products have already entered the market, with strong growth rates. Investors have started urging food companies to develop more of these products. Agricultural production could play a much stronger role in terms of carbon sequestration or even carbon sink (e.g. Powlson et al. 2016, Kämpf et al. 2016, Hawken 2017).

Building new houses from wood instead of concrete is another relevant option at least for countries in the Northern hemisphere to render new buildings from carbon emitters to becoming carbon sinks while improving the quality of living. Combined with low-carbon renewables and/or zero energy solutions for housing this provides notable potential for facilitating one-planet lifestyles. Running public transport on low- or zero-carbon renewables is feasible immediately and depends just on decisions by the providers in the case of electrified transportation. Bus transport could be either electrified or use waste-based biofuels as long as power-to-fuel options are not yet in use.

How fast can change happen?

In the present situation, average households in most Western countries would use up their remaining carbon footprint (CF) budget until 2050 within five years or less. Pilot studies show that change can happen relatively fast with households that are sufficiently aware and take an active role in implementing change. This could extend carbon budgets notably.

In a Finnish pilot study (Laakso 2016, Lettenmeier et al. 2015), the five participating households developed roadmaps for reducing their CF from 4-11 to 1.6-5.6 annual tonnes CO_2e/person by 2030, which means a reduction of 38-60%, and about half way towards zero tonnes in 2050. During a one-month experiment phase, households were able to reduce their CFs already by 26-39%, much closer towards their 2030 targets than expected, and reported an increase in quality of life because of, e.g., better mobility planning, home delivery of groceries or decreased living space. Although a part of the experiments was based on simulated services not yet existing on a regular basis in the region, the results showed that relevant footprint reductions can be achieved even in the short term with improving quality of life. In an interview round several months later the project households conveyed that several options tested or developed in the project were still going on, e.g., ride-sharing, giving up the second car, planning co-housing in the city centre and increasing vegetable-based food. On the other hand, some changes in life situations had also increased resource use, such as measures that required a new car. This provides an additional argument for the need for

[22] http://footprintcalculator.henkel.com/en and https://ilmastodieetti.fi/index_EN.html

changes in supply structures and urban infrastructure that go beyond individual behaviour changes and temporary experiments in order to facilitate sustainable lifestyles (Laakso 2016).

In another pilot study (Vähähiilinen 2016) with an even smaller financial budget (all solutions tested were on the market already) and less profound target-setting, the participating households dropped their CFs by 8-77% (from 4.6-11.8 to 2.6-8.3 annual t CO_2e/person) on the basis of the options tested during the project or considered for the near future.

In a similar way, a Swedish “One Tonne Life” study (Björck 2011) with one household showed a family that reduced its CF at best by 61% down to 3.5 tonnes CO_2e /cap/a, which could drop to 0.6 tonnes CO_2e/cap/a with an almost zero emission energy system in 2050. The study states food as the biggest challenge in terms of zero carbon life because agriculture causes notable emissions not related to energy use. On the other hand, agriculture could play a major role in carbon sequestration or even turn into a carbon sink (e.g. Powlson et al. 2016, Kämpf et al. 2016, Hawken 2017).

What next?

Although there are huge differences across households in both the level and composition of footprints, it looks obvious that present Western lifestyles are far from fitting within the means of our planet, if extended to everybody. In present Western societies, with current infrastructure and current technology, a comfortable lifestyle is hardly achievable within the planet’s ecological limits (Lettenmeier et al. 2012). Yet, there is huge need and potential for reducing footprints. Considerable reductions in the footprints of lifestyles are possible even in the short term and with increasing quality of life. A huge amount of solutions for decreasing carbon footprints already exists and with concerted effort by companies and authorities, remarkable footprint reductions can be achieved in the following years (e.g. Tynkkynen 2016) but require notable improvements in production, infrastructure and consumption. The more technology and infrastructure can be integrated into this change, the more space will be left for individual diversity in achieving sustainable lifestyles (Lettenmeier et al. 2014). There is every reason to believe that future sustainable lifestyles will be as diverse and rich as present lifestyles (Leppänen et al. 2012, Kuittinen et al. 2013).

Zero carbon footprints from lifestyles will require huge changes in production and infrastructure. Therefore, they should be aimed at immediately. In terms of infrastructure and production, should energy production, agriculture, transportation and buildings be tackled immediately in order to target investments into and not away from sustainability. Consumption-related measures and interventions can help achieve relevant and fast changes in order to extend the carbon budget available. Last but not least a zero carbon target can help to overcome the discussion on how to share the carbon emissions between different parts of the world because zero is always zero.

6. Sustainable Use of Natural Resources in Different Out-of-Home Catering Settings: Sustainability Assessment of Meals

Tobias Engelmann ✉, Katrin Bienge, Holger Rohn, Melanie Speck

Abstract

Within the research project NAHGAST (Developing, Testing and Dissemination of Concepts for Sustainable Production and Consumption in the Food-service Sector), a sustainability assessment tool for meals was developed and tested in five different catering settings. The meal assessment has been the basis for different interventions that aimed to promote a more sustainable catering.

This paper outlines the sustainability assessment method and tool and presents exemplary results of the meal assessment (by applying two indicator sets). Also, obstacles for creating valid results, correlations of the two NAHGAST indicator sets ("basic" and "pro") and consequences for further application of the tool are discussed.

Keywords: Sustainable Consumption and Production, Sustainable Nutrition, Sustainability Assessment, Sustainable Catering, Sustainable Out-of-Home Nutrition.

Introduction

Human nutrition is responsible for about 30 % of global resource use (European Commission 2011, Lukas et al. 2015). In order to get the resource use of the nutrition sector in line with planetary boundaries, a reduction by a factor of 2 (Lukas et al. 2015) is suggested. Supporting this effort, NAHGAST focuses on the catering sector, which represents the largest sales channel for nutritional products next to the food retail sector (BVE 2013). A decrease in resource use necessary for the product supply in the catering sector is required to support overall resource reduction goals. Within the NAHGAST project, an assessment tool was developed to analyse the sustainability performance of meals. Combined with several other assessment indicators in different sustainability dimensions (ecologic, health-related, social, and economic), the resource input necessary for the production of foodstuffs (Material Footprint) is a central assessment indicator in the NAHGAST tool. It is supposed to enable practitioners to assess and make informed decisions and measurable improvements to the sustainability performance of their dishes.

The NAHGAST Assessment Tool

Methodology and Implementation

The NAHGAST tool is designed to assess the sustainability performance of particular meals and their components. It consists of two modules: NAHGAST Meal-Basic and NAHGAST Meal-Pro[23]. It combines a selection of several indicators in ecologic, health-related, social, and economic dimensions of sustainability (see Figure 6-1).

[23] A third module – NAHGAST company – is not considered in this article. Speck et al. (2017) provide further information.

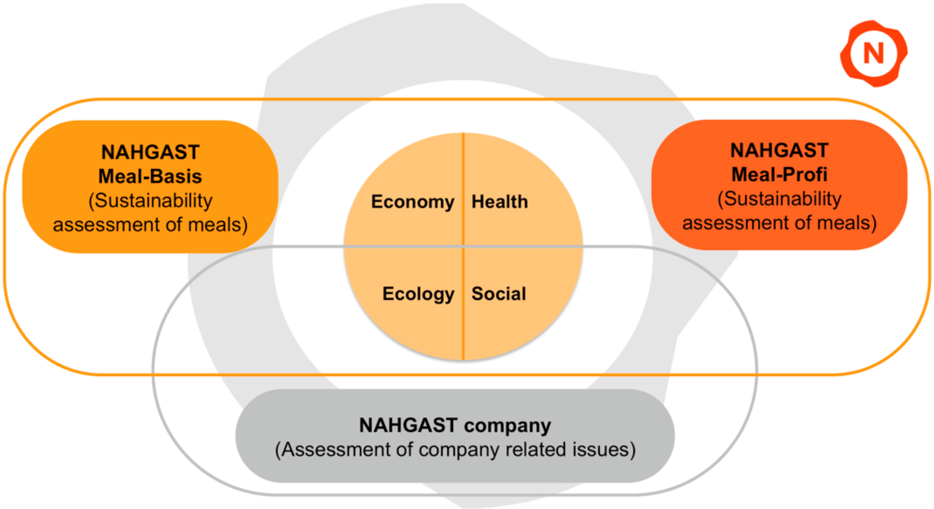


Figure 6-1: *Scheme of the NAHGAST sustainability assessment tool for meals (Speck et al. 2017).*

Moreover, it integrates qualitative indicators (such as regionality, seasonality etc.) as well as quantitative ones (such as carbon and material footprint), each related to estimated sustainable levels. The indicators and sustainable levels are presented in Figure 6-2 as part of the assessment of a fictive goulash dish.

In the tool, data for the majority of the indicators is generated or calculated automatically after entering the meals' ingredients in an Excel sheet. A single file is created for every meal assessed. For each of the two modules (NAHGAST Meal-Basic and NAHGAST Meal-Pro) separate spreadsheets are provided, one for entering the meal-related data and one for displaying the results. To automatically calculate results, another spreadsheet hosts the database for the different assessment indicators in each of the modules. The database supports several ecological and health-related calculations to generate assessment results for the two modules. For example, by entering type and amount of a certain component of a meal, the material footprint value and energy amount is automatically calculated. For this, some information has to be inputted manually, namely the recipe information (ingredients and their amount in grams) and information related to some qualitative indicators (yes/no) (Engelmann et al. 2018).

The results are generated by relating the data of the meals to previously defined sustainable levels. Depending on whether the value for an indicator matches the sustainable level or not, a rating as "recommendable", "restrictively recommendable" (for almost matching the sustainable level) or "not recommendable" appears. This rating is translated into numerically coded information (3, 2, 1). These values, defined for every single indicator, form the basis for calculating the overall sustainability performance. Each sustainability dimension (ecologic, health-related, social, and economic) forms a combined rating composed of several indicators and also the meal in total receives an overall score (1 to <1,5 means "not recommendable", 1,5 to <2,5 means "restrictively recommendable", 2,5 to 3 means "recommendable"). In addition, colour coding (green, yellow, red) emphasizes the coded information (Engelmann et al. 2018).

	Indicators – NAHGAST Meal-Basis													
	Ecology							**Social issues**	**Health**			**Economy**		Weight of the ingre-dients (g)
	Share of animal products	Share of seasonal products …	Share of regional products	Share of organic products	Share of GMO-free products	Share of sustaina-bly caught fish	Share of avoidable food waste	Share of fairtrade products …	Share of fruit and vegeta-bles	Energy (kcal)	Fibre (g)	Popularity	Cost coverage	
	31%	**0%**	**25%**	**0%**	**69%**	**0%**	**10%**	**13%**	**27%**	**605**	**5,9**	**level 2**	**level 2**	**487**
Sustaina-ble level:	< 30 %	> 90 %	> 50 %	> 40 %	100%	100% MSC or ASC or no fish	< 10 %	> 90%	> 40 %	< 670 kcal	> 8 g	level 3	level 3	
Results (1, 2, 3):	2	1	1	1	1	3	2	1	1	3	1	2	2	
Results (recom-menda-tions):	restric-tively recom-menda-ble	not recom-menda-ble	not recom-menda-ble	not recom-menda-ble	not recom-menda-ble	recom-menda-ble	restric-tively recom-menda-ble	not recom-menda-ble	not recom-mendable	recom-mendable	not recom-mendable	restric-tively recom-mendable	restric-tively recom-mendable	**total score 1.6**

	Indicators – NAHGAST Meal-Pro															
	Ecology				**Social issues**		**Health**						**Economy**		Weight of the ingredi-ents (g)
	Material Footprint (kg/meal)	Carbon Footprint (kg/meal)	Water demand (kg/meal)	Area required (m^2*a/meal)	Fairtrade	Animal Wel-fare	Energy (kcal)	Fibre (g)	Fat (g)	Carbohy hy-drates (g)	Thereof sugar (g)	Salt (g)	Populari-ty	Cost coverage	
	9,61	**2,39**	**169,38**	**2,59**	**13%**	**0%**	**605**	**5,9**	**24,8**	**58,2**	**6,1**	**3,4**	**level 2**	**level 2**	**487**
Sustaina-ble level:	< 2,67 kg/meal	< 0,8 kg/meal	< 640 kg/meal	< 1,25 m2*a/meal	> 90%	> 60%	< 670 kcal	> 8 g	< 24 g	< 90 g	< 17 g	< 2 g	level 3	level 3	
Results (1, 2, 3):	1	1	3	1	1	1	3	1	2	3	3	1	2	2	
Results (recom-menda-tions):	not recom-mendable	not recom-mendable	recom-mendable	not recom-mendable	not recom-menda-ble	not recom-om-mend-able	recom-om-mend-able	not recom om-mend able	restric-tively recom-menda-ble	recom-menda-ble	recom-om-mend-able	not recom-menda-ble	restric-tively recom-menda-ble	restric-tively recom-menda-ble	**total score 1.8**

Figure 6-2: *Indicators and sustainable levels in NAHGAST Meal-Basic and NAHGAST Meal-Pro; source: own work.*

Table 6-1 shows the assessment results of the fictive goulash dish assessed in Figure 6-2 (for further explanation of results and recommendations see Speck et al. 2017 and Engelmann et al. 2018).

Indicators	Recommendations	Scores
Fairtrade products:	not recommendable	1
Animal welfare	not recommendable	1
Energy amount:	recommendable	3
Fibre amount:	not recommendable	1
Fat amount:	restrictively recommendable	2
Carbohydrates amount:	recommendable	3
thereof sugar:	recommendable	3
Salt amount:	not recommendable	1
Material Footprint:	not recommendable	1
Carbon Footprint:	not recommendable	1
Water demand	recommendable	3
Area required	not recommendable	1
Popularity	restrictively recommendable	2
Cost coverage	restrictively recommendable	2
	Recommendation	**Score**
Total result:	restrictively recommendable	**1,8**
Dimensions:	**Recommendations**	**Scores**
Social dimension	not recommendable	1,0
Health	restrictively recommendable	2,2
Ecology	restrictively recommendable	1,5
Economy	restrictively recommendable	2,0

below 1,5:	not recommendable
1,5 to below 2,5:	restrictively recommendable
above 2,5:	recommendable

Table 6-1: *Assessment results of the fictive goulash dish with NAHGAST Meal-Pro; source: own work.*

Regarding the format in which the information should be presented to canteen managers and to the end customers, a certain degree of differentiation in the information provided by the assessment was considered essential in order to grasp the impact a certain improvement has on different indicators and sustainability dimensions. At the same time, information has to be concise and easily understandable in order to be compatible with canteen business processes and consumer settings (Engelmann et al. 2018, Langen et al. 2017).

Towards the catering companies, it was decided to provide the evaluation of each single indicator (particularly important for identifying potential for improvement), the evaluation of each sustainability dimension (ecology, health, society, economy) and the total evaluation. The results display numerical coding as well as the corresponding qualitative ("recommendable" etc.) and visual information (green, yellow, and red) (Engelmann et al. 2018).

Consumer decisions in canteen settings are made within a very short time frame (Langen et al. 2017) so it was decided to present a label with aggregated information. The position of a pointer on a colour gradient bar expresses the performance of each dimension (Engelmann et al. 2018).

Figure 6-3 shows the label that is generated based on the assessment results of the fictive goulash dish.

Figure 6-3: *Label for the fictive goulash dish; source: own work.*

The weighting of indicators is another option to put an emphasis on certain indicators and thereby accounting for certain sustainability dimensions, which are deemed more important than others. As for now, it was decided to consider the different indicators (or dimensions) as equally important. This is an issue that requires further discussion and implies a certain degree of normative decisions. Every user is thus urged to determine individually whether certain indicators are to be considered differently from others (Engelmann et al. 2018).

For all the pilot companies, one to three different recipes were assessed in eleven different dish categories (such as pasta, stew, vegetarian casserole etc.). The meal assessment formed the basis for different interventions, e.g. for labelling the best-assessed meals or for placing them on the most frequented counter and also for further improvement of recipes in order to create sustainable flagship meals (Engelmann et al. 2018).

The assessments make transparent that merely replacing the ingredients by e.g. an organic, fair trade or regionally produced alternative results only in a slight improvement in score. For greater improvements, more substantial changes are necessary, e.g. reducing the quantity of meat, increasing the amount of (seasonal) vegetables or substituting beef with other kinds of meat (Engelmann et al. 2018).

Challenges

Sustainability assessment is complex and controversial. One challenge is defining (and maybe "calibrating") the indicators properly (e.g. the time of consideration for seasonal products or the substitutability of deep-frozen or canned vegetables with fresh ones).

Data availability is another – far greater – challenge. Often, internal data can be determined in principle but are not monitored by the caterers (e.g. food waste). Some catering companies are reluctant to disclose certain data, such as the cost coverage per meal. Other data are missing because of the non-transparent supply chains (e.g. origin of products). Finally, data for many ingredients are not available in databases (e.g. different varieties of components produced in several countries); this also applies to different characteristic values of ingredients. Whether a foodstuff is grown free range or in a heated greenhouse, for example, can mean vast differences in resource use and other sustainability categories. Missing or incomprehensive data is a challenge that can significantly reduce the validity of the assessment results.

Although we tried to design the tool as user-friendly as possible, it remains quite complex and several data has to be entered manually. Since potential users are usually working to capacity, sustainability assessment is often seen as extra work. The final aim is thus to design an evaluation instrument that can be linked with ERP (Enterprise Resource Planning) or similar systems.

A challenge regarding the acceptance of the tool is the fact that some results are quite counterintuitive. Due to comprehensive sustainability assessment, some dishes are not as (or more) sustainable as they seem to be at first appearance so the tool and its results have to be explained thoroughly. Also, because different indicators are combined in each of the two modules, NAHGAST Meal-Basic und -Pro sometimes differ in their assessment results which also requires explanation (Engelmann et al. 2018).

Conclusions

The NAHGAST meal-assessment tool poses many opportunities to support sustainable changes in the catering sector. In regard to the operational process of canteens, the tool has the potential to provide detailed information to practitioners to plan their meals not only related to cost coverage and taste, but also concerning the impact the used ingredients have on sustainability dimensions in a wider context. As the optimization of the sustainability performance of products and services could become a growing demand in various business areas, a tool, such as the NAHGAST meal-assessment tool, could prove of value. On the side of marketing and the display of meals in catering settings, the tool can also create more transparency for consumers.

Within the project and in close cooperation with the pilot catering companies, the tool was tested and optimized and provided the basis for improvement suggestions in meal composition as well as for marketing methods highlighting sustainability aspects of meals. To be able to disseminate the tool in the wider context however, several aspects related to the tool require some more attention:

Firstly, challenges related to data availability for the sustainability performance of certain types of foodstuffs or in certain dimensions have to be improved in order to provide the information necessary for the calculations within the tool. Secondly, to make the tool compatible with canteen processes and (very importantly) the various computer-supported systems within canteen settings, more work has to be invested in its development. On the one hand, the tool should be compatible with a wide array of requirements in different canteen settings and, on the other hand, it must be customizable for individual requirements of certain canteens. Thirdly, more research is necessary to gain knowledge about the potential of the sustainability-related information generated by the tool resulting in marketing strategies for the end consumer.

7. How to Promote the Installation of Photovoltaic Systems

Nadia Sperr, Jürg Rohrer ✉

Abstract

The potential for solar energy production on existing buildings in Switzerland is estimated to be 40% of annual Swiss electricity consumption. At present, solar energy accounts for 3% of all electricity produced. In order to establish motivators for Swiss building owners to adopt solar photovoltaic (PV) systems and the barriers preventing them from adopting such systems, a survey of the owners of buildings with a high potential for solar energy production was conducted. The participants had been informed about the potential of their building as part of a previous study four years previously.

The evaluation of the 102 completed questionnaires showed that 60% of all respondents are still indecisive, even after having received information in a letter and at an event, with 30% having decided against installing a PV system. Information concerning the high potential for solar energy production and how to build a PV system did not seem to be sufficient to motivate building owners to take action. Initial efforts to address the attitudes of this large group of indecisive building owners were developed from their responses. The most frequently mentioned main reasons for not installing rooftop PV were the joint ownership of buildings and the perceived low financial benefits of PV systems, making up 30% and 20% of all responses respectively.

Response analysis also showed that different owner groups provided different reasons for not installing a PV system. Respondents with joint building ownership perceived the time needed for planning and realisation of a PV system to be greater than sole owners of buildings and also stated that an independent electricity supply was less important for them. For this reason, owners of privately owned flats and rented apartments should be dealt with separately, focusing on measures tailored to their specific needs, for example co-benefits rather than financial benefits.

Keywords: Solar Energy, Photovoltaic, Motivations & Barriers, Promotion.

Introduction

Ratification of the Paris Climate Agreement and the adoption of a new energy strategy "Energiestrategie 2050" has prompted the Swiss government to increase the share of renewable energy production. The defined target for national renewable electricity production is 11.4 TWh by 2035, excluding hydropower. This would meet 26% of the estimated electricity consumption in 2035 (FFA et al. 2017). It is believed that almost half of this renewable electricity production will come from Photovoltaic (PV) systems (Prognos 2013). However, the total potential for rooftop PV systems in Switzerland is even higher than this target, estimated at between 17.5 and 24.5 TWh (Assouline et al. 2017, Meteotest 2017)

While countries like Germany, Italy and Greece have PV power production of 7% of their electricity demand, Switzerland's share only makes up 3% (IEA 2017). Like Germany, Switzerland has taken policy measures to increase the number of newly installed PV systems by compensating for the difference between the market price for electricity and the production cost. However, the Swiss system of feed-in remuneration at cost has reached its limits and there is a long waiting list of registrations (SFOE 2017). The chance of newly registered PV systems successfully applying for this programme are small. Only PV systems with an installed capacity of less than 30 kWp can apply for one-off investment grants. Not only are the chances for these small scale systems to receive subsidies greater, but in 2018 the upper capacity limit will also be raised. To achieve Switzerland's goals, building owners will have to be further convinced to adopt rooftop PV systems, especially since ground-mounted systems are not being actively pursued in Switzerland. In order to promote solar PV systems, the motivators and barriers attached to the adoption of this technology need to be understood so that barriers can be removed and motivators strengthened.

To encourage the adoption of PV systems, in 2012, the city of Wädenswil identified the 300 buildings with the greatest solar potential. The owners were then informed about the suitable preconditions for solar power production through a written letter and invited to a well-received information event about the installation of PV systems. To then monitor the number of newly installed PV systems and to identify ways of (better) promoting solar electricity, a survey was sent to the owners of the same buildings four years later. The survey was not only to shed light on motivators and barriers for Swiss property owners, but also to enable a comparison with already established motivatiors and barriers in other European countries.

Motivators and Barriers

A number of motivators and barriers connected with the adoption of PV systems were identified in the literature. This short review will mainly focus on literature from European countries and provide an overview of currently known drivers and barriers.

Statistically speaking, the people most likely to adopt a PV system are highly educated, have a high income and a technical background (Sonnberger 2014). Besides demographic attributes, there are also motivators and barriers linked to perception and preference. The most important motivational factors and barriers are financial and ecological (Balcombe et al. 2013), but other categories such as security of supply, uncertainty, trust and inconvenience are also relevant (see subchapter Other Motivations and Barriers).

Economic Factors

High investment costs and slow return on investment are two barriers often found in the literature and recognised as some of the most significant barriers to not only PV adoption but also renewable energy production on buildings in general (Heiskanen and Matschoss 2017, Balcombe et al. 2013). Policy measures, such as feed-in tariffs, can increase the perceived economic benefit of PV systems and act as an important motivator (Karakaya et al. 2015). Furthermore, on-site consumption of some of the electricity and selling the remainder can result in substantial savings in energy bills (Briguglio and Formosa 2017).

Ecological Factors

PV systems and other renewable energy technologies are normally viewed as environmentally friendly. Greater environmental motivation makes people more likely to adopt PV systems and can be measured by people's general environmental problem awareness (NEP scale) (Jager 2006). Other studies have also shown that the reduction in carbon dioxide emissions achieved by the consumptioin of PV electricity is an important motivator for adoption (Balcombe et al. 2013).

Other Motivations and Barriers

Self-sufficient electricity production and thus decreasing dependence on mains electricity is another motivator for adopting PV (Palm and Tengvard 2011, Sonnberger 2014). Furthermore, increased self-sufficiency can mitigate the risks of rising electricity prices in the future.

As shown by Inhoffen et al. (2016), the number of already existing panels in a municipality has a positive influence on the number of newly installed systems. Accordingly, already knowing PV owners can be a reason in itself to install rooftop PV (Jager 2006).

An often cited barrier is lack of trust in the technology (Balcombe et al. 2013). This includes uncertainties in terms of actual electricity production as well as uncertainties connected to payback and reliability. The perceived complexity of new systems is normally higher than for older, proven systems (Karakaya et al. 2015).

The inconvenience of adapting to a new system is another barrier found in the literature (Balcombe et al. 2013). Perceived advantages of a PV system might not be high enough to justify modifications to rooves and the associated effort of planning and installing the new system. Especially since current systems are perfectly functional.

Methodology

A questionnaire was developed in 2016 for the building owners in the city of Wädenswil who had been informed about the high solar potential of their buildings in the earlier study in 2012. The main goals were to assess their interest in owning a PV system and to identify the main barriers preventing adoption. It aimed to show how many people from the chosen group had actually installed a PV system after receiving information about the solar potential of their building and practical guidelines on how to realise a rooftop PV system. There were also 17 statements for the participants to indicate their agreement with on a five-point Likert scale. Three additional questions allowed the building owners to be divided into different subgroups.

Descriptive statistical analysis was performed for both the closed and the open format questions. Different perceptions between groups were tested with Chi-square tests, Fisher-Freeman-Halton tests and t-tests depending on the number of responses and the scaling of the answers. The significance level was set to $\alpha \leq 0.05$.

Results and Discussion

The questionnaire was sent to the 387 owners of the 300 buildings with the greatest solar potential in the city of Wädenswil. The questionnaire was returned by 102 respondents, which corresponds to a response rate of 26%. Of the respondents, 30 (35%) were sole owner of the building and 55 (65%) shared ownership with at least one other person. 15 people (19%) were owners of residential buildings, 47 (60%) had a privately owned flat and 18 (22%) owned commercial buildings. Additionally 28 people (39%) stated that the whole building was rented out, 25 (35%) stated that it was partially rented and 19 (26%) stated that their building was not rented at all.

Interest in owning a PV system

The respondents were asked to choose from four answers to show if they had decided for or against adopting a PV system or if they were indecisive (Figure 7-1). Most of the respondents (53 owners representing 58%) were still undecided. This result was unexpected since the information event had been well attended. Knowledge about PV technology and the potential for a rooftop PV system on their own building did not seem seem to be enough for private owners to take action. This indicates that different approaches may be needed to motivate private property owners to invest in rooftop PV. Of all the respondents, 26 (28%) had decided against installing a PV system, whereas 13 (14%) were in the planning phase or had already installed a system.

Main Barriers

The main barriers were assessed through an open-ended question, where every respondent was asked to give their main reason for not adopting PV systems. The answers were then categorised in accordance with the main barriers found in the literature. The results showed that joint ownership of buildings, a barrier not often addressed in the literature, and economic factors were the two main barriers to PV system adoption (see Table 7-1).

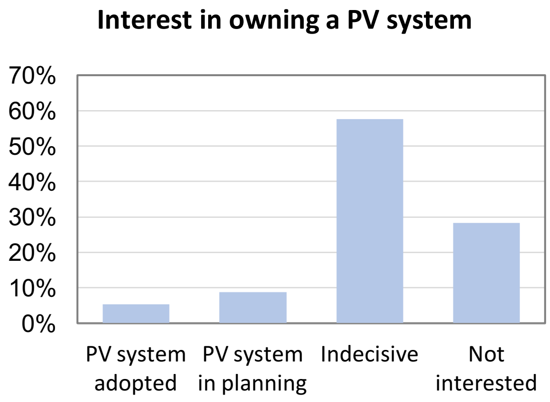


Figure 7-1: *Interest in owning PV systems (percentage of respondents).*

Main Barrier	Times Mentioned	Percentage of respondents
Joint ownership	30	32%
Economic factors	20	22%
Lack of interest	13	14%
Pending renovation	12	13%
Heritage protection	5	5%
Other	13	14%

Table 7-1: *Main barriers indicated by the respondents.*

Differing perceptions within subgroups of building owners

When comparing the responses of sole owners (n=24) with those of joint owners (n=52), a significant difference was revealed in the barriers mentioned (Fisher-Freeman-Halton, p=0.002). While joint ownership itself was seen as barrier when adopting a PV system, the other barriers applied to both groups. This indicates that it is more difficult to develop rooftop PV on buildings where multiple people have to act together to install a system. One reason could be the perception that PV technology is mainly suited to detatched houses.

It was also possible to see that financial barriers were proportionally more often mentioned for commercial buildings (n=13) than for residential buildings (n=12) and ones with privately owned flats (n=46) (Fisher-Freeman-Halton, p<0.001), suggesting that PV systems on commercial buildings need to perform better economically in order to be viewed as an alternative to mains electricity.

By dividing the respondents into subgroups of owners of rented buildings (n=24), partially rented buildings (n=17) and unrented buildings (n=22) it was possible to show that the main barriers were often not mentioned equally by the different subgroups (Fisher-Freeman-Halton, p<0.001). In partly rented buildings, joint ownership was noticeably more often mentioned than by the other two subgroups.

Agreement with survey statements

The respondents were asked to indicate their agreemnt with 17 statements on a Likert scale from 1 (does not apply at all) to 5 (fully applies). Figure 7-2 shows the distribution of the answers in the form of a boxplot. There was strong agreement on a desire for more independent electricity production (8th from right) and also on considering a solar-thermal system instead of a PV system (3rd from right). The median (thick black line) for both statements is 4 and the second and third percentile (blue boxes) range from 3 to 5.

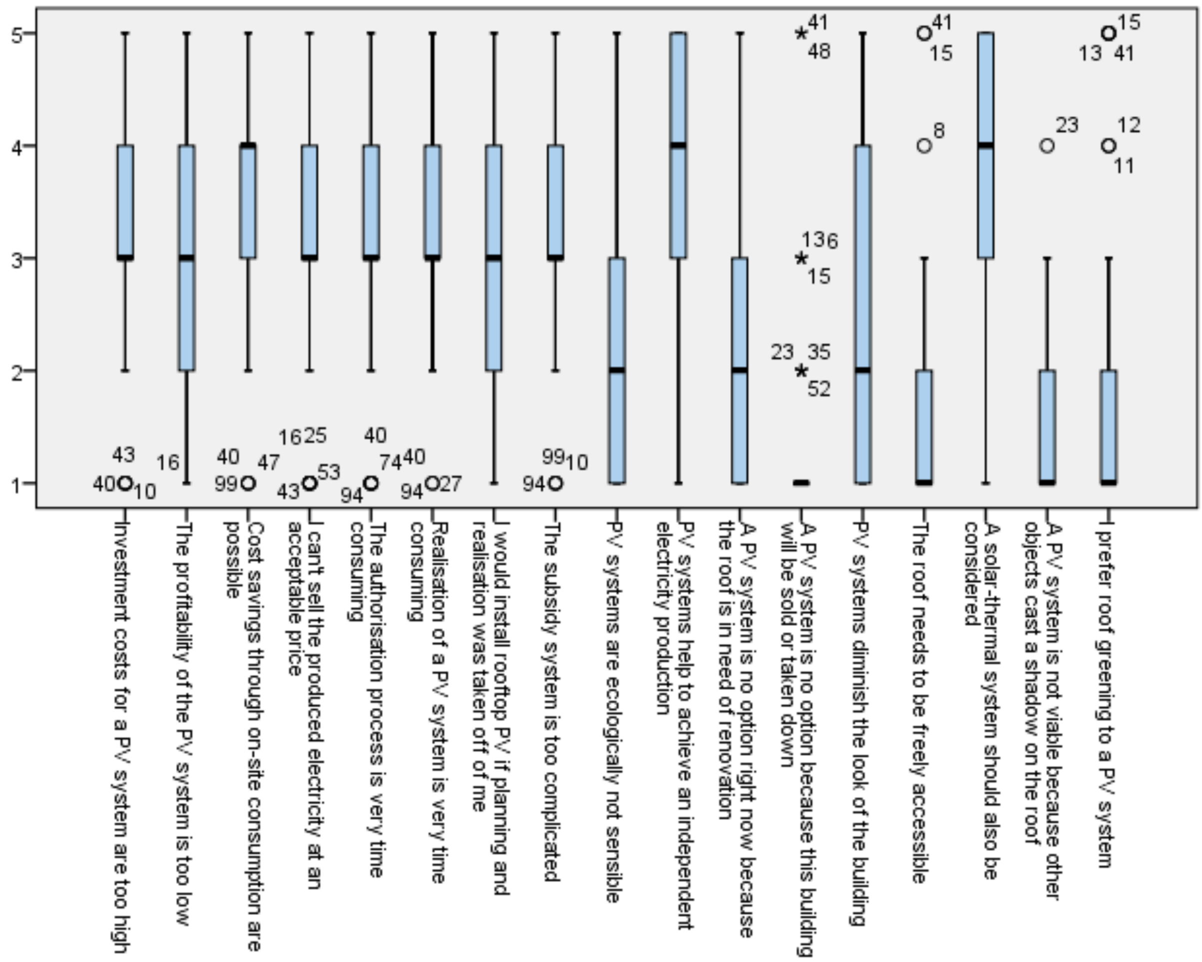


Figure 7-2: *Boxplot with the responses to the 17 statements (1 – does not apply at all / 5 – fully applies).*

The statistical tests showed that people with joint ownership (*n*=35) perceived the amount of time needed to plan and install a PV system to be higher than sole owners of buildings (*n*=20) (T (53) = -2.34, p = 0.023). More help during the planning and installation phases of PV systems on buildings in joint ownership would be appreciated (T (50) = -2.857, p = 0.006). This suggests that specialist contact points and guides on how to plan and install systems could be possible means of promoting PV systems on rooftops of buildings in joint ownership as well as buildings with privately owned flats.

The results also showed that self-sufficient electricity production is a stronger motivation for buildings in sole ownership (*n*=18) than for those in joint ownership (*n*=36) (T (52) = -2.515, p = 0.015). Therefore, further research into motivators and barriers is needed for groups of possible PV adopters who have different demands on their PV systems.

Conclusions

The survey showed that knowing their roof has a high solar potential and information on how to realise a PV system were not enough to convince private property owners to install rooftop PV. Even though the interest in the information event was strong, the resulting increase in PV adoption was not. Most participants were still indecisive about whether they wanted to install rooftop PV. Therefore, different approaches to motivating private property owners to take action are required if Switzerland's goals for renewable energy production are to be reached.

Financial factors were among the most frequently mentioned barriers, despite the fact that PV systems were actually profitable with the feed-in tariff in the year 2012. As could be seen in the responses, these owners did not perceive the financial costs and benefits objectively.

Respondents who cited financial reasons as the main barrier viewed the savings of on-site consumption to be low.

Buildings with multiple privately owned flats are a special case, with joint ownership of buildings being the most frequently mentioned barrier in this survey. These owners also more strongly believe that the planning and installation process is time consuming and that they would need help for these two steps. Therefore, separate approaches tailored to their needs could be a viable option.

Over half of the respondents to the survey are still indecisive and could, therefore, still be swayed to install a PV system. However, how this should be done cannot be answered conclusively in this study. Nevertheless, a possibility could be to draw more attention to co-benefits instead of mainly focusing on financial benefits. Detached houses where the owners are also the residents only make up 55% of the total Swiss residential building stock (FSO 2016). Only focusing on detached houses would neglect the 45% of buildings that are in different forms of ownership, therefore further research should be conducted focusing specifically on non-detached housing.

Part 2

Methods, Indicators, and Design for Resource Efficiency and Sufficiency

8. Towards a Fair Allocation of Raw Material Use for Indicators of Resource Efficiency

Dominique Guyonnet ✉, Jean-Louis Pasquier

Abstract

This paper examines the metrics used to assess the degree of efficiency of raw material utilization. Indicators of resource productivity used by various policy bodies typically divide gross domestic product (GDP) for, e.g., a country or a region, by an estimate of the amount of raw materials consumed by that country or region. But this estimate may be based on a variety of metrics defined using different system boundaries. This paper compares estimates of resource productivity calculated using three different metrics for raw material consumption: domestic material consumption (DMC), raw material consumption (RMC, i.e., "material footprint") and raw material input (RMI). The comparison is made using datasets published by UNEP and based on the EORA environmentally-extended multiple-region input-output model.

Keywords: Resource Productivity, Economy-wide Material Flow Accounting, Raw Material Equivalents, Material Footprint, Environmental Burdens, EUROSTAT, UNEP.

Introduction

The efficient utilization of raw materials constitutes one of the three pillars of the Raw Materials Initiative (CEC 2008), which is a fundamental building block of Europe's policy with respect to the sustainable supply of raw materials. To be effective, policy implementation requires indicators that can help monitor progress and guide further orientations. An important indicator of the efficient utilization of raw materials, promoted in particular by Eurostat (EC 2016), is resource productivity (RP) defined as the ratio between gross domestic product (GDP) and domestic material consumption (DMC). The DMC of a country, calculated using economy-wide material flow accounting (Fischer-Kowalski et al. 2011, Eurostat 2001; Figure 8-1), adds imports (raw materials, finished and semi-finished products, in e.g. tons) to domestic extraction within the country and subtracts exports. Therefore RP is an indicator of wealth generated within a country per unit mass of raw material consumption.

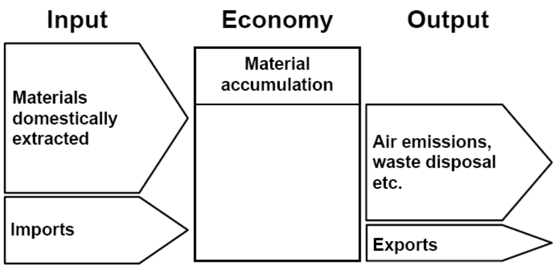


Figure 8-1: *Scope of economy-wide material flow accounts (Eurostat 2001).*

A shortcoming of this indicator, well identified by, e.g., Eurostat (Schoer et al. 2012), Munoz et al. (2009), Wiedmann et al. (2013), is that DMC only considers imports and exports in terms of weight contents of raw materials, but does not account for the raw material consumption required to generate these imports or exports (i.e., "embedded" raw material consumption). To overcome this problem, indicators expressed in terms of raw material equivalents (RMEs) have been proposed. RMEs are upstream used material flows required along the production chain (Munoz et al. 2009). A raw material consumption (RMC), also referred to as "material footprint" (MF, Wiedmann et al. 2013, UNEP 2016a), can be derived which is an analog to DMC expressed in terms of RMEs. Wiedmann et al. (2013) showed that the use of material footprint

(RMC) "*as a measuring rod results in reduced resource productivity for import-dependent countries*".

In this paper we look at the influence that the choice of metrics has on estimates of resource productivity. The various metrics are based on the following definitions (Fischer-Kowalski et al. 2011, Eurostat 2001 and others):

DE = domestic extraction
Imports = material amounts imported (weight at border)
Exports = material amounts exported (weight at border)
DMI = direct material input = DE + Imports (1)
DMC = direct material consumption = DE + Imports – Exports (2)
RME = raw material equivalents
RMC = raw material consumption (or material footprint; MF) = DMC expressed in RMEs
= DE + imports in RMEs – exports in RMEs (3)
RMI = raw material input = DMI in RMEs = DE + imports in RMEs (4)

Note that RMEs considered in the establishment of RMC (or RMI) are "used" raw materials: unused raw materials such as, e.g., overburden extracted during a mining operation in order to access an ore deposit, is therefore not taken into account. Such unused material would enter into the calculation of TMC (total material consumption; Fischer-Kowalski 2011). On the other hand, the gangue, i.e., the worthless material that is closely mixed with a wanted mineral in an ore deposit and is separated during ore processing, is taken into account.

Multi-region input-output (MRIO) data

The increased spatial separation between production and consumption, with resource extraction and agricultural production performed in some parts of the world while industrial manufacturing and consumption take place in other parts, has led researchers to develop global analytical tools for addressing sustainability (Wiedmann et al. 2011), such as multi-region input-output (MRIO) models. Basic building blocks of these tools are economy-wide input-output tables (Leontief 1986), which represent the interdependencies between the different branches of an economy, considering economic activities, imports, exports, final demand, etc. In Europe for example, individual member states provide yearly their national input-output tables including environmental accounts (NAMEAs) to Eurostat. But contrary to national tables compiled by, e.g., OECD or Eurostat, MRIO tables include full trade matrices between all countries (with off-diagonal matrices). MRIO tables also account for raw material consumption related to the production of imports or exports, based on the raw material equivalents (RMEs) mentioned above: when extended to material flows, MRIO models enable to estimate material equivalents of products, including those imported or exported. Therefore MRIOs are referred to as "environmentally-extended, multi-region input-output tables".

There currently exist several initiatives that are developing MRIO models. One such initiative is the EXIOBASE dataset (Tukker et al. 2018, Stadler et al. 2018) which aims at developing an environmentally-extended input-output framework for 28 EU members and 16 major economies. The dataset uses supply-use tables in a 163 industry by 200 product classification. The Global Trade Analysis Project GTAP 9 data base (Aguiar et al. 2016) is made of symmetric input-output tables covering 140 regions and 57 economic sectors. Environmental extensions include greenhouse gas emissions, energy volumes, land use, etc. One of the most complete MRIOs to-date is the Eora dataset (Lenzen et al. 2013, 2012). Eora disaggregates the world into 187 countries with a detail of up to 500 economic sectors. It also provides a historical time series from 1990 to 2010, i.e., two decades of data which help appreciate whether decoupling between economic growth and raw material consumption is occurring or not. The sources of data used for constructing the Eora dataset are input-output tables from national statistical offices, compendia of input-output tables from Eurostat or OECD, the UN National Accounts Main Aggregates Database (United Nations, 1982-present), UN Comtrade, etc.

The data published by UNEP (2016a, 2016b) on global material flows and resource productivity are based on the Eora dataset. The UNEP tables present a variety of parameters and metrics including DE, DMC, RMC (or MF), Imports and Exports, RMEs of imports and exports, consumption per capita, etc. Values are presented for 4 categories of raw materials: biomass, fossil fuels, metal ores and non-metal ores. The raw materials included within these categories are shown in Table 8-1. The data presented in the next section are based on summations of these four categories.

Category:	Biomass	Fossil fuels	Metal ores	Non-metal ores
Raw materials:	Wood fuel Crop residues Timber Fodder crops Grazed biomass Cereals Sugar crops Other	Natural gas Crude oil Lignite/brown coal Coking coal Bituminous coal Other	Zinc ore Copper ore Nicker ore Tin ore Iron ore Aluminium ore Precious metal ores Other	Salt Construction minerals Clays and kaolin Chemical and fertilizer minerals Other mining and quarrying products

Table 8-1: *Raw materials included in the different categories of the UNEP (2016a, 2016b) dataset.*

Comparing metrics of resource productivity

Indicators of resource productivity used by various policy agencies typically divide gross domestic product (GDP) by a measure of raw material use. Below we compare estimates of resource productivity obtained by dividing GDP (in US dollars expressed in purchasing power parity at 2005 constant prices) and three metrics of raw material use: DMC, RMC (i.e., “material footprint”) and RMI. These three ways of calculating resource productivity are noted below as, respectively, RP_{DMC}, RP_{RMC} and RP_{RMI}.

Figure 8-2 shows that, following which metrics are selected for raw material use, different countries fare more or less favourably in terms of resource productivity. Countries that have high levels of domestic extraction and are net exporters of raw materials, e.g., Chile and Australia, have values of RP_{RMC} that are higher than RP_{DMC}. Conversely, countries that are major importers of raw materials and/or products, with embedded raw material flows, have higher values of RP_{DMC} than RP_{RMC}. An extreme case is Hong Kong, which shows an enormous RP_{DMC}, as it relies nearly entirely on imports. Countries like Luxemburg for example (for which the data are missing in the UNEP database) would show a similar picture. In all cases, values of RP_{RMI} are lower or equal to the other two metrics, because exports are not retrieved from RMI.

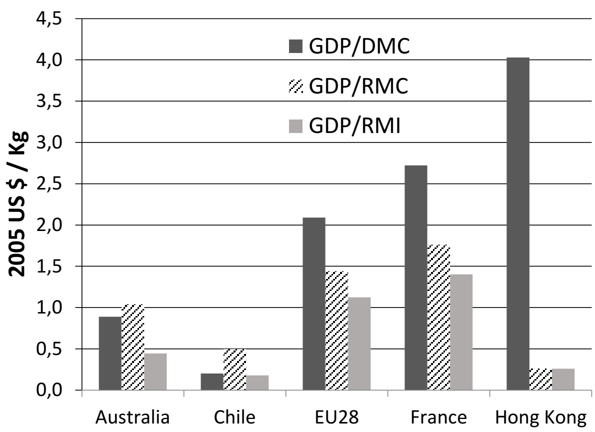


Figure 8-2: *Estimates of resource productivity in 2010 based on three metrics of raw material use. Data from UNEP (2016b).*

Looking at the data in terms of time-series provides information regarding the relative decoupling of economic growth and raw material consumption. If RP_{DMC} is the rod by which such decoupling is measured, then most countries considered appear to be on the right track in terms of creating more added-value per unit mass of used raw materials. But if upstream raw material flows, required along the production chain (RMEs), are accounted for, then the picture appears to be less optimistic. The discrepancy between RP_{DMC} on the one hand and RP_{RMC} (or RP_{RMI}) on the other hand, is particularly apparent in the case of the UK and Hong Kong data (Figure 8-3). Figure 8-3 illustrates the issue of "apparent decoupling" between economic growth and raw material consumption, which is one of the main motivations behind the development of environmentally-extended input-output tables (see, e.g., Wiedmann et al. 2008).

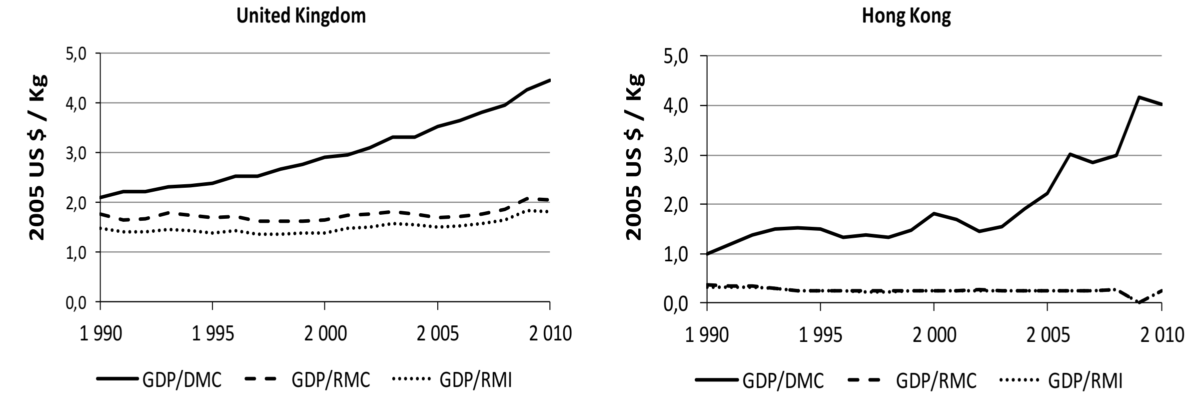


Figure 8-3: *Trends in resource productivity based on the data of UNEP (2016b): UK and Hong Kong.*

The discrepancy is also visible, albeit to a lesser extent, for the EU-28 and e.g. France in particular (Figure 8-4). When considered in terms of RMEs, decoupling between economic growth and raw material use in the EU-28 as a whole is not obvious. Worth noting in Figure 8-4 (right) is the sudden increase in all indicators starting from 2008. This is probably related to the financial crisis, which slowed down raw material consumption worldwide, while the impact on GDP was not as severe in relative terms.

Figure 8-5 shows the trends for two countries that are major producers and exporters of mineral raw materials; Chile and Australia. For these countries, the curves based on RMC as an indicator of raw material use are seen to lie above the curves based on DMC. This is because with RMC, raw materials embedded in exported products containing metals are retrieved from the metric. Although not shown here, data for China suggest an increase in resource productivity whichever the metric used.

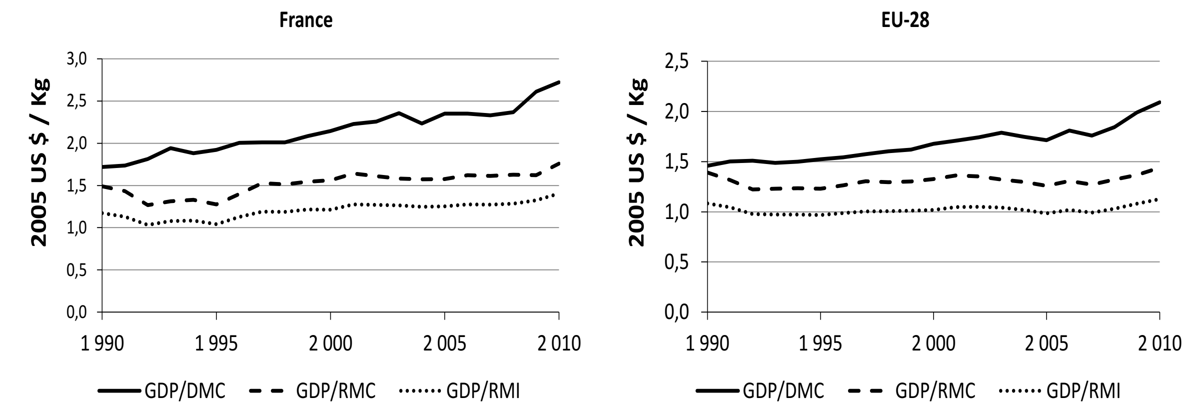


Figure 8-4: *Trends in resource productivity based on the data of UNEP (2016b): France and EU-28.*

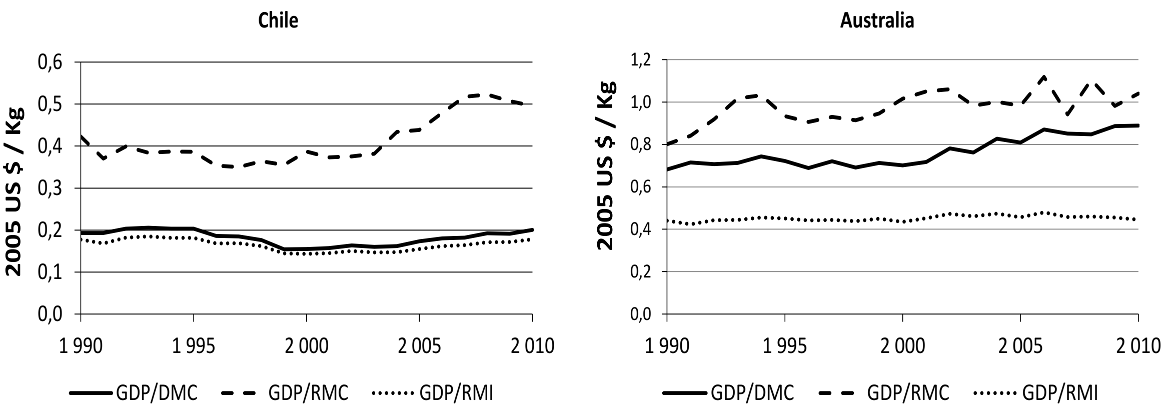


Figure 8-5: *Trends in resource productivity based on the data of UNEP (2016b): Chile and Australia.*

Conclusions

This paper compares estimates of resource productivity based on three different metrics of raw material use. It illustrates that DMC (domestic material consumption; Equation 2) tends to favour countries that are net importers of raw materials and/or finished or semi-finished goods, because raw material flows embedded in these imports are only accounted for in the domestic extraction of the exporting countries. DMC is a useful metric for highlighting countries that rely largely on domestic extraction, but it should not be used for estimating resource productivity. Taking the case of Europe, such a metric is damageable to the European extractive industry because it encourages the import of mineral raw materials rather than production from European sources. This is in contradiction with the second pillar of the Raw Materials Initiative (CEC 2008) and promotes the import of raw materials from countries where environmental emissions are often much higher than if they were produced in Europe. RMC (or material footprint; Equation 3) is a far superior metric for estimating resource productivity, but it tends however to favour countries that are net exporters of raw materials because embedded raw materials in exported products or semis (e.g., copper mattes) are retrieved from the metric.

As an alternative, we suggest using RMI (raw material input; Equation 4) for estimating resource productivity. RMI is a measure of the quantities of raw materials used directly or indirectly by a country in order to create value, as reflected in GDP. It is expressed in raw material equivalents and provides a coherent basis for comparison with the economic wealth generated by a country. The fact that exports are not retrieved from the metric would seem more “fair” in terms of a shared responsibility for environmental burdens. Raw material flows embedded in exports participate in the creation of wealth reflected in GDP and therefore should not be retrieved from the indicator. It is worth noting that the German Resource Efficiency Programme (FME 2016) has selected raw material input (RMI) as a basis for calculating raw material productivity. Despite inherent (and to a certain extent irreducible) uncertainties in environmentally-extended, trade-linked, multi-region input-output tables, it would seem important to further develop such tools in order to provide policy makers, but also the general public, with a realistic view of the true dependencies of our consumer societies on the use of raw materials. Realistic indicators are essential if policies in favour of a circular economy are to be effective.

9. The WORLD6 Integrated System Dynamics Model: Examples of Results from Simulations

Harald Ulrik Sverdrup ✉, Anna Hulda Olafsdottir, Kristin Vala Ragnarsdottir, Deniz Koca, Ullrich Lorenz

Abstract

The WORLD6 model is a fully integrated dynamic world systems model. It includes a biophysical global economic model, based on first principles of physics and thermodynamics, forcing it to be fully consistent with the underlying mass- and energy balances. The WORLD6 model first creates value from extraction of natural resources, input of human labour, the efficiency effect of mechanization and automation, the effect of innovation and their use in manufacturing of goods and services, and the secondly does monetization through market mechanisms and debt financing. The model includes 7 different capital stocks for: (1) industrial resource extraction, (2) industrial manufacture, (3) social service capital, (4) agricultural capital for land use and food production, (5) military capital, (6) speculative capital tied up in derivatives, real estate, consumer credits, (7) criminal or illegal capital. There are 3 different debt pools; (1) general, (2) speculative and (3) pensions. These are all linked through a number of feedbacks in the system to resource extraction, energy production, population dynamics, food production and phosphorus extraction, manufacture of consumer goods and services. The WORLD6 model connects to environmental pollution with feedbacks and inputs to human health and climate change inside the model. The model includes money flows, stocks as well as debt dynamics and how this is connected to the capital base and the governance. The WORLD6 model has earlier been extensively tested on natural resource extraction rates, resource ore grades, supply volumes and market price for resources with very good success. The WORLD6 model system was tested in its economic aspects against observed GDP for the period 1850 to 2015 and GDP per capita, commodity prices, extraction rates and resource supply rates with good success. These results were obtained from first principles only and without calibrating the model to any type of data time-series.

Keywords: WORLD6 Model, Economic Model, Society, Natural Resources, Environment, Base Case Scenario, Policy Development.

Introduction

The WORLD6 model is a fully integrated dynamic world systems model. It includes a biophysical global economic model, based on first principles of physics and thermodynamics for consistency. It goes beyond stock-and-flow consistent models, by forcing it to be fully consistent with the underlying mass- and energy balances. There are efforts to achieve several goals for the decades to come:

1. A long term sustainable energy supply and to be independent as far as possible from fossil fuels by 2040.
2. The future energy visions needs the assessment of long term natural resources suppy. Alternative energy technologies and ways in using energy, demand larger use of rare metals and materials. Will there be enough?
3. On synthesizing measures and solutions to address the challenges, it emerges the necessity to consider what constitutes sustainable society and resource use, and what the implications are in terms of energy, natural resources, social, cultural and political aspects. Changes may be of technological nature, but also on consumer behaviors and habits areas.

The WORLD6 was run to investigate what it would take to make some of these policy visions a reality. Simulations were run for the period 1850 to 2400 and it was checked on historical performance. The system delays are significant for many of the processes involved, from short term (a few years, business cycles), via intermediate (10-30 years, generational times) to long delays (100 or more years, carbon cycle, population dynamics, extraction cycles, lock-in into fundamental heavy infrastructures).

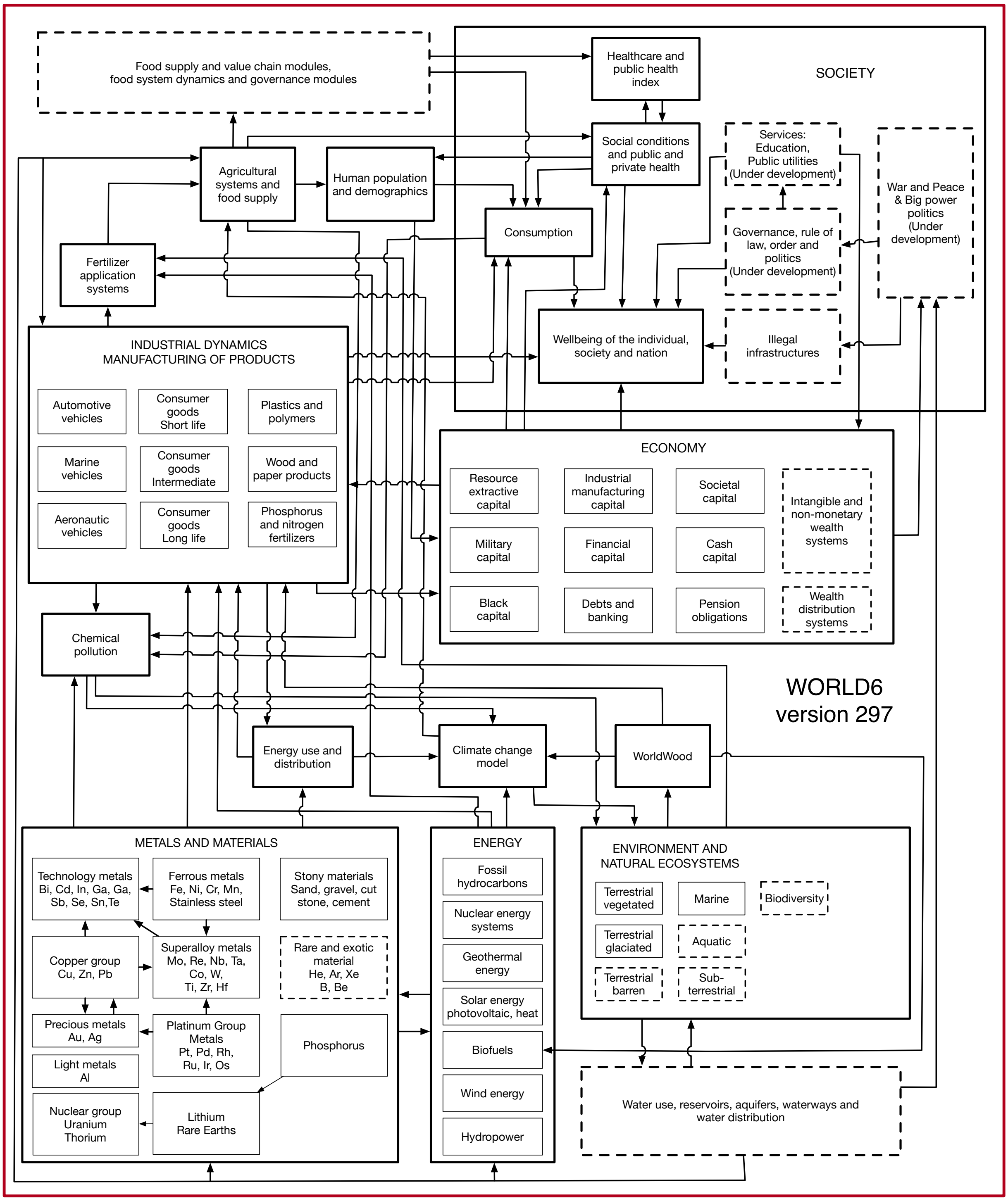


Figure 9-1: *Overview of the WORLD6 and its submodules in Version 297. In the model, nearly everything is connected. The model links the biophysical world, and the social world of humans, and from them generate the economy within the bounds of the world.*

Outputs dealt with from the WORLD6 model

The peak curves for the key resources are as described in the following. The key large scale resources are:

1. Fossil hydrocarbons; oil, gas, coal
2. Fertilizers and proxies for food: Phosphorus global supply (The food module also deals with land area for agriculture and soils per land area unit. Phosphorus is used as a proxy for food)
3. Stony materials; sand, gravel, stone, cement, concrete
4. Woody materials and paper
5. Polymers and plastics
6. Metals; iron, steel, stainless steel, nickel, chromium, manganese, aluminium, copper, zinc, lead, antimony, bismuth, cobalt, indium, gallium, germanium, selenium, gold, silver, tellurium, molybdenum, rhenium, niobium, tantalum, wolfram, tin, lithium, rare earth elements, platinum, palladium, rhodium

The technology metals are quite small in volume, and sometimes modest in production value. However, they hold key positions for many different key technologies that are essential for making a transit to a new sustainable society with respect to energy and materials. In former work we reported on the extraction, supply, price, and depletion of different metals, such as silver (Sverdrup 2014a), copper (Sverdrup 2014b), lithium (Sverdrup 2016a), and cobalt (Sverdup 2016b). The assessment of global metal supply sustainability was also discussed by Sverdrup et al. (Sverdrup 2017). In the model, all losses and wastes in each transformation are counted up. Waste is the starting point for recycling. Recycling is driven by market mechanisms in the model. That implies technical capability (which change over time) and profitability, depending on price and cost of recycling. In the WORLD6 model, a number of interdependencies are made between different modules and sectors. These are:

1. Demand linkages
   a. For many energy production technologies, special materials are needed. When this is the case, they are included in the demand, and taken away from their extraction module and taken to the energy module. Examples of this are: silver, gallium, germanium, indium, rare earths for alternative energies. Stainless steel requires nickel, manganese and chromium. Production is reduced when demand cannot be fulfilled.
   b. The extraction of all materials require energy and this energy is taken from the markets in the energy module. Production is reduced when demand cannot be fulfilled.
   c. Demands in some modules are taken from other modules
2. Supply linkages
   a. For the dependent materials, secondary extraction is done from mother metals, and the rate depend on the extraction rate of the mother metal.
   b. When actual supply to a module is less than demand, then the production is reduced.
   c. When more energy is demanded by resource extraction, than what is available, then resource extraction is reduced.
3. Recycling
   a. Recycling is done for all metals and materials
4. Economy
   a. Resource extraction generate income, costs and profit, a basis income in the economic model. This income makes up about 40-50% of all value generated. The rest comes from human labour and knowledge input.

Figure 9-1 shows an overview of the WORLD6 model and its submodules in Version 6.260. WORLD6 runs on a daily time-step in the integration.

Modelling energy extraction, production and consumption

Energy is an important resource as it allows for use of machinery that greatly amplifies the human effort. This justifies its prominence in the WORLD6 model. The energy module in the WORLD6 model considers the following sources of energy for distribution :

1. Fossil fuels: (1) Hydrocarbons (2) Nuclear fuels
2. Renewable energies (1) Biofuels to heat or to electricity, (2) Hydropower to electricity
3. Technology energies: (1) Photovoltaic solar harvest to electricity, (2) Wind power to electricity (3) Geothermal power to heat or electricity

In “oil” are all types of oil contained; crude oil, tar sands, tight oil, shale oil, heavy oil, offshore etc. This variety is taken care of into the ore grade classification. The same principle applies to natural gas and coal of all kinds being extracted. It is also considered the production of gas from oil, gas conversion to oil and the production of synthetic gas and crude oils from coal, when this is profitable or done by necessity.

Economic modelling in the WORLD6 model

In WORLD6, a simple economic model has been constructed, based of biophysical principles. Mass and energy balances apply, and money flows with the materials, commodities and the services. The economic module in the model is simplified, and under development and steady upgrading (Figure 9-2). In it, we take into account industrial capital (To produce goods and food), social service capital (To provide public services), resource industry capital (To extract resources), military capital and illegal black capital (money outside the regular society), as well as a global capital stock (Cash to pay bills) and a stock of debts. Debts are incurred as a part of any investment and for replenishing the capital stock of liquid cash. The debts taken are paid down over 30 years in the model and incur interest payments at an average rate of 3%. All capital is subject to wear (depreciation) and all capital stocks such as industrial capital, resource industry capital, social capital or military capital, requires maintenance, which all come as a cost. Debts cannot be taken of the debt to GDP ratio is more than 150%. Each step in the supply chain is demanded to run at a profit. When the profit declines, the production decrease, and if supply falls below the demand, immediately rising the price, keeping profits up as long as there is demand, and supply can be done. The increase in price along the supply chain, is determined by the required profit margin and the resource use efficiency.

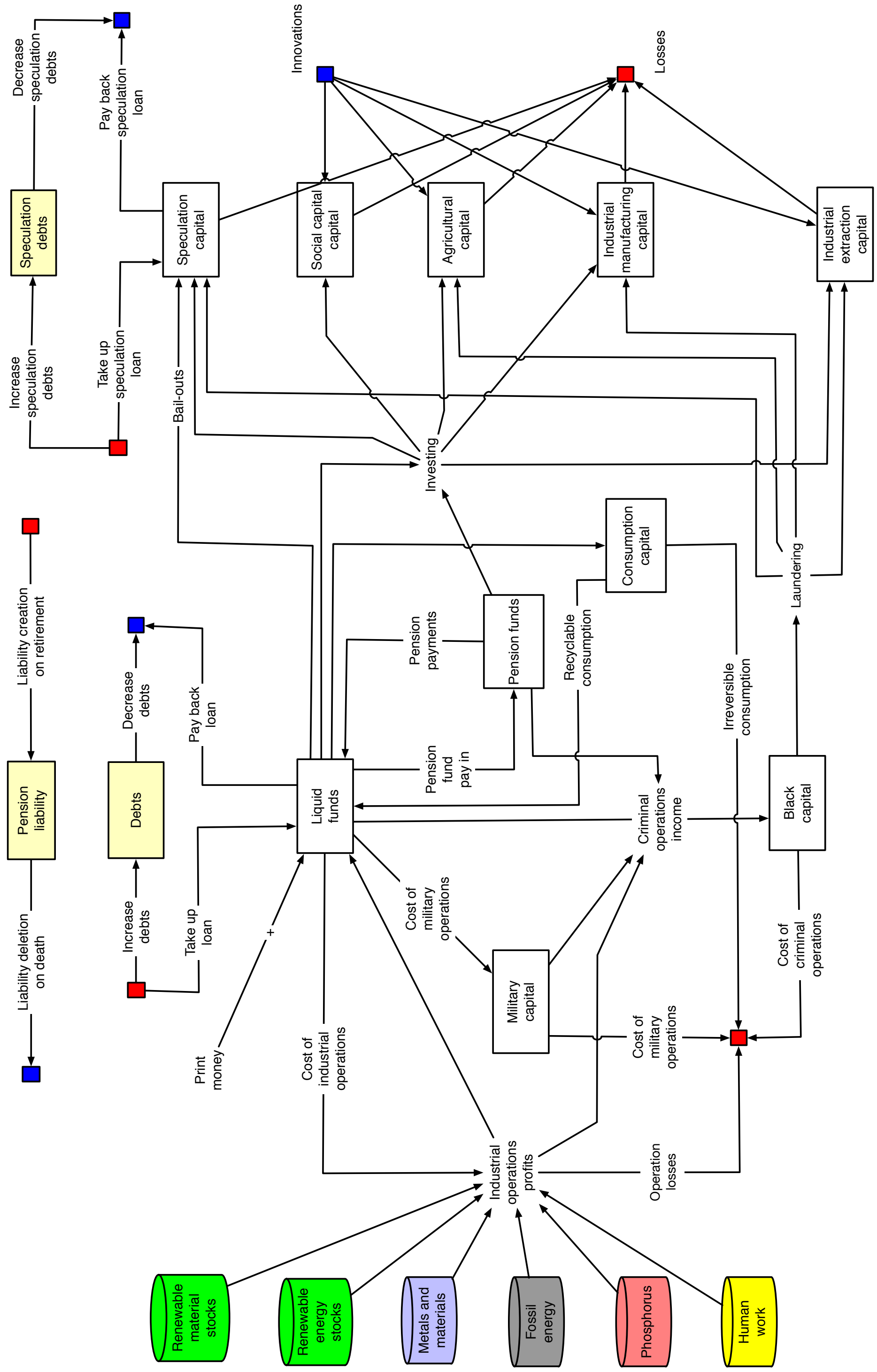


Figure 9-2: *Overview flow chart of the economic module included in WORLD6.*

The resource use efficiency is made up of the production yield and the production losses. The basic principles in the economic model used are as follows:

1. Income arise from resource extraction and input of human labour and innovation in the supply chain from raw material to commodities and consumables. Profit is generated along supply chains, as the difference between sales income and cost of production.
2. Resource supply: Raw material (resources) costs come from extraction, treatment, refining and supply costs to the market for raw materials. Raw material income is the amount supplied to the market times the market price at that point in time. The profit is the income minus the cost of extraction and supply.

3. Commodity supply: For commodities, the costs come from amount of raw materials used, their market price and cost of input of human labour and innovation. For commodities, the income is the amount supplied times the market cost. The profit is the income minus the production costs as outlined above. Resource use efficiency and yield factor for each transformation is used.
4. Service supply: Services also use resources and commodities, and require certain infrastructures to be present, even when the target supply is only a service. Income is generated by delivery of the service times the market price for that service.

Resource conversion is the most important source of revenue. Important other sources of value generation are inventions, innovations, organization of production and service provision and input of human labour. Important sinks are material losses, infrastructure and commodity wear or depreciation of capital. The WORLD6 model has used simplified supply chains for some commodities and materials. In the primary production, profits arise as the difference between income from sales and extraction costs. In the next step, sales of commodities and services become the source of income, whereas the resources used or used and lost are costs, profits being the difference (Figure 9-2). This way, the economic model is tied to biophysical flows and events.

The base scenario and its outputs

The base case scenario in WORLD6 does not introduce any new policies that involve active interventions, beyond the already built-in feedbacks. These feedbacks are part of the systems, and operate endogenously in the model. Important such feedbacks are the following:

1. Extraction increases as a response to increased profit. Profits increase when prices rise more than extraction costs do. When the profit drops to zero or below, the extraction stops. Over time, extraction cost decrease because of technological advances.
2. The demand declines with increasing price
3. The price increase when the tradable amount in the market decline, and decrease when the market tradable amount increases.
4. Recycling increases with increases in market price or when the profit of recycling increases. Recycling costs goes down with time, as the recycling technology improves.
5. The extraction module has some built-in scaling functions.
    a. A mining and extraction efficiency with time function, based on data from literature.
    b. Extraction costs increase with decline in resource quality, both in terms of work requirements (Extraction costs) and energy requirements (EROI).

The basic scenario is capable of reconstructing the past observations of mining rate, market price, and when data is available, ore grade, stock-in-society, known reserves. The model is not calibrated to any dataset, it is not data-driven, but operates up from basic physics and ecology, confined by mass- and energy balances. Important are to get good estimates of all technically feasible extractable resources, regardless of extraction cost, as the model decides internally over what will get extracted, based on what is the most economically profitable.

Assessing resource access per person on the global level and other simulation outputs

For the assessment of risks for scarcity, two types of diagrams are central to the evaluation of scarcity and whether it an apparent challenge or a real challenge that demands a policy consideration and potentially measures to be taken: Supply as amount per person per year and stock-in-use per person. Supply per person will be used for replacing irreversible losses, new investment to stock-in-use for new persons added by population growth, and growth of present standard. These indicators have been calculated for all resources investigated. Stocks-in-use per person is an indicator of the service provision.

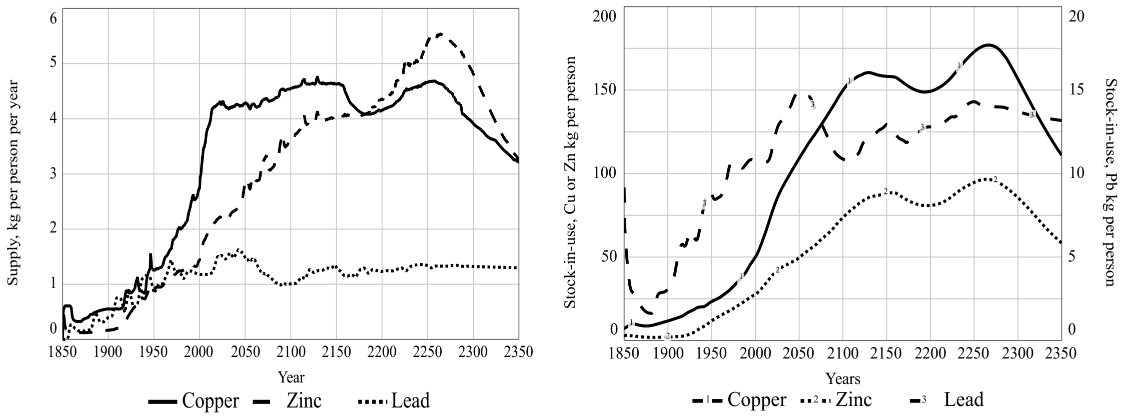


Figure 9-3: *The supply in kg per person and year (left) and the stock-in-use (right), kg per capita, for copper (-1-), zinc (-2-), and lead (-3-) as calculated using the WORLD6 model.*

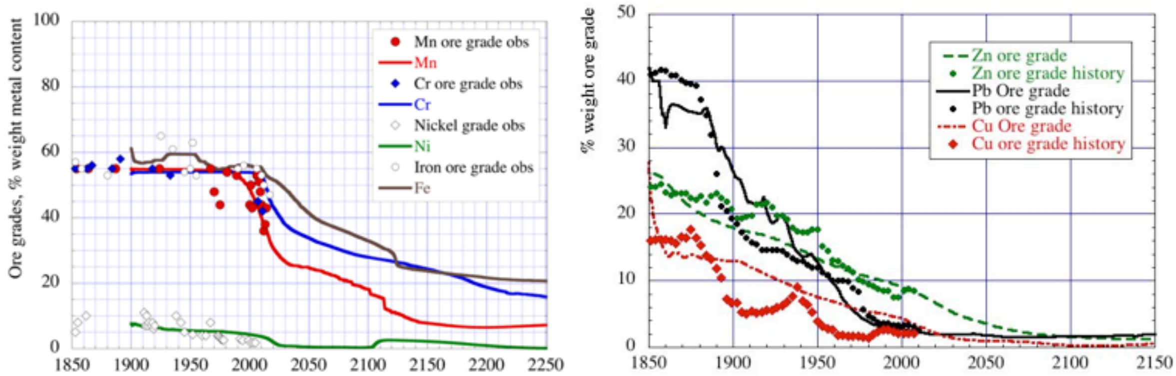


Figure 9-5: *Ore grades for iron, manganese, chromium and nickel as simulated using the model (left), and ore grades copper, zinc and lead (right), as compared to the observed ore grades. Declining ore grades are a very powerful signal that the resources are becoming exhausted.*

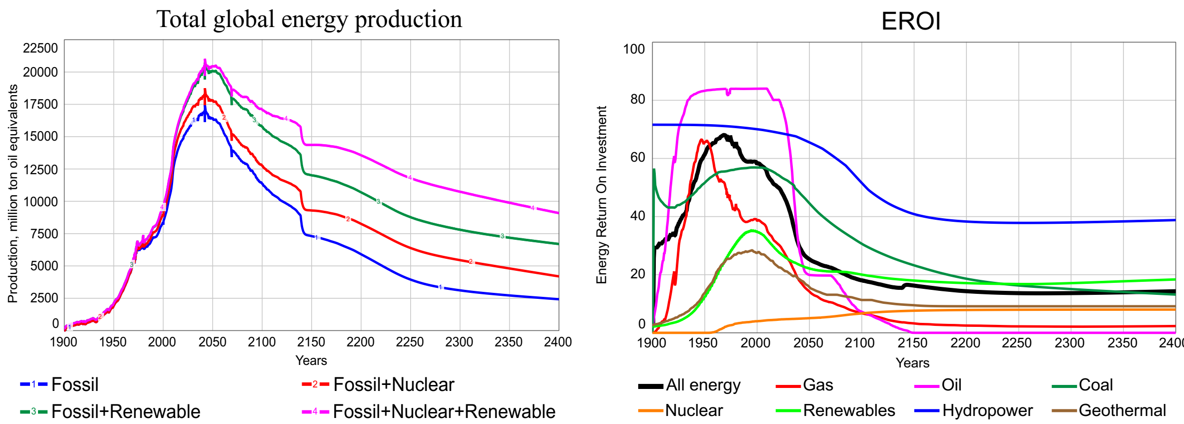
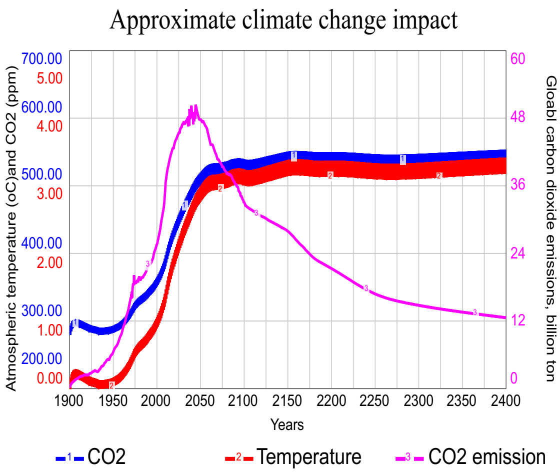


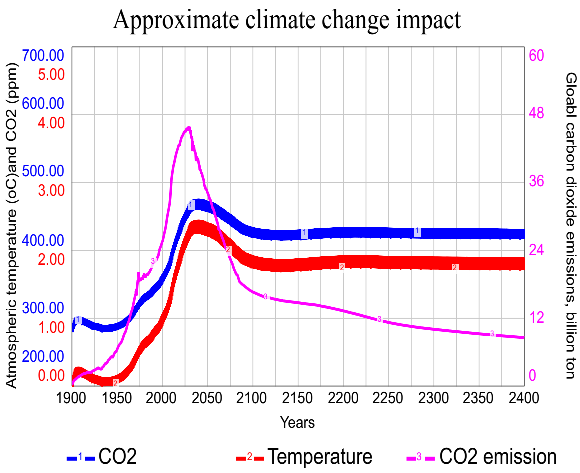
Figure 9-6: *Overview of the energy produced in the WORLD6 model (left) and the Energy Return on Investment for different energy types (right).*

Growth in stock-in-use per person is correlated to material standards and a decline, suggests a decline in the degree of provision, suggesting a decline in provision of material quality of life. Efficiency of service provision per unit stock-in-use has not yet been developed but would be the next natural step to take. A significant part of the large, but ultralow grade coal resources will not be fully extracted due to low energy return on investment and high extraction costs that cannot compete with more cost-efficient renewables. The results from the scenario runs are as follows:

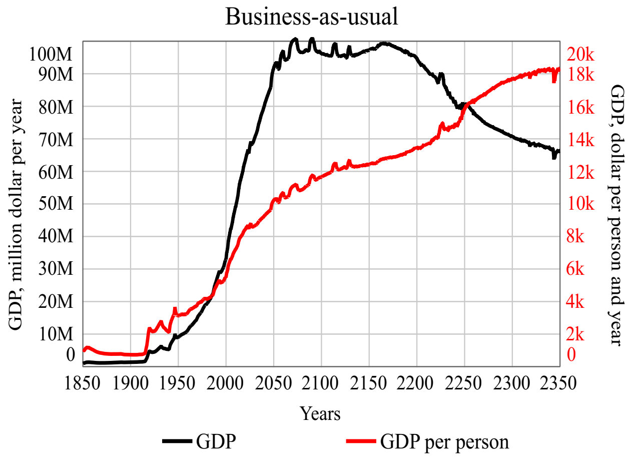
1. **Base case scenario** for GDP is shown, with and without climate change damages counted. The climate change damage was estimated as land inundation and city flooding damaging costs. Costs of conflicts and war were not counted.
2. **Maximum 2°C climate change**, done by shutting down fossil hydrocarbon extraction by 90% in 2020-2060. GDP is first reduced by 3% during 2030-2060 because of already incurred damages before 2020 and the loss of oil revenues. The scenario is letting the GDP level off at a value above the level of the base scenario. Thus, mitigating climate change and resource scarcity is beneficial to industry.
3. **UN population scenario** The GDP is higher for the larger population, because of the way GDP is defined. Climate and pollution damages are subtracted from the GDP. The UN population scenario, leads to a CO_2-polluted, and heavy metals-contaminated, overcrowded and a worn-down Earth, with massive climate change ecological and economic damages. This prevents an economic recovery, and GDP stabilize at a significantly lower level than the Maximum 2°C scenario and the base case scenario.



a: WORLD6 Base case scenario.



b: Max 2°C warming Draw down fossil fuels 90%.



c: GDP for base case scenario.

Figure 9-8: *Climate change outcomes for 4 different scenarios tested with the model. The climate change model is internal to the WORLD6 model. Estimated GDP for the base case scenario. Estimated GDP for maximum 2°C climate change, done by stepping down fossil hydrocarbon extraction 2020-2060 is nearly identical to the base case scenario, but ends slightly higher. Phasing out fossil fuels do not lower the GDP, but create a small increase.*

Policy implications

The purpose of the model is to assist in policy development towards a long term sustainable society, where all aspects are linked; economy, *natural resources, environment* and society. This is not really the case today, and the model is an alternative to economic models based on statistics, of which some have little or no connection to any reality. The present simulations show that many natural resources will peak in the period from 2040-2070, creating a number of simultaneous supply crisis. Increased recycling or resource efficiency may be used to drag the supply peaks out in time, softening the problems. The resource peak can be moved with several parameters using policy instruments:

1. Total resource use with less CO_2 impact: Limit extraction of carbon-based energy resources, Limit calcination of fossil carbonates (Cement production and carbonate ores). Use of more wood materials for infrastructures which sequester CO_2 in their production and use
2. Resource use efficiency can be improved in the extraction step, by decreased losses in every transaction and less losses in recovering and recycling. Important is better utilization efficiency in the consumption step and smaller material and energy consumption overall
3. Recycling implies that the material is reused and less net supply is required from primary sources, extending the life-time of our natural non-renewable resources.
4. Efficiency of use: Better use efficiency, based on better durability, repair, retrofit or design for recycling during or after consumption. Reduction of irreversible losses in the system: extraction, refining and supply, manufacturing and transaction losses, use losses, recycling losses

Some of these are already somewhat promoted in the market system, but several can be significantly improved on by policy measures. For several of the technology materials, this appears to be necessary. Either as supportive or constraining regulations and stimulants. It would appear that taking initiatives to become market leaders and in several segments will create a position of priority in the market. The model runs suggests that a horizon of 2040-2050 for a phasing out 90% of all fossil fuels is challenging but realistic.

10. A Methodology to Estimate Benefits from WEEE Recycling, Ecodom Case Study

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Abstract

WEEE is Waste Electrical and Electronic Equipment and its proper treatment is one of the challenges Europe is facing, because of economically essential materials recovery and of proper treatment of environmentally critical components they contain (CFC, PCB, lead). Ecodom has developed the methodology presented here, which covers all the phases of the WEEE recycling system, and considers the impacts in term of energy used (GJ) and of equivalent CO_2 emissions caused. The considered system starts from waste generation, when users decide to dispose of electrical and electronic equipment, and it ends with the recycling or final disposal of the components obtained through WEEE treatment. The information used for the computation come from Ecodom activity (data come from business data-mining operations); for what concerns the coefficients (for instance Italian electrical mix), they come from literature (for instance, database Ecoinvent or information from Transportation Ministry). The novelty of this approach stands in evaluating environmental benefits through the comparison with a scenario in which Ecodom does not exist and WEEE is managed by other individuals (Scenario B).

Keywords: WEEE, Sustainability, LCA, GRI Guidelines.

Introduction

Waste electrical and electronic equipment is one of the fastest growing and most critical waste stream in Europe (Biganzoli et al. 2015). In fact, WEEE contains several hazardous substances, such as metals and ozone-depleting gases, which needs to be treated in a proper way to avoid environmental and human health risks. In Italy WEEE is classified in 5 different categories (DM n.185 of the 25th of September, 2007): R1: heaters and refrigerators; R2: large household appliances; R3: TV monitors; R4: small household appliances; R5: lighting equipment. They are separately collected since 2005, following the implementation in Italy of the European legislation (Directives 2002/95/CE, 2002/96/CE and 2003/108/CE) by means of the national Decree 151/2005 (Decreto Legislativo n.151 2005). During year 2016 a total amount of 283,075 tonnes of WEEE was collected and treated in Italy, with an increase of 13.6% from the previous year, while the national collection average is 4.67 kg of WEEE per capita (WEEE Italian Coordination Center 2016). Ecodom is one of the leading WEEE take-back systems in Italy, with a share of 50.3% in R1 market of 65.4% in R2 market. It is a private entity established in 2004 and working since 2008, formed by 27 producers of electrical and electronic appliances, operating on Italian market. Ecodom's main goal is to avoid pollution, through proper treatment of disposed appliances, as well as to maximize materials recycling. It is in charge of WEEE collection and treatment activities, on behalf of the associated producers, who are responsible by law of proper disposal of domestic WEEE, for an amount corresponding to their market share (Decreto Legislativo n.49 2014). More in details, Ecodom manages WEEE coming from categories R1, R2, R3, R4, and R5 with a total amount of WEEE managed in year 2016 of 95,889 tonnes, corresponding to the 33.9% of the total amount of WEEE collected in Italy in the same year, by all the take-back systems (WEEE Italian Coordination Center 2016). Ecodom collected WEEE from 4,558 points, in every part of Italy, working with 46 treatment and transport suppliers and 41 different plants, dislocated as well in several Italian regions. Ecodom seeks to make all its activities' results clear and accessible; this is the reason why every year a Sustainability Report is published, containing all the information on environmental, social and economic performance of the take-back system. The objective of this research is to present a methodology to estimate environmental benefits coming from a proper WEEE collection and treatment system, such as the one operated by Ecodom. Instead of using a LCA approach, a new comparative methodology is investigated, thus extrapolating the environmental benefits of waste management through a comparison between different possible systems.

Materials and methods

Ecodom managed in 2016 95,889 tonnes, divided in the 4 Groups as follows: 37,606 tonnes of R1, corresponding to 49.4% of the total R1 collected in Italy; 57,383 tonnes of R2 (63.7%); 55 tonnes of R3 (0.1%); 845 tonnes of R4 (1.7%). The methodology was applied to 2016 data, but it is repeatable for different years and different take-back systems. The boundaries of the methodology consist in all Ecodom and its suppliers activities and in operations taking place before and after Ecodom. Upstream, the boundaries are set to citizens deciding to dispose off their appliances, transforming them in waste. Downstream, it is considered the impact of the final state of materials, whether they are recycled, recovered or landfilled. In the following paragraphs all the phases considered are described more in details.

From citizens' houses to collection points

Every year Italian citizens produce on average 4-5 kg of WEEE per capita. In order to correctly dispose off this waste they have three options. The first possibility is to bring their own waste to the Municipal Collection facility; otherwise they can take advantage of the Municipal Collection service, calling an operator to directly collect the waste at their houses. Finally they can bring them to electronic equipment shops (Decreto Legislativo n.49 2014) In this methodology, it is estimated that 50% of citizens directly bring WEEE to Collection facilities and shops (i), while the remaining 50% use the Collection services (ii). In case (i) citizens use their own cars and are able to transport for each trip 42 kg of R1 (average weight of a fridge) or 65 kg of R2 (average weight of a washing machine) or 15 kg of R3 (average weight of a TV). By hypothesis, there are not transports dedicated only to R4, since the appliances are very small and citizens are more likely to bring them while disposing off bigger appliances.

The average distance travelled by citizens for each trip was estimated starting from the number of Collection facilities in each region, in order to identify an average catchment area and therefore an average radius, travelled by citizens. Furthermore, in order to estimate the energy consumption and CO_2 emissions of this phase, a national average was computed using the values related to the most used car in Italy for different fuels (Automobile Club Italiano 2015). In case (ii), WEEE is transported from citizens' houses to Collection facilities by municipal waste service, using small trucks weighting 7.5 tonnes at full load. These trucks can transport respectively 1 tonne, 1.5 tonnes and 0.4 tonnes of R1, R2 and R3 per trip. As for the citizens, there are not dedicated travels for R4. The average diesel consumption of this kind of truck is 0.168 kg/km (Ministero delle Infrastrutture e dei Trasporti 2011, FIRE 2012).

From collection points to treatments plants

WEEE are transferred from Collection facilities by Ecodom transport suppliers. They use trucks of 26 tonnes at full load, with an average diesel consumption of 0.20625 kg/km (Ministero dei Trasporti 2011, FIRE 2012). All the information entered in the methodology (number of transports, distances travelled, weight, etc.) comes from Ecodom management system. For year 2016, Ecodom has been in charge of a total amount of 41,969 trips, with an average distance travelled of 95.5 km and an average weight carried of 2.3 tonnes.

Treatments

WEEE are treated in 41 specialised plants, operating with different energy sources, with a share of renewables of 15.7%. An average energy consumption is computed over all the plants; it is 155 kWh/tonnes for R1, which need a more sophisticated treatment to avoid ozone-depleting gases emissions, and 80 kWh/tonnes for the other Groups.

Ozone depleting gases extraction

WEEE of Group R1 contains ozone-depleting gases, such as CFC (Chlorofluorocarbons). They are used in the refrigerating circuits and foams and their release in the environment can be very dangerous both for the stratospheric ozone layer and for global warming (since they also have a strong warming potential). The first part of R1 treatment consists therefore in CFC extraction from circuits and subsequently, while milling, in continuous and careful gases aspiration. Ecodom performs every year audits on treatment plants, in order to monitor their performances. In particular, audits on R1 treatment plants aim at understanding if the CFC extraction from circuits and foams respects the quality threshold. Starting from audits results, the methodology computes the avoided emissions of CFC, and subsequently of equivalent CO_2. In year 2016, Ecodom's suppliers were able to extract the 93.2% of CFC in circuits (i.e. 2,219 g CFC12/t of R1 treated), as well as the 81.9 g of CFC per kg of foams (i.e. 6,434 g CFC11/t). The methodology also considers the fact that not all the amount of R1 reaching the plant is intact and that only a certain percentage contains CFC (newest appliances work with pentane). Suppliers are asked to sample 3% of the collected materials in order to extrapolate this information. In year 2016, 20.2% of R1 reaching the plant were damaged or were missing the compressor and only 60.1% contain CFC. Considering the Ozone Depletion and Global Warming Potential coefficients stated by WMO and IPCC (WMO 2011, IPPC 2013), it is possible to estimate the total amount of CFC and CO_2 emissions avoided, thanks to the proper and careful treatment.

Transport after treatment

Ecodom's suppliers are asked to precisely describe each fraction originated by the treatment process, such as pure metals, cables, compressors, mixed fractions, etc. For each of these materials they have to trace weights and further movements in a dedicated software, called Reptool. Therefore, it is possible to follow the material from the treatment plant to its final destination, whether it is a foundry, a recovery plant, an incinerator or landfill. In this phase of the methodology, it is considered an average trip for different kinds of fractions, in order to compute energy consumption and emissions of the transfer.

Recycling or final disposal

Different recycling or disposal methods can cause different environmental impacts. To model this phase the related Ecoinvent 3.2 coefficients were used, in order to estimate energy consumption and emissions for every fraction.

Comparative Scenario

All the steps presented in the previous paragraphs refer to Ecodom real activity, as it is performed every year. In this methodology we propose to assess the real impact and benefits of the system by comparing it with a situation in which Ecodom does not exist and therefore WEEE are managed in a different way. The easiest hypothesis would have been to consider a scenario in which all WEEE not collected by Ecodom are directly landfilled. However, this option does not trace the real world and overestimate the benefits, since WEEE contain a lot of valuable materials, which attract all kind of operators. Therefore, we selected a scenario in which:

- 50% of WEEE are managed by operators only interested in valuable fractions, and not in environmental problems;
- 50% is managed by a system similar to Ecodom with lower treatment performances for CFC/HC extraction.

All the phases described in paragraphs 2.1 to 2.6 are now revised in order to present the comparative scenario. In the following, for simplicity the real scenario will be called Scenario A, while the comparative one, Scenario B.

From citizens' houses to collection points

Since this phase concerns citizens' behavior and it is not influenced by WEEE management systems (taking into account that the collection facilities remain the same), impacts are the same as in Scenario A.

Transport and treatment

The new operators who are not interested in environmental problems will not look for the best operating plants, but will send WEEE to closest suppliers, in order to avoid transport costs. By hypothesis the distance travelled for each trip is equal to the lowest average distance travelled by Ecodom in Scenario A. In this case, it corresponds to 76.6 km, which is the average distance travelled for Group R2. The trucks characteristics are the same as in Scenario A. Moreover, these treatment plants operate with lower performances, in particular for R1 treatment, since they are not interested in avoiding dangerous substances emissions. Therefore, the energy consumption is equal to 80 kWh/t for all the Groups. For what concerns CFC emissions, the total amount avoided by Ecodom in Scenario A is here released, since there is no operation applied to avoid this emission. On the other hand, the operator similar to Ecodom acts for its share as Ecodom in Scenario A, except for CFC extraction. In fact, he operates with lower performances, by hypothesis the one experienced by Ecodom in its first year of activity (2008). This assumption comes from the awareness that without investing on quality in years the situation does not evolve.

Final fractions transport and disposal

External operators are only interested in valuable fractions. They will send to recycling only iron, copper and aluminum, while they will send to landfill disposal all the rest. The methodology does not only consider the impact of different disposal methods but also take into account the impact deriving from new materials production, such as wood panels, plastic components, etc. The operator similar to Ecodom acts as Ecodom in Scenario A.

Results and discussion

In Table 10-1 and 10-2 it is possible to see the impacts of Scenario A and B, for each phase, in terms of energy consumption (GJ) and emissions (tonnes of equivalent CO_2). It is possible to note that in Scenario A the most affecting phases are recycling and transport to treatment plants, which are still impacting in Scenario B but are surpassed by the impact of new materials production and CFC emissions. Concerning Scenario B, the impacts related to external operators are lower in many phases, since they try to minimize costs and energy consumption, to the detriment of the environment. If we look at the final phases (new materials production and CFC emissions), we can see the high environmental impact caused by these operators. Once all the impacts of both scenarios are computed it is possible to compare them; the benefits of a proper waste cycle correspond to the difference between the impacts of the comparison scenario and those related to the real scenario. In Table 10-3 the impacts of both scenarios are resumed and the according benefits are computed. Through proper WEEE management it was possible to save more than 340 thousand GJ of energy (96.7 million kWh), which correspond to the annual consumption of a city of more than 82,000 people, and to avoid the emission of more than 800 thousand tonnes of equivalent CO_2, corresponding to the CO_2 that is able to absorb a wood of 800 km2 in one year (Terna Rete Italia 2012, Regione Piemonte 2009).

Activity	GJ	CO_2eq t	Activity	GJ	CO_2eq t
1. From collection points to treatment plants			**5. Recycling**		
R1	41,451	15,223		203,035	13,649
R2	28,199	10,668		260,642	18,294
R3	148	53		332	24
R4	1,205	436		4,596	337
2. Treatment			**6. Thermal destruction, landfill**		
R1	20,985	2,917		5,010	14,993
R2	16,527	1,932		2,297	2,779
R3	16	3		9	5
R4	246	36		273	132
3. From citizens' houses to collection points					
R1 – citizens	4,263	548			
R2 – citizens	4,203	541			
R3 – citizens	17	2			
R1 – service	2,702	382			
R2 – service	2,748	408			
R3 – service	10	1			
4. Transport after treatment					
R1	9,372	3,848			
R2	4,120	2,263			
R3	30	12			
R4	134	70			
			TOTAL	612.570	89.555

Table 10-1: *Environmental impacts of Scenario A (year 2016).*

Activity	GJ	CO_2eq t	Activity	GJ	CO_2eq t
1. From collection points to treatment plants			**2. Treatment**		
R1 – interested in valuable fractions	13,880	5,097		5,415	863
R2 – interested in valuable fractions	14,099	5,328		8,263	1,316
R3 – interested in valuable fractions	41	14		8	1
R4 – interested in valuable fractions	419	152		122	19
R1 – similar to Ecodom	20,726	7,612		10,493	1,459
R2 – similar to Ecodom	14,100	5,334		8,264	966
R3 – similar to Ecodom	74	26		8	1
R4 – similar to Ecodom	603	218		123	18
3. From citizens' houses to collection points					
R1 – citizens	4,263	548			
R2 – citizens	4,203	541			
R3 – citizens	17	2			
R1 – service	2,702	382			
R2 – service	2,748	408			
R3 – service	10	1			
4. Transport after treatment			**5. Recycling**		
R1 – interested in valuable fractions	1,411	866		76,463	5,222
R2 – interested in valuable fractions	1,382	847		109,793	7,466
R3 – interested in valuable fractions	6	4		26	2
R4 – interested in valuable fractions	13	8		1,311	91
R1 – similar to Ecodom	4,686	1,924		101,517	6,825
R2 – similar to Ecodom	2,060	1,132		130,321	9,147
R3 – similar to Ecodom	15	6		166	12
R4 – similar to Ecodom	67	35		2,298	169
6. Thermal destruction, landfill					
R1 – interested in valuable fractions	2,058	3,344			
R2 – interested in valuable fractions	3,150	5,118			
R3 – interested in valuable fractions	7	4			
R4 – interested in valuable fractions	67	110			
R1 – similar to Ecodom	2,505	7,497			
R2 – similar to Ecodom	1,149	1,389			
R3 – similar to Ecodom	4	3			
R4 – similar to Ecodom	137	66			
7. New materials production (only for external operators)					
R1	275,696	13,496			
R2	121,765	3,847			
R3	486	75			
R4	11,681	342			
8. CFC emissions					
R1 – interested in valuable fractions		542,880			
R1 – similar to Ecodom		253,192			
			TOTAL	960,819	895,424

Table 10-2: *Environmental impacts of Scenario B (year 2016).*

	GJ	CO_2eq t
Scenario A	612,570	89,555
Scenario B	960,819	895,424
Benefit (B-A)	348,249	805,869

Table 10-3: *Impacts of Scenario A and B and benefits (year 2016).*

		SCENARIO A		SCENARIO B		Benefits (B-A)	
Group	WEEE (t)	GJ/t	t CO_2 eq/t	GJ/t	t CO_2 eq/t	GJ/t	t CO_2 eq/t
R1	37,606	7.6	1.4	13.9	22.6	6.2	21.3
R2	57,383	5.6	0.6	7.3	0.7	1.8	0.1
R3	55	10.2	1.8	15.8	2.8	5.6	1.0
R4	845	7.6	1.2	19.9	1.5	12.3	0.3
TOT	95,889	6.4	0.9	10.0	9.3	3.6	8.4

Table 10-4: *Summary of Scenario A and B (year 2016).*

Conclusion

The presented study proposes a methodology to evaluate the environmental impacts of the WEEE management system. The first step consists in the investigation of the impact determined by the WEEE management system within which ECODOM operates. This step records a negative impact on the environment due to the required high energy demanding activities performed, as transportation and WEEE treatments.

The second step consists in the assessment of the impact that would be caused on the environment without Ecodom. Imagine that Ecodom is not operational, 50% of WEEE would be managed by WEEE operators only interested in the exploitation of economically valuable materials, while the remaining 50% would be managed by operators characterized by similar performance to the ones recorded by Ecodom in Italy in 2008.

Consequently, this second step would provoke an environmental impact much greater than the impact caused by the activities performed during the proper management of WEEE.

Concluding, the main results of the presented research are summarized below:

- Properly managing WEEE, it has been possible to save 340,000 GJ of energy (96.7 million kWh), equivalent to the annual consumption of a city with a population of over 83,000 inhabitants.
- Properly managing WEEE, it has been possible to avoid the emission of 800,000 tonnes of CO_2 equivalent, comparable to the amount of CO_2 absorbable yearly by a 810 km^2 forest.
- The ecological cost of an inappropriate management of WEEE from the environmental point of view in closely linked to the lack of control on the quality of treatments.
- The main negative environmental impacts due to the absence of Ecodom in the WEEE management system are related on one hand to the emission into the atmosphere of ozone-depleting substances and, on the other hand, to the lack of recycling of economically unprofitable materials such as plastic and wood.

11. Material and Energy Flow Analysis and Associated Environmental Impacts of Swiss Mobility

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Abstract

The development of material flow analysis (MFA) on large-scale systems is challenging due to the complexity and breadth of data that are required and the magnitude of the mass flows involved. This is true, for example, when trying to determine the material and energy flows at the country level of a whole sector, such as mobility. Various studies have provided data on particular aspects of these flows, but they often use different methodologies and generate inconsistent results. The challenge is to structure the data system without getting lost in details. In the frame of this study the mobility sector of Switzerland, defined as the entire vehicle fleet moving inside the country, has been for the first time intensively assessed using a bottom-up approach and depicted in a simple flow diagram (Sankey). 78 categories of vehicles - from electric and not electric bikes, cars and buses to airplanes passing through trains and boats - nine types of materials and two types of energy sources have been characterized. For each of the 78 categories, different studies and statistics on quantity, material composition, growth rate, lifetime, fuel consumption, distance travelled and end-of-life paths have been examined. Different data sources served as a starting point for developing the material and energy flow analysis. The 78 categories have been aggregated into 12 groups. For each of the groups the actual stock as well as the ingoing and outgoing flows have been calculated. Additionally, the amount of fuel and electricity needed to move the vehicles and the amount of greenhouse gases emitted have been calculated and represented in the same Sankey diagram by depicting the flows in annual tonnes oil- and CO_2-equivalents, respectively.

Keywords: Material Flow Analysis (MFA), Mobility, Switzerland, Environmental Impacts, Energy, Vehicles, Sankey Diagram.

Introduction

To determine the efficiency of material resource use in Switzerland, the MatCH project (“Material and Energy Resources and their Environmental Impacts in Switzerland”), commissioned by the Swiss Federal Office for the Environment (FOEN), aims to quantify and depict the material flows of the Swiss economy in different consumption sectors. The aim is to create a basis for assessing the material efficiency over time and, based on this, to estimate future developments through scenario analysis. Furthermore, the project will enable the identification of "hot-spot" materials and sectors, particularly concerning the potential for improving material circularity and the development of measures for its improvement. The project is divided into three complementing sectors: i) Construction (Gauch et al. 2016), ii) Mobility (Gauch et al. 2017), and iii) Production & Consumption (Gauch et al. 2018).

This paper describes the work undertaken in the sector "MatCH - Mobility: Material and Energy Resources and Environmental Impact of Mobility in Switzerland" (Gauch et al. 2017), and covers all means of transportation (road, rail, ship, air traffic and other) in Switzerland. Such means of transportation also require infrastructure, such as roads and railways, which were considered within the construction sector (see the MatCH - Construction report by Gauch et al. 2016) and are therefore not covered here.

Methodology

A bottom-up approach covering 78 different categories of transportation means was used to determine the quantity of materials currently available in the Swiss mobility sector (starting value for modelling the stock mass). Material composition was determined for all 78 categories based on data from the literature. The number of vehicles was based on data from the Swiss Federal Statistical Office (FSO). The 78 categories have been summarized into 12 groups. The stocks and flows of materials were determined based on the numbers of vehicles inside or moving in or out of the system multiplied by their individual material composition. The resulting material flows keep the Swiss mobility sector functioning (depending on the service life and useful life of the vehicles) and expand or reduce depending on the economic situation. Calculation steps are summarised in Table 11-1. The selected model approach enables the depiction of material flows and stock. However, no claim can be made for precise and fully consistent figures due to inconsistencies among the various data sources used.

Material flows and stocks	Calculation steps
Mass of stock	Bottom-up approach, number of vehicles in the Swiss Mobility (based on statistics of the FSO) multiplied by the material composition of the 78 categories of vehicles.
Stock growth	Definition of stock growth (data from FSO data). Interval: 2010-2015.
Used vehicles	Definition of share of resold used vehicles in Switzerland. Data was only available for passenger cars. Estimates have been made for the remaining categories.
Outflow	Dependent on the service life of the various vehicles.
Export	Definition of the export quota (data from the Swiss Customs Administration foreign trade statistics) corresponding to used vehicles sold abroad (Switzerland itself has no car manufacturing industry).
Flow 'Unknown'	For some vehicles (principally passenger cars), it is unclear whether they were brought outside of Switzerland for usage abroad or disposal. The flow was quantified based on data from the Foundation Auto Recycling Switzerland (2015) and Restrepo et al. (2017).
Flow into disposal after exportation	Corresponds to the outflow minus the export E and the unknown flow F.
Reuse of parts	Derived from estimates based on ongoing work at Empa, as well as information from industry representatives.
Disposal and processing of secondary materials	The disposal (G - H) is divided into three categories: recycling, incineration and landfilling. Landfilled materials are generated from incineration residues only as Switzerland has a landfilling ban for all organic waste. The breakdown among these three categories is based on information from industry representatives.
Inflow	The inflow (B + D) is defined by the replacement of old vehicles and by the growth of the stock, which depends on market conditions.
Import	Corresponds to the inflow of imported vehicles as well as of energy (J - H).
Energy flow (operation)	Energy for operation (including electricity) is considered in terms of mass (oil equivalents). It has been calculated using a bottom-up approach based on energy consumption per km driven and the total amount of kilometres driven in a year by an average vehicle. Energy sources (such as gasoline, diesel, and electricity) have been converted into oil equivalents, which enables the display of energy flows as mass flows.
Consumption (DMC)	The Domestic Material Consumption is defined as the annual quantity of raw materials extracted from the domestic territory, plus imports minus exports. As virtually all new vehicles are imported (no industry in Switzerland) and export involves used vehicles mainly, they have not been included here.

Table 11-1: *Calculation steps for the assessment of material flows and stocks.*

The material flows of Swiss mobility generate various environmental impacts. These were assessed through a simplified life cycle assessment by multiplying the individual material flows with emission factors taken from the ecoinvent v.3.2 database (ecoinvent 2016) for the following indicators: greenhouse effect, non-renewable cumulative energy demand and total environmental impact (UBP, Frischknecht and Büsser Knöpfel 2013).

Results

Composition of the Swiss vehicle fleet

Figures 11-1 and 11-2 below show the calculated mass of the stock for the year 2016 and for the different material and mobility categories. The total stock of the vehicle fleet in Switzerland is approximately 11.16 million tonnes (Mt), with steel as the largest contributing material (6.84 Mt). Passenger cars are the dominant vehicle type, making up almost two thirds of the entire mass of the vehicle fleet (around 7.04 Mt).

Compared with more than 1,000 Mt of road and rail infrastructure (Gauch et al. 2016), vehicles account for about 1% of Switzerland's total mobility infrastructure. This means that 1 tonne (t) of mobility (vehicles) requires an average of about 100 tonnes of infrastructure.

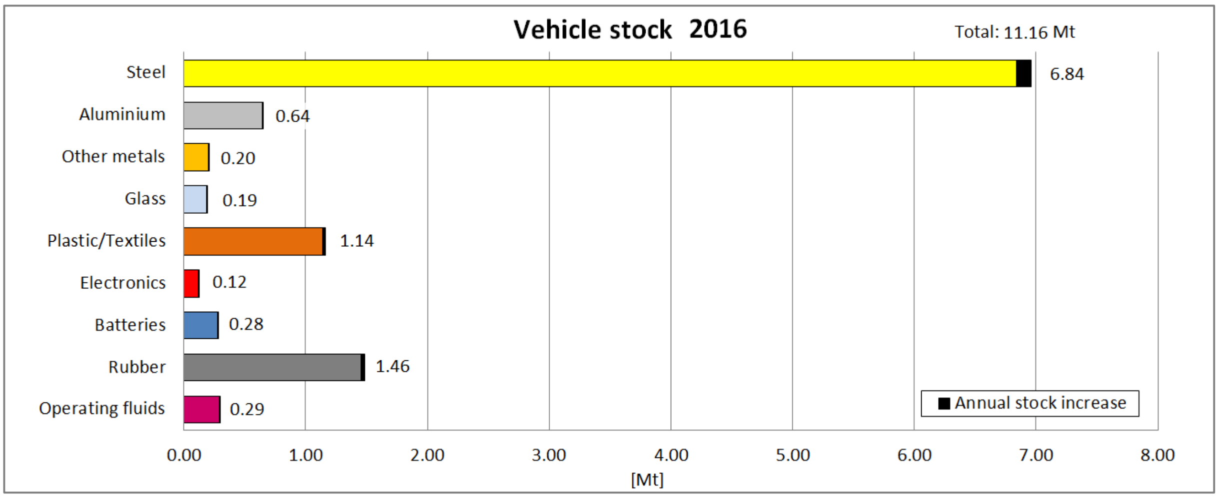


Figure 11-1: *Masses of different material categories in the Swiss mobility stock in 2016.*

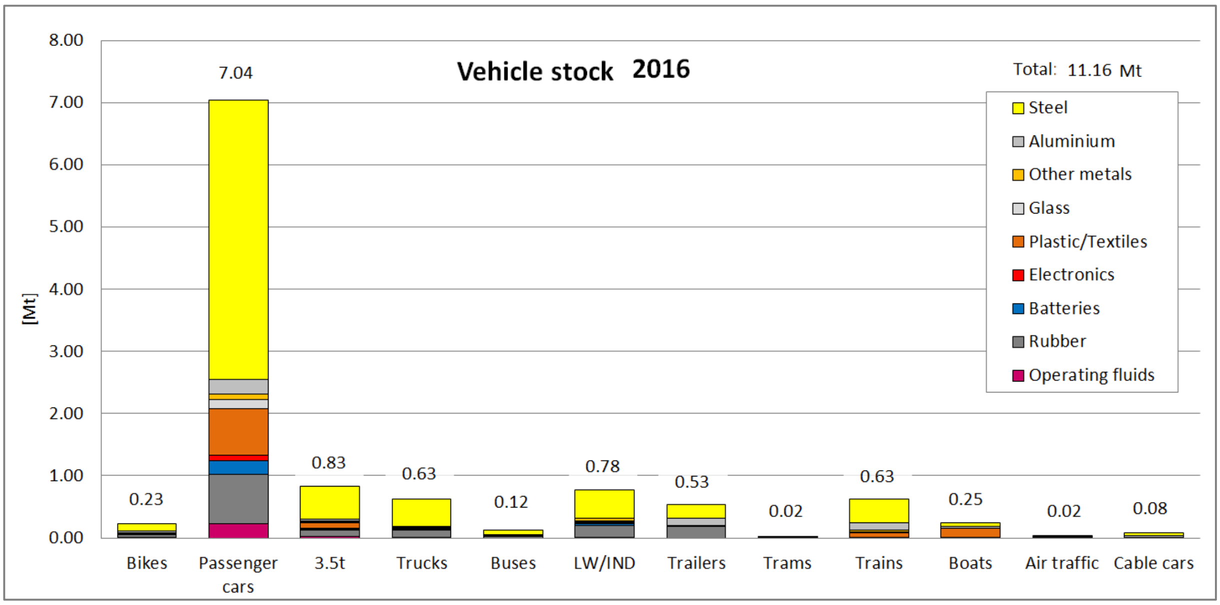


Figure 11-2: *Masses of different vehicle categories in the Swiss mobility stock in 2016.*

Material and Energy Flows

A material flow diagram of the Swiss mobility system, comprising all material and energy stocks and flows, is shown in Figure 11-3. The left hand side shows the material flows into Swiss mobility, as well as the energy flow that is necessary to operate it. The central box represents the stock, i.e. the total mass of vehicles in the country. A considerable share is sold and reused every year as used vehicles. As shown on the right hand side a certain quantity of vehicles leave the Swiss mobility system - mostly for reasons of age - and either enter the recycling chain in Switzerland or continue to be used as second-hand vehicles abroad. The whereabouts of an astonishingly high proportion of vehicles is unknown; most likely these were exported without de-registration. Interesting are the dimensions of the energy flows needed for the operation of all vehicles (depicted in oil equivalents) and the resulting mass flow of greenhouse gas emissions, which accounts for about twice the mass of the mobility stock.

Environmental impacts due to material and energy requirements

Mass flows were assessed for their environmental impacts using a simplified life cycle assessment. If one considers not only the consumption of materials (DMC) but also the associated environmental impacts (greenhouse-effect, non-renewable cumulative energy demand, total environmental impact) it becomes clear that the combustion of fuels causes by far the greatest environmental impacts in each of the impact categories considered (Table 11-2, Figure 11-4). Regarding materials, industrial base metals (steel, aluminium and others) and electronics show the greatest overall environmental impacts. The other materials, with the exception of batteries, have a comparatively low impact.

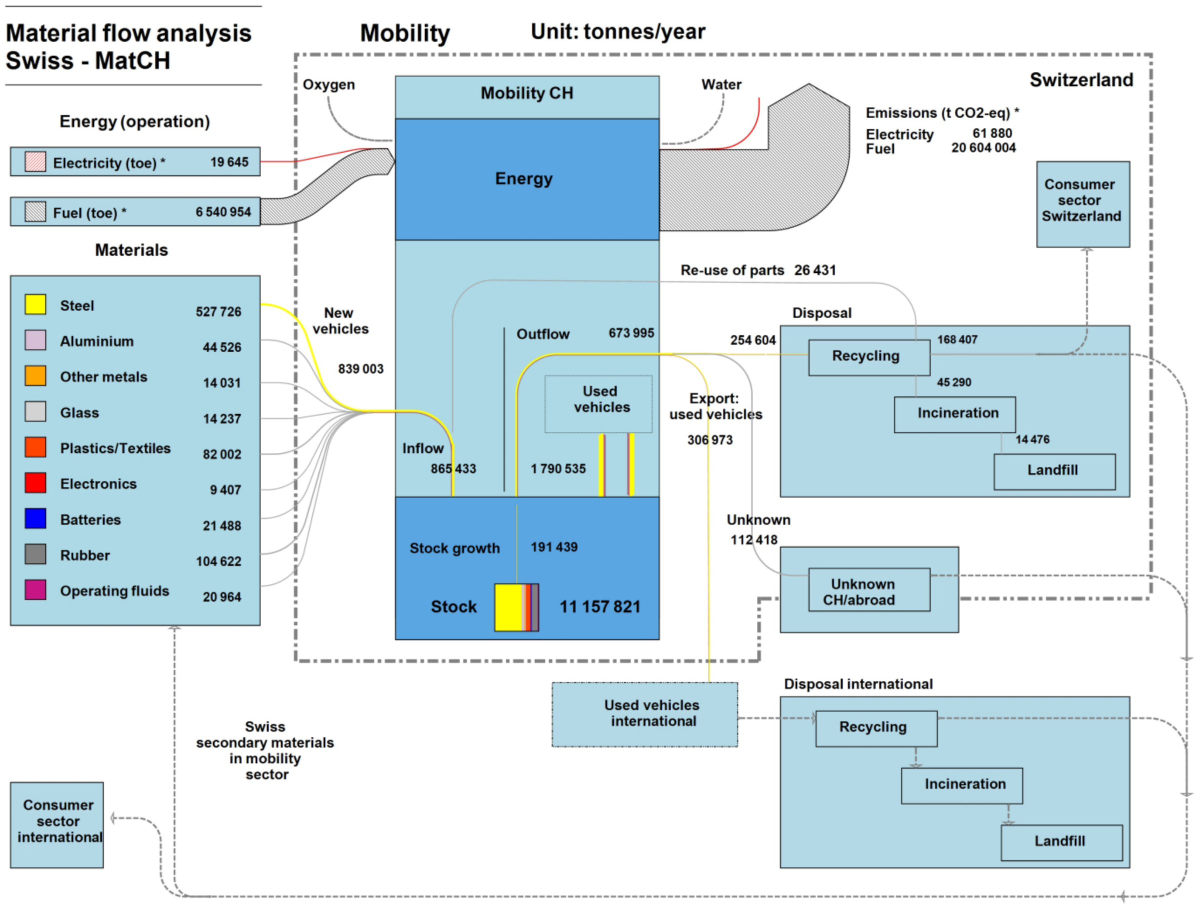


*Figure 11-3: Overview of material and energy flows for the Swiss mobility sector in 2016. *: Energy flows for the operation of vehicles (pure use phase without upstream processes) are shown as tonnes of oil equivalents (toe). Hatched arrows show disposal flows abroad, which are not considered in this study.*

2016	Material flow		Environmental impacts					
	Consumption (DMC)		Greenhouse effect[1]		Cumulative energy demand [1,2]		Total environmental impact [1]	
	t/y	Percentage	t CO_2-eq/y	Percentage	TJ/y	Percentage	Mio. UBP/y	Percentage
Electricity (toe)	19 645	0.3%	61 880	0.2%	12 611	2.8%	367 423	1.2%
Fuel (toe)	6 540 954	88.4%	26 345 647	89.8%	397 410	87.8%	23 269 047	74.7%
Steel	527 726	7.1%	1 224 191	4.2%	13 209	2.9%	2 365 441	7.6%
Aluminium	44 526	0.6%	540 660	1.8%	4 925	1.1%	671 169	2.2%
Other metals	14 031	0.2%	200 091	0.7%	2 443	0.5%	1 574 313	5.1%
Glass	14 237	0.2%	15 018	0.1%	178	0.0%	16 174	0.1%
Plastic/Textiles	82 002	1.1%	175 098	0.6%	6 205	1.4%	146 894	0.5%
Electronics	9 407	0.1%	399 228	1.4%	5 045	1.1%	1 331 061	4.3%
Batteries	21 488	0.3%	37 009	0.1%	555	0.1%	762 180	2.4%
Rubber	104 622	1.4%	305 300	1.0%	8 686	1.9%	457 272	1.5%
Operating fluids	20 964	0.3%	42 498	0.1%	1 548	0.3%	206 559	0.7%
Total energy	**6 560 598**	88.7%	**26 407 527**	90.0%	**410 020**	90.5%	**23 636 469**	75.8%
Total materials	**839 003**	11.3%	**2 939 092**	10.0%	**42 795**	9.5%	**7 531 064**	24.2%
Total Swiss mobility	**7 399 601**	100.0%	**29 346 619**	100.0%	**452 815**	100.0%	**31 167 534**	100.0%

[1] Including upstream processes and use

[2] Non-renewable

***Table 11-2:** Annual material and energy consumption (DMC) of the Swiss mobility sector in 2016 with associated environmental impacts (toe: tonnes of oil equivalents). The consumption of energy carriers refers to pure consumption by vehicle use (without impacts generated during the upstream chain of energy production). Environmental impacts include production and transport. UBP: eco-points, toe: tonnes of oil equivalents, DMC: Domestic Material Consumption.*

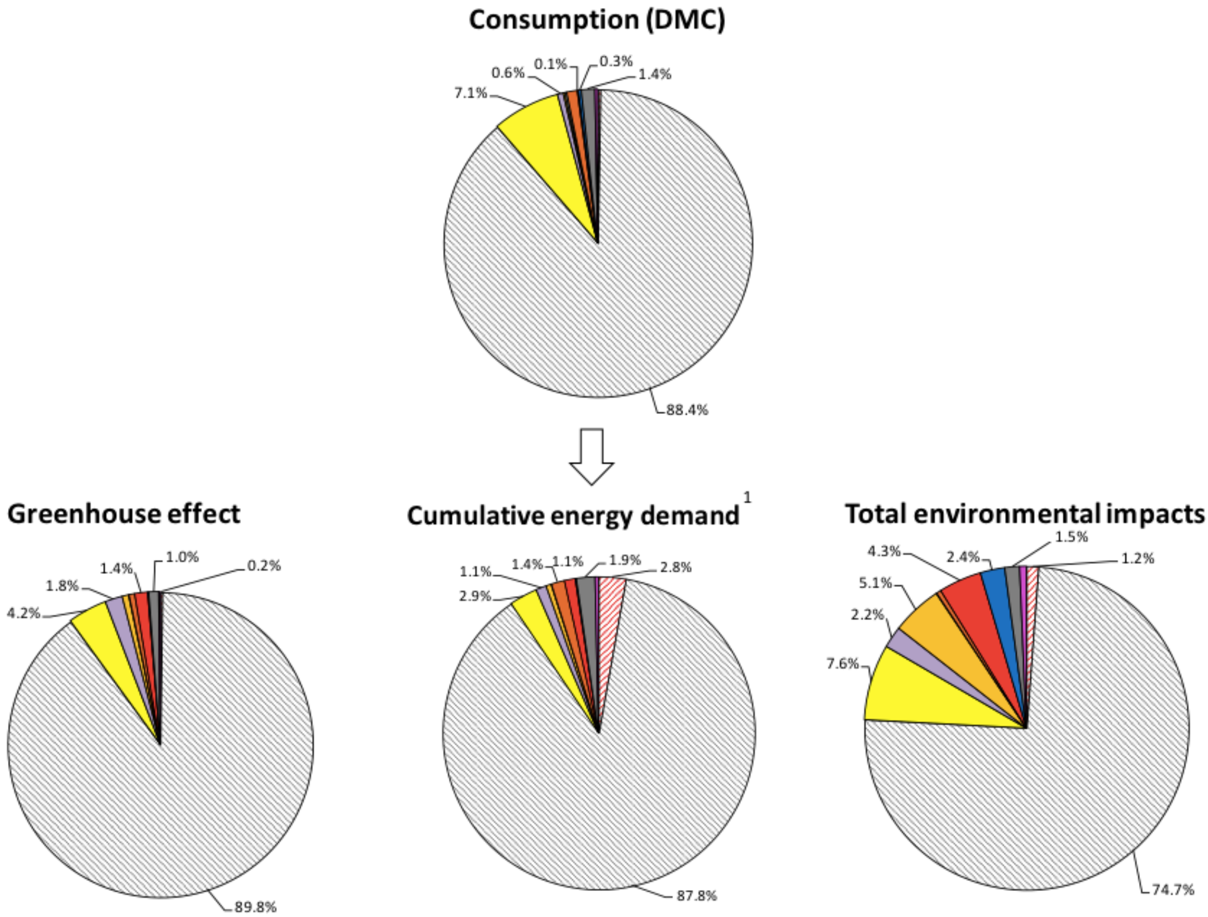


***Figure 11-4:** Material and energy consumption (DMC) and the resulting environmental impacts in three categories. Colours refer to the materials categories presented in Table 11-2. [1]: Non-renewable.*

Conclusions

From this research, the following conclusions can be drawn (see also Figures 11-2, 11-3 and Table 11-2):

- With approximately 7.04 out of 11.16 Mt. passenger cars clearly dominate the material stock induced by the Swiss Mobility.
- With 6.56 Mt, the total mass of energy required annually to operate the vehicle fleet accounts for 60% of the total mass in the stock.

  → On average, 0.6 t of fuel are needed per tonne of vehicle per year, the production and combustion of which causes 2.4 t of CO_2 equivalents.
- The total annual consumption amounts to 7.40 Mt, of which 88.7% is energy (6.56 Mt) and 11.3% (0.84 Mt) is materials. Steel is clearly the dominating material (7.1% of the total mass; 0.53 Mt).

  → The mass of fuel required to operate the vehicle fleet is about 8 times greater than the mass of materials used to maintain and expand the vehicle fleet.
- Regarding greenhouse gas emissions from the Swiss mobility sector, contributions are clearly dominated by fuel combustion (90.0%; 26.41 Mt out of 29.35 Mt CO_2eq.). The consumption of materials accounts for 10.0% of emissions (2.94 Mt CO_2eq), with steel having the greatest environmental impact among all materials (4.2% of emissions; 1.22 Mt CO_2eq), followed by aluminium (1.8% of emissions; 0.54 Mt CO_2eq).
- Fuel combustion is also the dominating contributor to the total non-renewable cumulative energy demand (87.8%; 0.40 Mt J out of 0.45 Mt J), followed by steel and electricity (2.9% and 2.8%, respectively; each around 0.013 Mt J).
- 75.8% of the total environmental impact of the Swiss mobility (expressed as eco-points UBP) is caused by energy consumption. With a share of 24.2%, the environmental impact of materials consumption are almost three times higher than in the other two impact categories considered (i.e. greenhouse effect and total non-renewable energy demand). In particular, metals cause considerable environmental impacts (14.9%), whilst despite their low mass share (0.1%), electronics account for a sizable 4.3% of total environmental impacts.
- Although most public transport is electric, the contribution of electricity consumption to total environmental impacts of the Swiss mobility sector is only 1.2%.

Results of this study were compared with data from the Swiss Federal Customs Administration (FCA[24] - import), the Swiss Federal Office of Energy (SFOE 2016 – energy inflow), the Swiss Federal Office for the Environment (FOEN 2016 – greenhouse gases emissions) and other previous studies (Rubli and Jungbluth 2005 – partially inflow and stock) and showed a good overall correlation.

[24] Swiss-impex.admin.ch

12. A System Dynamics Assessment of the Supply of Superalloys using WORLD6; Sufficiency for Civilian and Military Aviation Needs

Harald Ulrik Sverdrup ✉, Anna Hulda Olafsdottir, Peter Schlyter ✉

Abstract

The extraction, supply, market price and recycling of the metals used for superalloys were modelled using the systems dynamics model WORLD6. Peak production per capita (Supply Security) and stock-in-use per capita (Utility of Use) as well as resource stock lifetime during self-supply (Resilience) are key indicators. The resource estimates made resulted in significantly larger estimates than previous studies for nickel, tantalum, niobium, wolfram, molybdenum, cobalt, rhenium, titanium, zirconium and hafnium. The study shows that while for some elements (Co, Nb, Ta, W, Ni, Re), the size of the extractable resource may pose a challenge. For other elements, the intricacies and interdependencies of production will provide challenging limitations (Co, Re, Hf). Resource stocks of key metals are asymmetrically distributed among the larger powers and their dependants, posing strategic challenges for the future. Future patterns of scarcity, in space and time, of key resources may jeopardize strategic supply advantages presently enjoyed by major state actors. On the global scale, many of the key metals will run into hard scarcity around 2080-2100 AD, where the amounts demanded simply cannot be delivered. The recycling rates are too low for some of the key metals used in superalloys. This is contributing to shorter society service time that what could have been achieved otherwise. Both market mechanisms and other incentives through governance can be used for getting a better recycling of the important metals. Without these metals, several technologies will become difficult to produce, with serious implications for both military and civilian uses of high performance hardware. Additionally, increased competition between various technology sectors, e.g. aerospace, energy production and the IT-sectors.

Keywords: Aerospace, Turbines, WORLD6 Model, Superalloys, Energy Production.

Introduction

In modern society, some of the most important and promising uses of metals like tantalum and niobium, but also other metals are in the use of superalloys (Co, Cr, Hf, Zr, Ti, Re, Mo, Ru, Ir, Al, W). Superalloys are metal mixes that have high strength at elevated temperatures and also good corrosion resistance at such conditions. A superalloy has high mechanical strength, resistance to thermal creep, excellent corrosion resistance also at high temperatures and surface structural stability. Chemical and petrochemical processing, combustion power plants, and oil and gas industries use superalloys in their technical installations. They find use in turbine blades, jet engines, rocket engines, nuclear energy technologies and specialized chemical environments. Superalloys mainly rely on dispersion of coherent L12 γ'-austenitic precipitates in a face-centered cubic γ metal matrix for excellent high temperature mechanical properties (Collier et al. 1988, Harada 2012). Corrosion resistance is enhanced by components creating corrosion resistant oxide coatings at high operation temperatures. The resistance to corrosion also makes them difficult and expensive to decompose and refine to single metals for recycling, as well as difficult to melt, and reuse. Thermal barrier used to reduce heat conductance and allow for higher temperatures (Clarke et al. 2012).
The extraction, supply, market price and recycling of the metals used for superalloys were modelled using the systems dynamics model WORLD6. The resource estimates made resulted in significantly larger estimates than earlier studies for nickel (URR=300 mill ton), tantalum (URR=0.32 million ton), niobium (URR=80 million ton), wolfram (URR=30 million ton), molybdenum (URR=100 million ton), cobalt (URR=28 million ton), rhenium (URR=0.02 million

ton), titanium (URR=3,600 million ton), zirconium (URR=405 million ton) and hafnium (URR=9 million ton). While for some elements (Co, Nb, Ta, W, Ni, Re) the size of the extractable resource may pose a challenge, for others the intricacies and interdependencies of production will have challenging limitations (Co, Re, Hf). The integrated systems dynamics models can be shown to reconstruct the observed extraction rates and price histories well. The model outputs show that all these metals are finite resources, and that they will soon be exhausted unless the degree of recycling will be significantly improved. Peak production is estimated to take place 2030-2055 for tantalum, in 2055 for niobium, and molybdenum and rhenium production reaches a maximum in the same time interval. They will run into hard scarcity around 2100 AD, where the amounts demanded simply cannot be delivered.
The recycling rates are generally low for some of the key metals (Zr, Hf, Re, Co, Mo, Nb, Ta) used in superalloys. This is contributing to shorter society service time that what could have been achieved otherwise. Both market mechanisms and other incentives through governance should be used for getting a better recycling of these important metals. If not, they will become scarce within the coming decades with significant negative effects for the industrial economy and the technological potential. Without these metals, several technologies will become difficult to produce, with serious implications for both military and civilian uses of high performance hardware. The superalloys are used in a rapidly expanding range of applications from aerospace; disks, bolts, shafts, cases, blades, vanes, combustion chambers, thrust reversers. They are much used in civilian power plants; bolts, blades, stack gas reheaters, in high performance turbines for better thermal efficiency of energy conversion, in automotive vehicles for turbo-changers and exhaust valves. They are also becoming important in medical components because of their good resistance to corrosion and strength. In nuclear power generating systems they are used where repairs can only take place with huge difficulty because of radiation challenges such as for control rod drives, valve stems, springs, ducting and such places where great strength and corrosion resistance is needed. Chemical industry it is used for chemical reaction vessels, piping, valves, bolts and pumps. They are used in space vehicles in aerodynamically heated skins, rocket nozzles, turbo-pumps, rocket engine compressors and service turbines (Donachie and Donachie 2002, Sims et al. 2008, Clarke et al. 2012, Harada et al. 2012, Kawagishi et al. 2012). Price and available amounts seems to be the limitation to wider use.

Objectives and scope

The goal was to assess the sufficiency of the molybdenum, rhenium, niobium, tantalum, cobalt and nickel supply for production of superalloys, considering its technical use in rocketry, high performance turbines and advanced jet engines. Further, superalloys are being considered as candidates for inert electrodes for aluminium and light metal smelting.

System dynamics modelling

The main modelling method uses systems analysis and systems dynamics. We analyse the system using flow charts based on box-arrow symbols, causal loop diagrams defining the mass balance expressed differential equations and numerically solved using the STELLA® systems dynamics methodology (Sverdrup et al. 2014a,b, 2015a,b). The model is used to first reconstruct the past (1900-2015) to assess performance and robustness of the model. When the performance is satisfactory, then the model is used to simulate the possible future (2015-2300), having the support of being able to reconstructed the observed past pattern (Sverdrup et al. 2015).

Metals and metal uses

Table 12-1 shows an overview of important alloying metals for superalloys. The metal production numbers are taken from a number of earlier studies by the author. Table shows our estimate of the civilian aircraft demand and superalloy needs for the next 20 years. The amounts depend on engine weight, number of engines per aircraft and the lifetime of the superalloy parts inside the engines. Each new civilian aircraft are assumed to be twin engine planes with an average engine weight of about 3 ton per engine. In addition to these amounts comes turbines for land-based power production and superalloys for different types of rocketry. Tables 12-2 and 12-3 shows the demand for metals during the next 20 years. The assessment is based on new resource estimates by the authors (Sverdrup and Ragnarsdottir 2014, Sverdrup et al. 2016a,b,c, 2017a,b,c) for this study. The flow of superalloy components is shown in Figure 12-1. We have also indicated if these metals are in soft scarcity (compensated with higher price) or hard scarcity (compensated with higher price and with limited amounts that can actually be delivered. Typical for this are the platinum group metals, which at times cannot be delivered at the amounts desired). Superalloys are alloys developed for heat resistance, shape stability at high temperature and corrosion resistance. They have either iron, cobalt or nickel base as the majority meta l, and then additions of other metals that contribute to strength, chemical resistance to corrosion, thermal stability and resistance to fatigue failure. Recent research seem to suggest that there will be an upper temperature around 2,200^{o}C where the ceramic coatings start to lose their mechanical strength and be susceptible to corrosion. Most alloys are nickel-based at present, but cobalt-based alloys are going through improvements and seems to be set for a come-back. Characteristic for all these components are that they have high melting points, low vapour pressure at the melting points and that they tend to make very hard alloys. Metals like wolfram, molybdenum, niobium, tantalum, rhenium and hafnium are needed in the superalloy to increase the heat tolerance of the superalloys. Ceramics and metal-ceramics composites are used in the combustion section to increase heat resistance and insulation and corrosion resistance. The ceramics have poor resistance to shocks and movement, but there are few of these in the combustion compartments. A bit further down in the engine, in the hot turbine, the gasses have cooled only slightly, and the metal must have extraordinary strength, good corrosion resistance implying superalloys. The turbine blades are often single crystal blades. Earlier in jet engine development, stainless steels were used, but as higher performance is demanded, superalloys with several layers of barriers are used). The exhaust nozzle use Inconel or stainless steel alloys (nickel-chromium-iron alloys). When the temperature over the turbine is allowed to increase from 500^{o}C to 1,600^{o}C, then the thermic conversion efficiency of the engine increase from about 27-30% to 48-52%. Superalloys have been composed for heat resistance, shape stability at high temperature and corrosion resistance.

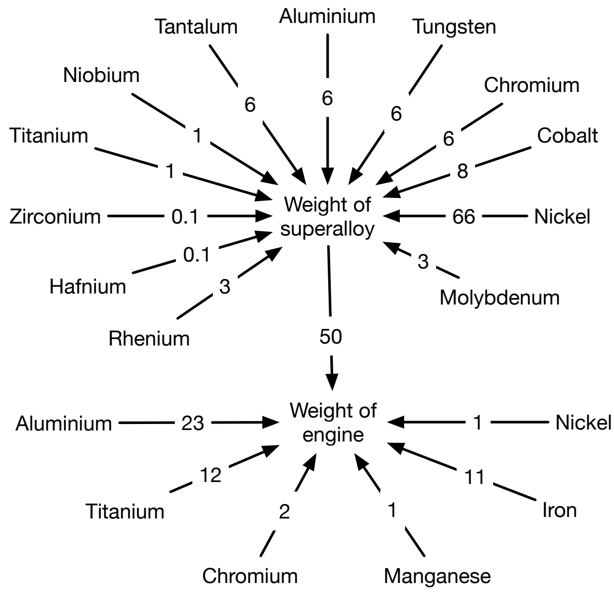


Figure 12-1: *Diagram explaining the flow of metals to each jet engine. This was used in the WORLD6 model.*

The WORLD6 model

Data and materials

Table 12-4 shows a summary of total superalloy demand during the next 20 years. As a basis for this analysis we also look back on earlier work done to verify the performance of the WORLD6 model on specific groups of metals.

Strategic considerations leading to metal demand

With the new fifth generation jet fighter planes and very high performing jet turbine engines, a significant amount of superalloys will be needed for turbine blades. The United States and its allies in NATO intend to build about 3,100 new F-35 during the next 10 years (50% of the total present production). In addition, comes other 1,000 US high performance military aircraft. Possibly, other big military powers (China, Russia, France, Great Britain, Ukraine, India) will possibly need superalloys for their comparable number of aircraft with possibly 3,000 or more of high-performance military type of jet engine turbines for the next 10 years and the demand for the next 20 years will be 8,600-10,000 aircraft. Rolls Royce estimated in 2011 that 149,000 jet engines will be demanded during the next 20 years, used to power 68,000 civilian jet aircrafts of different types. Military aircraft come in addition to these estimates.

Metal (2015)	Metal production ton/year	Dynamic model peak year estimate	URR Mill ton	Dependent Extraction
Molybdenum	0.27	2032	55	**Partly,** Cu
Rhenium	50	2035	0.016	**Yes,** Mo
Cobalt	120,000	2040	29	**Yes,** Cu, Ni, Cr, PGM
Niobium	65,000	2055	52	No
Tantalum	1,200	2045	0.5	**Partly,** Nb, Sb
Titanium	310,000	2080	3,600	No
Zirconium	45,000	Cost limited	410	**Partly**, Ti
Hafnium	80	Cost limited	11	**Yes,** Zr, Ti
Nickel	2,500,000	2030	300	No
Wolfram	85,000	2045	55	No

Table 12-1: *Overview of important alloying metals for superalloys. The metal production numbers are taken from a number of earlier studies by the author. Million metric ton.*

Country	Military aircraft	Number of engines for new craft	Number of planes with engine retrofits	Total number of engines	Engine weight per plane, ton	Superalloy weight per engine, ton	Superalloy weight demanded ton
USA	3,000	4,500	2,000	6,500	1.8	0.9	5,850
Russia	1,400	2,000	2,000	4,000	2.6	1.4	5,600
China	2,000	3,000	2,000	5,000	2.2	1.2	2,640
India	500	600	300	900	2.4	1.3	3,120
Turkey	200	300	-	300	2.4	1.3	3,120
Sweden	500	500	400	900	1.7	0.8	1,360
Europe	1,500	2,200	2,000	4,200	1.9	1.0	1,900
Canada	200	350	350	700	1.8	1.0	1,800
Other	200	300	600	900	2.2	1.2	2,640
Sum	9,000	13,750	9,650	23,400			28,030

Table 12-2: *Superalloy demand for military aircraft during the next 20 years. A total of 24,000 new engines are estimated to be needed.*

Country	New aircraft	Engine per plane	Engines	Engine retrofits	Sum	Engine weight	Total amount, ton
United States	14,000	2.2	31,000	10,000	41,000	3	123,000
Russia	2,000	2.2	4,400	500	4,900	3	14,700
China	4,000	2.2	8,800	6,000	14,800	3	44,400
India	1,000	2.2	2,200	2,000	4,200	3	12,600
Europe	10,000	2.2	22,000	10,000	32,000	3	96,000
Canada	3,000	2.2	6,600	2,000	8,200	3	24,600
Brazil	2,000	2.2	4,400	2,000	6,400	3	19,200
Other	2,000	2.2	4,400	7,500	11,900	3	35,700
Sum	38,000	2.2	83,600	30,000	113,600	3	370,200
Demand	1,900	-	-	1,500			18,510

Table 12-3: *Civilian aircraft demand and superalloy needs for the next 20 years. The amount depend on engine weight, number of engines per aircraft and the lifetime of the superalloy parts inside the engines. Each new civilian aircraft are assumed to be twin engine planes with an average weight of about 3 ton per engine. In comes turbines for land-based power production and superalloys for different types of rocketry. Amounts are in ton metal.*

	Civilian aerospace	Military technology	Technical and chemical	Sum
Demand next 20 years	370,200	28,030	15,000	413,230
Annual demand	18,510	1,402	750	20,662

Table 12-4: *Summary of superalloy demand during the next 20 years, 2017-2037, ton metal.*

Metal		Content in super-alloy, %	Content in engine, %	Amount per year used for super-alloy, ton/year	Annual supply ton/year	% of annual supply	Risk for scarcity
Molybdenum	Mo	5	-	1,050	320,000	0.3	No
Rhenium	Re	1	-	210	80	260	**Yes**
Niobium	Nb	2	0.3	460	60,000	0.8	No
Tantalum	Ta	1	-	210	1,400	11	**Maybe**
Cobalt	Co	10	-	2,100	60,000	4	No
Platinum	Pt	0.1	-	21	180	12	**Yes**
Nickel	Ni	63	1	13,400	2,500,000	0.5	No
Titanium	Ti	1	12	2,730	310,000	0.9	No
Zirconium	Zr	0.1	-	21	45,000	0.05	No
Hafnium	Hf	0.2	-	42	74	57	**Yes**
Wolfram	W	5	-	1,050	60,000	2	No
Chromium	Cr	10	2	2,500	7,000,000	0.04	No
Aluminium	Al	1	23	4,830	80,000,000	0.04	No
Manganese	Mn	-	1	210	18,000,000	-	No
Iron	Fr	-	11	2,200	1,500,000,000	-	No

Table 12-5: *Need for individual metals for aviation technologies.*

Metal	Aviation super-alloys, ton/year	Power plant Turbines, ton/year	Chemical plants ton/year	Sum ton/year	Priority use	Annual total supply ton/year	Risk for scarcity
Molybdenum	1,050	500	250	250,000 1,800	Stainless Superalloy	320,000	No
Rhenium	210	100	50	360 10	Superalloy Catalyst	80	**Yes** **Yes**
Niobium	460	220	110	790 50,000	Superalloy Steel alloys	60,000	No **Yes**
Tantalum	210	100	50	1,000 360	Electronics Supoeralloys	1,400	**Yes**
Cobalt	2,100	1,000	500	3,600 120,000	Superalloys Batteries	60,000	**Yes**
Platinum	21	-	-	21 140	Superalloys Catalysts	180	**Yes** **Yes**
Nickel	13,400	6,000	5,000	24,300 2,000,000 500,000	Superalloy Stainless Other	2,500,000	**No** **Yes** **No**
Titanium	2,730	1,000	4,000	7,730 250,000 10,000	Airframes Structural Medical	310,000	No No No
Zirconium	21	10	30	61	Nuclear	45,000	No
Hafnium	42	-	-	42	Superalloy	74	**Yes**
Wolfram	1,050	500	250	1,800 30,000	Superalloys Cutting tools	60,000	No No
Chromium	2,500	1,500	1,500	5,500	Stainless	7,000,000	No
Aluminium	4,830	1,000	200	6,030	Structures	80,000,000	No
Manganese	210	100	100	410	Iron alloys	18,000,000	No
Iron	2,200	300,000	300,000	602,200	Structural	2,200,000,000	No

Table 12-6: *Need for individual metals for all technologies summarized.*

Superalloy weight in a typical modern jet engine has stabilized at 40-50% of the engine weight. This may lead to a specialty metals demand that is larger than the actual supply at present. The civilian aircraft's new generations high-performing jet engines use superalloys in the turbine blades (Airbus A360, A380, Boeing 777, Boeing 787 and several coming new models from other vendors).

The Boeing Corporation in Seattle estimates that 38,000 new civilian aircraft will be taken into service by 2034 (next 20 years) worldwide (1,900 commercial aircraft per year) (Boeing website 2017). That corresponds to 30,000-60,000 ton of superalloy of at least 4th generation performance during the period, or 1,500-3,000 ton superalloy per year will be needed, at 6% tantalum, that corresponds to about 90-180 ton per year (Donachie and Donachie 2008, INSG 2013). Table 12-5 shows the superalloy demand for military aircraft during the next 20 years. The amounts depend on engine weight, number of engines per aircraft and the lifetime of the superalloy parts inside the engines, and how many retrofits of the engines that will be needed. These are based on rough estimates. Each new civilian aircraft is assumed to be twin engine planes with an average engine weight of about 4 ton per engine. In addition to these amounts comes turbines for land-based power production and superalloys for different types of rocketry. We have taken two of the newest high-performance engines as the average engine and used their weight specifics as the template for the future; the military engines by Pratt and Whitney 135 and General Electric and Rolls Royce F136 engines. These are used in the F-22, a twin engine high performance superiority jet fighter plane, its total empty weight is 19.7 ton, twin engine of each a weight of 1.8 ton, total engine weight in the plane is 3.6 ton. The superalloy weight is about 1.8 ton. F-35 with a single engine, has a single engine, aircraft weight is 13.4 ton, the engine weight 1.7 ton, the superalloy weight is about 0.9 ton. Typically, the turbine rotates at 3300 rotations per minute, resulting in a tip speed of 1,700-2,00 km h^{-1}. Typically, an engine will last about 10,000 flights before it is scrapped. Civilian aircraft engines vary a lot in size and weight. Much efforts have been made in later years to bring down overall weight, increase thrust to weight ratio and increase overall fuels use efficiency. We have looked into the latest series created by Rolls Royce in the Trent series. The jet aircraft engines are used in planes from Airbus are; A330, A340, A350, A380 and Boeing 777 and 787. They are all twin-engine aircraft. Typical engine weight for these turbofan engines range from 3.5 ton per engine to 7.1 ton per engine depending on the aircraft size and year of production. In 1950, only 10% of a jet engine weight would be superalloy, by 1985 this fraction had reached 50% of the engine weight (Donachie and Donachie 2002). In 2017, this was still the case, with a small upward trend. This is based on averaging constituents in the newer alloys in the market. There the contribution from each metal to the superalloy is shown in % weight of the metal, as well as the metals used for the rig and body of the engine. The superalloys make up about 50% of the engine weight, due to the high density of the constituents (8.8-9.2 g cm^{-3}).

Results

The WORLD6 model was run for the time period 1900-2400, but for some of the diagrams we have chosen to show only the last and the next 100 years, 1900-2100. From the model simulation outputs, we have chosen to show the time period 1900-2100 for both niobium and tantalum. The reason for this was that most of the interesting changes in the dynamics takes place in this time period. Table 12-6 shows the civilian aircraft demand and the superalloys needs for the next 20 years together with an assessment of the sufficiency of provision. It can be seen that there is a scarcity risk for rhenium, tantalum, cobalt, hafnium and platinum in the future. Under certain circumstances, there may be some scarcity risk for niobium and nickel.

Discussion

We have been living in a society for the last two decades dominated with a political climate where “market solutions” have been thought to efficiently self-regulate all markets. It is becoming more and more evident that this is not correct, and that unregulated markets tend to develop into oligopoly (Fukuyama 2015, Roberts 2011), leading to manipulated prices and unchecked speculations. There are sufficiently many empirical cases available to prove beyond reasonable doubt that scarcity issues are not efficiently solved by the market mechanisms alone, and that this approach as a solution is a dead end. Such an approach is inviting failure and will cause irreparable scarcity situations. It should be met with the resistance it scientifically deserves. Most countries do not have any strategic governmental policy on resources, and there are no International unified policies for recycling.

13. Life Cycle Assessment of Dry Parchment Coffee in Two Coffee Crops in Cundinamarca, Colombia

Catherine Andrea Guzmán ✉, Juliana Andrea Pardo, Kenneth Ochoa

Abstract:

The coffee sector is one of the pillars of the colombian economy. It generates nearly 800 thousand directs jobs at the rural sector and about 1,6 million indirect jobs. Although its social value, the coffee is going over a crisis where it opens a consideration about the current production models, starting from a Life Cycle Thinking perspective. Therefore, the aim of this study is to perform the Life Cycle Assessment (LCA) from one (1) Kg of dry parchment coffee (DPC) in two crops from San Francisco, Colombia. Product environmental impacts were identified, based on ISO 14044:2006. The impact assessment method selected was the Eco-indicator 99, which evaluates three damage categories: human health, ecosystem quality and resources, using SimaPro 8 software. As results, it was found that usage of synthetic fertilizers contributes to a higher negative affectation, within the ecotoxicity and acidification/ eutrophication indicators, associated mainly to heavy metal emissions present in both air and soil. Finally, based on the most relevant environmental impacts raised in the DPC LCA, a series of recommendations were made based on the principles of the environmental management and focused on contributing to the national coffee industry sustainability and quality performance.

Keywords: Dry Parchment Coffee, Life Cycle Assessment, Environmental Impact, Coffee Growing.

Introduction

At present, there are many ways to implement the lifecycle approach concept. LCA is one of many tools that can be used for this purpose. It refers to a quantitative type methodological proposal, in which product or system inputs, outputs and potential environmental impacts are collected and assessed throughout its life cycle (Asociación Española de Normalización y Certificación 2006). In this way, it is possible to provide true and transparent information, and also be able to prioritize decision-making, regarding the application and development of clean production processes, which represent environmental, social and economical benefits (Hernández and Tobar 2014, Life Cycle Initiative 2016).

The first LCA studies date back from the late 1960s and early 1970s, where environmental issues such as energy efficiency and resources, pollution control and treatment of solid waste, began to establish themselves as part of the main concerns of public interest (Curran 2012). At present, these types of studies are developed in different economic sectors such as agriculture, where, despite the complexity posed by these systems (given by the behavior, types and modeling of different products inside the sector), there has been made significant progresses leading to reduction of the environmental impacts.

Particularly in Colombia, the LCA studies for agricultural systems are quite limited, because just a few are registered and, in the majority, with a high uncertainty in the results associated specially to the difficulty of obtaining data from the farmers for the respective consolidation of the Life Cycle Inventory (LCI) (Arango Ramirez et al. 2014). In most of the cases, this factor generates a lack of awareness of the environmental performance of agriculture and, therefore limited opportunities to innovate and improve, which is directly related to the various challenges faced by the agricultural sector in Colombia, as a consequence of individual decisions and cultural practices of producers, high production costs and the implementation of inadequate technologies, which in most cases lead to the degradation of natural capital (Rojas 2012).

Given the role of coffee as an agricultural product in the national economy with a 3,1% GDP, and, in response to the great challenges faced by Colombian coffee production in social, economic and environmental terms, the objective of the research was to perform one (1) kg of Dry Parchment Coffee (DPC) LCA, in two crops of San Francisco, Cundinamarca, under the ISO 14044: 2006 methodology, to establish the potential environmental impacts associated with each system under study, and make environmental management recommendations, based on the interpretation of the significant issues resulting from the LCI and the LCIA, to mitigate negative impacts identified.

Method: according ISO 14044:2006

Objective and scope definition

The study objective was to perform the comparative LCA for one (1) kg of DPC production in two crops of the municipality of San Francisco, to obtain sufficient information in order to identify the potential environmental impacts caused in each of the studied systems. It is important to mention that the selected farms for the development thereof are registered under the Federación Nacional de Cafeteros (FNC).

Regarding the scope definition, coffee was selected as the system under study, due to its role in the national and international economy. Two coffee farms in the municipality of San Francisco were used, since they are an example of the country's coffee production model, which is developed on a small scale, with a national average per farm that does not exceed two hectares planted with coffee (Rojas 2012).

The functional unit selected corresponded to one (1) DPC kg, and the limits of the system were defined from the sowing stage to the commercialization of DPC in the municipality of San Francisco.

Life Cycle Inventory (LCI)

Information required for the LCI was consolidated based on field visits made to each farm's owner and subsequently recorded in spreadsheets (Arango Ramirez et al. 2014, Curran 2012). The consigned data was normalized to the established functional unit, from a conversion factor.

In turn, and in accordance with the method described by Goossens et al. (2017), air emissions, derived from the use of fertilizers throughout the coffee growing process, were determined in terms of nitrogen oxide, ammonium, nitrates, phosphorus and carbon. As for the emissions of heavy metals, especially to the soil, also from the use of the same, were estimated as proposed by Nemecek et al. (2014).

Finally, for the active ingredient of the pesticides and its emissions factors were calculated according to Goossens et al. (2017), and the emissions resulting from the use of the pesticides, mainly to the soil resource, were estimated by Blonk Agri Footprint BV (2015).

Life Cycle Impact Assessment (LCIA)

The selected impact assessment method was Eco-indicator 99, which includes three categories of damage assessment: human health, ecosystem quality and resources. The software used was SimaPro 8.

Life Cycle Interpretation

In order to define critical points of the coffee units and its respective comparison analysis, 11 category indicators were evaluated according to Eco-indicator 99.

Results

Objective and scope definition

In Table 13-1, the differentiating aspects of each of the evaluated production units are presented briefly, with special emphasis on both the cultivated hectares and the DPC production.

Data for 2015	Farm 1	Farm 2
Farm age (years)	11	35
Hectares in *Castilla* coffee (Ha)	2	0,64
Coffee plants	10000	3200
DPC Production (Kg)	1842	767
Yield (Kg/ha)	921	1198,44
Rainforest Alliance Validity	Active	Active until 2016

Table 13-1: *Characterization and description of the 2 coffee farms under study.*

Among the reasons that motivate the study, there are, firstly, that this study is consolidated as a first approach, from the implementation of the LCA tool to agricultural systems, such as coffee, mainly given by the lack of information at national level regarding the development of this type of studies. Second, based on the determination of the environmental performance of each crop, it is possible to provide the respective farms owners with a comprehensive knowledge of the environmental performance of their systems, so that they can make informed decisions and oriented to improve the profitability of both their products and their farms.

Life Cycle Inventory: Data collection

For the investigation, five processes were defined, corresponding to: seedling development, maintenance of the crop, planting, post-harvesting and marketing of DPC. The aspects considered in the entire process are described below:

- Water: Water usage in each of the two farms is related to the grain washing process, within the post-harvest stage. Although a primary water treatment resulting from the post-harvest is carried out in both farms, this process was excluded from the analysis due to the lack of similarity with the different processes found in the consulted databases.
- Fertilizers: For the case study, the farms used both organic and synthetic fertilizers. Specifically, for each of the production units, the content of macronutrients and micronutrients were calculated. However, due to software issues, the amounts associated with micronutrients were excluded since the program, by the time of the research, did not have the option to insert this type of nutrients.
- Pesticides: The farms under study, use chemical and biological products for the control of pests and diseases within the crop. Thus, for products of chemical nature and according to the personal recommendation of Goossens et al. (2017), only emissions derived from usage of mentioned products were estimated, based on the active ingredient.

As for the products of biological nature, due to the lack of similarity in the processes present in libraries of *SimaPro*, these quantities were excluded. As Meier et al. (2015) expressed, in most LCA studies in agriculture, the lack of truthful data is the main limitation, especially as regards the characterization factors of the biological/natural and inorganic pesticides that are partially described in organic agriculture usage.

- Soil entry: Land use in terms of occupation, is expressed in Ha/year. It was assumed that all the soil occupied by coffee cultivation has been used for agricultural purposes for a specific time for each farm because, according to the owners, they have not changed the crop during the tenure years.

Life Cycle Interpretation

Critical points identification

In Table 13-2, farm 2 presents lower impacts in seven of the indicators. However, in the indicators of ionizing radiation, ozone layer and ecotoxicity, the situation was reversed giving the three, 100% impacts compared to farm 1, which has a negative impact of 43.1%, 33.2% and 88.2% respectively.

Indicators	Farm 1 (%)	Farm 2 (%)
Carcinogenic substances	100	71,6
Organic substances inhalation	100	47,8
Inorganic substances inhalation	100	64,1
Climate change	100	53,1
Ionizing radiation	43,1	100
Ozone layer	33,2	100
Ecotoxicity	88,2	100
Acidification / Eutrophication	100	40,8
Soil usage	-91,7	-100
Mineral exhaustion	100	59,2
Fossil fuels exhaustion	100	63,2

Table 13-2: *Percentages of each crop under study for the characterization indicators (Eco-indicator 99).*

Subsequently and in order to evaluate the critical processes for every farm, it was assessed eleven indicators for the most relevant processes in terms of participation. Six of the total processes stand out for both farms: synthetic potassium, synthetic nitrogen, propane gas, low density polypropylene, high voltage electricity and inorganic waste treatment.
Among these, four do not have contributions in the totality of indicators and, the remaining two, corresponding to: use of propane gas and use of Low Density Polyethylene (LDPE), have negative contributions in the 11 indicators evaluated in the entire process. Due to the total contribution presented by the previous processes, it is inferred that these are the critical points within the coffee process for the two farms.

Comparative analysis

In order to determine the impact of the two farms under study, the comparative analysis between the two units for the characterization indicators is presented. It is clarified that, for this comparison, the transport processes were excluded, since in the previous results they did not present contributions greater than 1% for either case study. First, Figure 13-1 (at the end of this paper) provides a global view of the contribution of different crop-associated processes for each of the impact category indicators. In this way, it can be observed that the farm 1 has a greater environmental impact (7 of the 11 indicators) than the farm 2. The visual trends of this graph are evaluated in more detail below.
For the carcinogenic effects indicator, a negative contribution was found for both farms. This is influenced by the heavy metal emissions from the use of synthetic fertilizers, specially arsenic and cadmium, as they argue Goossens et al. (2017).
For organic and inorganic substances inhalation indicators, it is established that farm 1, has a negative impact of 100% for both categories, compared with farm 2, of 40% and 63%, respectively, also negative. It is presented that the use of LDPE for both farms is the largest contributor in terms of emissions; the high values recorded for the two indicators are due to the quantities used by each farm and, specially, to the type of treatment the plastic must be put through at the end of its lifespan (Lleras and Moreno 2001).
The impacts associated with climate change for both production units were negative. There is evidence of a contribution of carbon dioxide emissions, where Goossens et al. (2017), argue

this situation may be due to the use of energy, mainly diesel consumption and the emissions associated with it.
As for the impacts associated with the ozone layer deterioration, it was found that although the two production units exert a negative impact, farm 2 presented an affectation of 100% compared to farm 1 with 32% This is largely due to the considerable demand for propane gas usage and the emissions derived from both the process of transformation and its use.
The ecotoxicity indicator has a negative impact on both farms, with a share of 90% and 100% respectively. According to Goossens et al. (2017), this may be influenced by emissions of heavy metals, especially due to pesticides and fertilizers usage.
Impacts associated with acidification / eutrophication indicator show a greater negative impact on farm 1 compared to farm 2, with 100% and 40% affectation, respectively. Acidification processes influence is mainly due to the use of synthetic fertilizers in terms of emissions of ammonia and nitrogen oxides (Goossens et al. 2017).
Regarding mineral resources and fossil fuels depletion impact, although both production units registered a negative effect. According to Goossens et al. (2017), these impacts for minerals are caused entirely by the high dependence and use of synthetic fertilizers, situation that is reflected in farm 1. As for fossil fuels, this impact is associated with the usage of energy in terms of gas and oil.
Soil use, as Brandão, Milà i Canals, & Clift (2011) argue, is the main contributor to soil degradation. However, sometimes beneficial effects can occur, depending on the management practices that are performed. Thus, within the context of the LCA, the environmental impacts associated with the use of the soil, are evaluated by the occupation and transformation (Mattila et al. 2011).

Conclusions

LCA development allowed to identify the potential environmental impacts associated to the two coffee farms selected for the study, where through the LCIA it was established that the critical points in the coffee value chain correspond to the use of polyethylene plastic and use of propane gas, during the seedling development (nursery) and DPC drying in the post-harvest period.
LCA studies for products such as coffee, and in general for the agricultural products, is consolidated as a rigorous and complex activity, given the absence or limited information on the sector and quality requirements. However, to date, both the development and publication of this type of studies are necessary, in order to consolidate a solid data basis, which allows an assessment and understanding of the magnitude of the different potential environmental impacts generated in each of the stages of the systems under study and thus, establish measures aimed at reversing such situation.
Although this study will provide the initial basis for understanding the development of the coffee production system and the different environmental impacts derived from it, future studies in the sector are necessary, aimed at deepening the development of LCA, taking into account inputs of great importance for coffee cultivation, such as water footprint, the use of pesticides and covering the entire cycle until their corresponding final disposal, in order to provide a more comprehensive knowledge to the respective decision-makers.

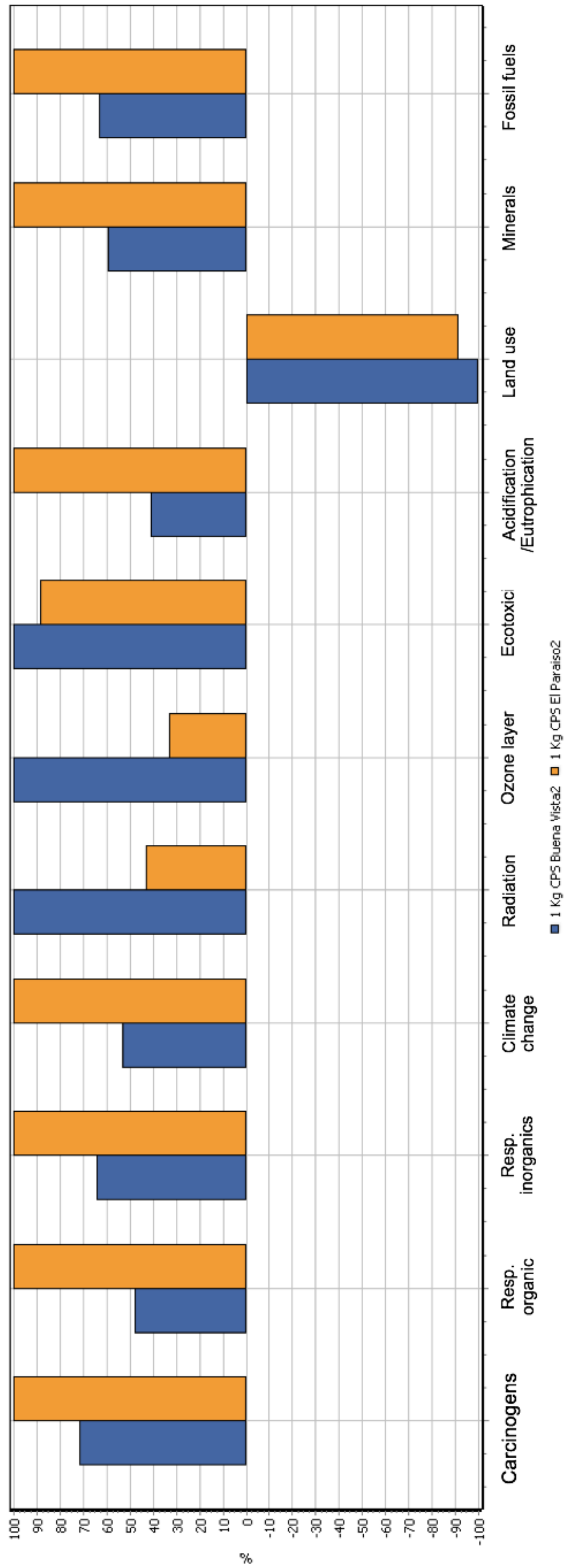


Figure 13-1: *Comparative analysis for farms under study. Key: Orange: farm 1; Blue: farm 2. (Comparando 1 p '1kg CPS Buena Vista2' con 1 p '1 kg CPS El Paraiso2'; Método: Eco-Indicator 99 (H) V2.10 / Europe EI 99 H/A / Caracterizati*ón).

14. Advances and Gaps in the Research of Environmental Impacts of Food Packaging Applications using LCA

Ankit Aggarwal ✉, Horst-Christian Langowski

Abstract

Developing food packaging applications based on materials from renewable resources, such as biobased plastics, is considered as potential solution to reduce the environmental impacts of packaging. While each specific industry applies the Life Cycle Assessment (LCA) method customized to its standard practices and requirements, a scientifically established LCA tailored approach to support packaging designers and engineers in developing environmental friendly food packaging applications from biobased plastics is still in nascent stage. The work presented here aims to discuss existing studies which have been used to quantify environmental impacts of food packaging with focus on LCA. Most of the studies focus on comparative evaluations of packaging materials on a mass basis, thereby neglecting the specific functions the materials usually fulfill to a different degree. Moreover, the selection of environmental indicators is often done in-consistently, for instance in using generally agreed indicators like greenhouse gas emissions together with process related indicators such as compostability. In addition, often stages of the life cycle like disposal are focused instead of the total life cycle. The outcome of the analysis of the studies will present two main conclusions to develop a tailored approach for incorporating packaging functions in LCA studies: a) A function-driven approach that normalizes the impacts with view on the packaging functions as required for specific product classes, b) A consistent list of function driven parameters to be regarded in any study.

Keywords: Environmental Impacts, Food Packaging Functions, Biobased Plastics, Life Cycle Assessment.

Introduction

The goal to achieve sustainability continues to drive global interest in the environmental impacts of food packaging. While the first such studies were already carried out in 1969 (Notarnicola et al. 2017), the topic continues to be a subject of active research in context of packaging materials (Ingrao et al. 2015, 2017), food waste and loss (Conte et al. 2015, Gutierrez et al. 2017, Wikstrom et al. 2010, Wikstrom and Williams 2016) and shelf life (Bertolini et al. 2016, Gutierrez et al. 2017). As a result, developing novel food packaging materials and applications has been a subject of continued interest for packaging design and development. Within this context, several solutions are presently being pursued - such as packaging material reduction, use of biobased plastics, and application of advanced packaging techniques such as active packaging to enhance food safety and shelf life, reduce food waste and fulfil multiple other packaging functions.

Life Cycle Assessment (LCA) is a well-established standard tool to calculate the environmental impacts of packaging materials. LCA enables quantifying environmental impacts of a product or a service based on functional unit (ISO 2006). While each specific industry applies the Life Cycle Assessment (LCA) method customized to its standard practices and requirements, a scientifically established LCA tailored approach to support packaging designers and engineers in developing environmental friendly food packaging applications from biobased plastics is still in nascent stage. Many of the food packaging LCA are focused on the containment function of packaging (i.e. the functional unit is just normalized to a given total content) or just compare impacts of materials on a mass basis. This fails to take into consideration the differences in the material properties (Cooper 2003), hence packaging functions. As a result, there is a need to consider additional functions of packaging in packaging LCA studies.

The current study presents the advances and gaps in the research of environmental impacts of packaging from the perspective of packaging functions; with the goal of highlighting the need for a function driven approach towards quantification of environmental impacts of food packaging. The key packaging functions are outlined in section 2, followed by an overview of recent studies on environmental impacts of packaging as per packaging life cycle, i.e. packaging manufacturing, use and end of life, presented in section 3. Section 4 describes the proposed function driven approach and its relevance to incorporate packaging functions in the quantification of environmental impacts. This sequence is exemplified for a specific case of yoghurt packaging. Finally, conclusions and outlook for future research are presented in section 5.

Packaging Functions

Packaging plays a fundamental role in preserving and delivering food and therefore simultaneously fulfils several functions. A recent study by Lindh et al. (2016) provides an overview of key packaging functions and a comprehensive list of further studies highlighting the relevance of multiple functions for packaging food and their indirect contribution to sustainable development. The overall food packaging functions can be defined under four main categories, abbreviated by "PCCC", which stands for Protection, Containment, Communication and Convenience (Robertson 2012).

Protection refers to the ability of the package to protect the food from the external environment and its effects, such as mechanical damage, contaminants, temperature, humidity and gases. It is a determining factor for shelf life and quality of the packed food.

Containment is another fundamental function of packaging i.e. the ability to contain or hold food. For a specific package it may mean how much volume or mass of the food a package can hold.

The function of Communication includes how a package conveys information, e.g. how to prepare the packed food, lists of ingredients and nutritional facts. This function also includes commercial information such as labels, barcode and at the same time enables compliance with regulations.

Convenience includes functions which are relevant in the transportation, storage and consumption such as handling, distribution, delivery, opening, reclosing/sealability or the option to use the package for food preparation. Figure 14-1 shows key packaging functions for a typical food packaging with examples of further sub-functions for protection and convenience.

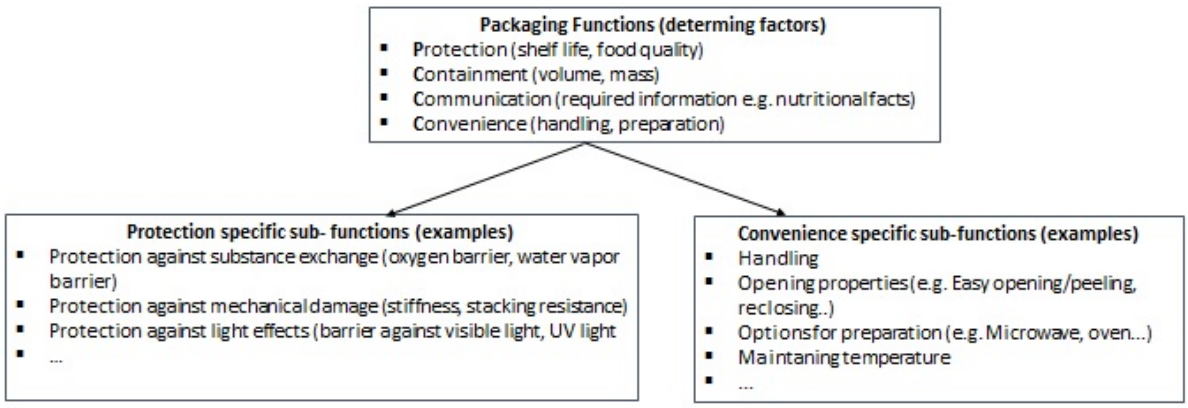


Figure 14-1: *Packaging functions with examples of further sub-functions*

Recent studies on environmental impacts of food packaging

Vignali et al. (2016, 2017) presented a comprehensive review of studies that have been performed on the environmental impacts of food packaging. At the same time, there have been recent studies reviewing LCA specific to packaging for food and beverage applications (UNEP 2013) providing guidelines for practitioners, packaging designers as well as policy makers. From these studies, the following different goals can be identified as their motivation as per packaging life cycle, i.e. packaging manufacturing, use and end of life.

Manufacturing

Development of packaging applications based on alternative packaging materials such as bioplastics: The application of bioplastic for food packaging has received widespread attention in the recent years. Peelman et al. (2013) presented a comprehensive information on bioplastics and its application in food packaging; highlighting its key characteristics and applications. Bioplastics are plastics from renewable resources, hence called bio-based, or plastics which are biodegradable/compostable. Therefore, it is also essential to note that bioplastics often biodegrade only under specific conditions. A recent study by Van den Oeven et al. (2017) presented facts and figures related to technical, economic and sustainability aspects of bio-based and biodegradable plastics for food packaging.

Packaging use

Packaging optimization and packaging reduction: Advancements in material science such as improvements in material performance or packaging weight reduction may reduce the overall environmental impacts of packaging. They may lead to quantifiable environmental benefits provided their application does not reduce the shelf life. The advantages of packaging reduction without affecting shelf life have been demonstrated for the use of PET in the beverage industry (Coriolani et al. 2006) and for bread packaging (Licciardello et al. 2014, 2017).

Packaging from the perspective of food loss, food waste and shelf life: Considering the critical role of different quota of food losses in environmental impacts of packaging has also received increasing attention in recent studies. Several studies have demonstrated the potential of packaging in context of increased shelf life and food waste reduction along the food value chain and household level. In Europe, almost 280 kg of food is wasted per capita per year across the entire food value chain (Gustavsson et al. 2011), of which 45% is wasted at the household level (Beretta et al. 2013). 20-25% of the household waste is packaging related (Williams et al. 2012); highlighting the need for improvements in food packaging. Licciardelo et al. (2017) discussed the need for a more in-depth look at the protective function of packaging to establish a fair correlation between environmental impacts of packaging and its ability in avoiding food waste and losses. Many studies suggest that packaging able to reduce food loss may provide environmental improvements even if the packaging alone may have higher environmental impacts (Wikstrom and Williams 2010, Williams and Wikstrom 2011). Licciardelo et al. (2017) proposed a strategic framework (PREI) for different food categories based on packaging relative impacts.

End of Life

End of Life (EoL) options for packaging materials: The lack of degradability and difficulties associated with recycling of plastics is a current concern in the public (EU Report 2018). Earlier attempts to quantify the impact of different EoL options of food packaging insinuated that mechanical recycling is the most suitable option for waste treatment over incineration and landfill (Michaud et al. 2010). At the same time, contamination of packaging by food residues makes mechanical recycling practically challenging (Siracusa et al. 2008). Therefore, the use of biopolymers in combination with composting is considered as a solution. Ingrao et al. (2015, 2017) demonstrated this by comparing the use of PS and PLA for meat packaging. Although not specific to food packaging but a recent comparison of environmental impacts of production and end of life options for fossil as well as biobased plastics showed variations in environmental impacts across different environmental indicators depending upon waste management scenarios; such as incineration, landfilling, compostability. The study showed no clear advantage for either of the two different groups of materials from an environmental point of view (Troy et al. 2013, 2017).

Function driven environmental impacts and their relevance for food packaging

While there is need for in-depth and thorough consideration of packaging functions in environmental evaluations of packaging (Vignali 2016, Licciardello 2017); a recent study (Lindh et al. 2016) presented a systematic theoretical framework to define key packaging functions and their relevance for sustainable development. However, there is a lack of related studies for specific food packaging applications.

Several studies have been carried out based on a functionality-based approach towards quantification of environmental impacts in the field of product development (Santucci and Estermann 2005) and early stage material selection (Broeren et al. 2016, Hesser 2015). However, one of the practical problems in the use of such a function driven environmental evaluation is a systematic characterization of the functions and their quantification in the functional unit (Cooper 2003, Ruhland et al. 2000).

This challenge also applies to LCA's of food packaging especially. Usually, the functional unit in packaging is given in terms like "to pack 1000 Litres of milk and enable transportation to the retail store". As a result, most the packaging LCA studies just deal with the packed amount (i.e. containment) and other functions are either neglected or considered as being identical. Therefore, what is often missing is a proper consideration of different shelf life characteristics, differences in the quality at the consumer, different wastage rates both in the logistic chain as well as at the consumer, and different waste management schemes.

A typical framework for packaging design is presented in Figure 14-2. Most often, the choice of the packaging material is strictly based on the material properties which at the same time must fulfill the requirements for food, storage conditions and design process of the packaging.

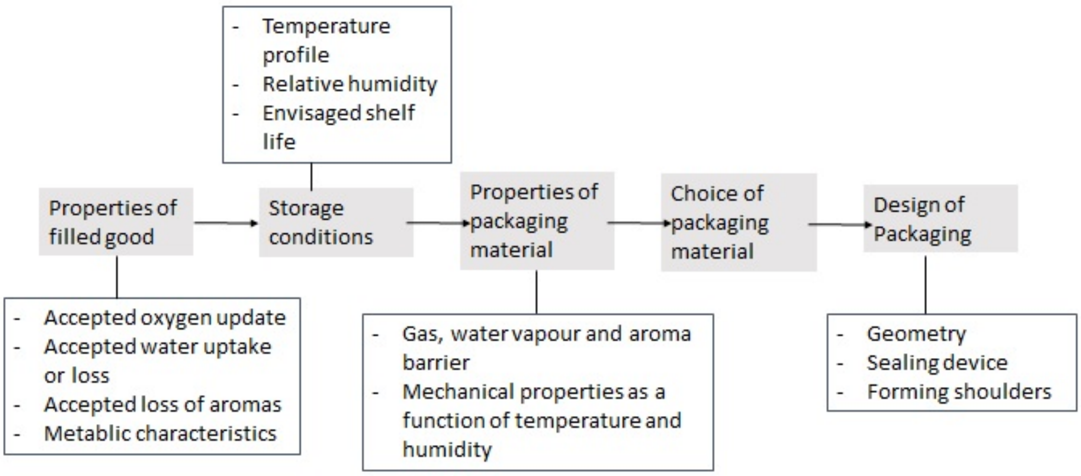


Figure 14-2: *Typical framework for material selection in packaging development (source: Fraunhofer IVV).*

Based on the framework, the following function-driven approach for food packaging is proposed:

Step 1. Characterization of packaging functions to determine function-driven parameters based on product specific material properties: key functions for packaging applications are expressed and quantified in terms of function-driven parameters of the packaging media, which in turn are based on the properties of the material used. Material properties may include mechanical and barrier properties of the packaging material such as yield strength, young's modulus, yield strain, oxygen and water vapor permeation coefficients.

For a yoghurt packaging this could be applied as shown in Table 14-1. The global functions (parts of "PCCC", see section 2) consist of a multiplicity of more specific functions some of which are quantifiable. Only quantifiable functions that are directly related to material properties help to estimate the amount of the specific material needed to produce the package under study. If packagings of the same geometry are to be compared, this amount is represented by the weighted average of the material thickness. Table 14-1 exemplifies this for sub-functions of the main functions Protection and Containment for a yoghurt packaging. Among these examples, some parameters linearly depend on the material thickness, others non-linearly, whereas others are independent of it.

Packaging Function	**Function-driven Parameters**	**Material properties**	**Relation to physical quantities (*h*: material thickness)**
Stackability (i.e. absence of strong deformation under max. permissible load)	Strength, *S*	Yield strength σ_y	$S \sim \sigma_y h$
	Bending stiffness, S_t	Young's modulus E_t	$S_t \sim E_t h^3$
	Elasticity	Elongation at yield/yield strain ε_y	Independent of sample dimensions
Protection from oxygen/oxygen barrier	Reciprocal oxygen transmission rate, OTR^{-1}	Oxygen permeation coefficient P_{O2}	$OTR^{-1} \sim h / P_{O2}$
Avoidance of water losses/water vapor barrier	Reciprocal water vapor transmission rate, $WVTR^{-1}$	Water vapor permeation coefficient P_{H2O}	$WVTR^{-1} \sim h / P_{H2O}$

Table 14-1: *Example of packaging functions for yoghurt packaging, related function-driven parameters, corresponding material properties and relation to physical quantities (adapted from Aggarwal 2017))*

Step 2. Quantification of material properties to derive scaling factors: The performance of the material i.e. its material properties determines the amount of packaging required. Ashby described a methodology to relate the amount of material required for a specific application to its properties (Ashby 1999). This can be used to derive scaling factors or material substitution factors (MSF). This is useful to account for differences in the technical properties between materials for a defined function and has been applied in few studies, especially for early stage design and development of materials and their applications (Broeren et al. 2016, Hesser 2015, Aggarwal et al. 2017).

Step 3. Use of scaling factors to normalize the environmental impacts obtained from LCA/Eco-profiles: based on the scaling factors the environmental impacts from LCA data or cradle to gate LCA data, also called eco-profiles (Plastic Europe) can be corrected for the differences in the material properties. In a recent study by Aggarwal et. al. (2017) such scaling factors have been calculated for PLA and PS based yoghurt packaging and used to normalize environmental impacts, namely: non-renewable energy use and greenhouse gas emissions, to the protection function of the packaging using function-driven parameters such as material strength, stiffness, oxygen barrier and water vapor barrier.

Step 4. Identification of bottleneck parameters for further improvements: The function-driven approach can serve as a useful tool for material selection strategies or for directing future research efforts in research and development. For food packaging, the function-driven approach can be used to identify and evaluate packaging materials to support early stage material selection for specific food packaging applications - as shown in the application of this approach to yoghurt packaging (Aggarwal et al. 2017).

Conclusions: limitations and outlook for further research

Any strategy for packaging such as material reduction or substitution, avoiding food waste by enhancing shelf life, or improving end of life options for materials will ultimately influence the packaging design in physical aspects (such as change in packaging thickness) and subsequently influence its functional properties. Based on the initial experiences with the function-driven approach – as highlighted in this study, different packaging materials can be identified and evaluated based on the differences in their function specific material properties such as barrier properties (WVTR, OTR) and mechanical properties (strength and stiffness). This can be useful to identify and evaluate material selection as per specific food packaging applications.

However, some of the challenges remain. Accounting of the probable food losses due to a possible change in the shelf life is yet to be included. This will require further treatment of the food production chain to include food loss. Being work in progress, a complete solution so far not achieved and there is a need for additional reliable data. However, the application of the approach provided two main conclusions to develop a tailored approach for incorporating packaging functions in LCA studies: a) A function-driven approach that normalizes the impacts with view on the packaging functions as required for specific product classes, b) A consistent list of function driven parameters to be regarded in any study.

15. Methodology for the Life Cycle Assessment of Clay Masonry from Energy and Water Consumption

Sergio Alfonso Ballén Zamora ✉, Liliana Medina Campos ✉, Luz Amparo Hinestrosa Ayala, Adriana Cubides Pérez, James Ortega Morales, Adriana Marcela Serrano, Oscar Mauricio García

Abstract

Considering the clay masonry production, energy and water's resources consumption has a high relevance, mainly at raw extraction materials, and transformation phases, highlighting the environmental impacts ensued by these types of activities. Life Cycle Assessment Methodology (SIMAPro v8) applied to evaluate the environmental impact, and water and energy consumption, at "cradle to gate" for a Non- structural masonry unit (1) Clay hollow brick No. 5, revealed a highest energy consumption (55%) at Benefit & Transformation phase, followed by drying & baking consuming 45% from total energy required. Green water (known as collected rainwater) is highlighted as low as resource consumption, requiring a total of 0,3696 kg H_2O (rainwater)/unit. Raw material´s extraction activities result as an impact evaluation greatest generator; Mixing, Crushing and Molding are the second energy demanding and impacting activities. Baking activity is the third activity that can cause impact, mainly due by Eutrophication, Acidification, Photochemical oxidation, Global Warming Potential and Human toxicity. Considering the Colombia´s commitments to achieve a 20% reduction of emissions by 2030, results are demonstrating even higher environmental impact related to the change in land usage, in order to extract construction materials. This alarming situation requires an urgent environmental intervention, and tougher rules for construction companies, which help to prevent and mitigate the environment degradation.

Keywords: Life Cycle Assessment, Cradle to Gate, Energy Consumption, Water Consumption, Water Stress, Emissions, Impact Analysis, Impact Categories, Clay Masonry.

Introduction

The building sector contributes directly to 6.4% of emissions (IPCC 2014). The production of construction materials such as clay mason is not specifically referred by the IPCC, however, it is related to the increase of the emissions by 2.7% (Ibidem), due to mining extraction. The water consumption for a specific product (production process) reported by the clay masonry industry water, will be evaluated based on the ISO 14046 methodology (ISO 2014). However, elementary flows —to determine the impact on the water demand— will be evaluated as an indirect water footprint for an organization (Hoekstra 2003).

Considering a global water requirement (scenario projected to 2050), for the productive sector of 4000 km^3 (WWAP 2015), the blue water footprint evaluated for the industrial sector in Colombia (CTA et al. 2015), is 65.4 million m^3/y, which does not consider precisely the masonry industry. Studies on hollow clay brick energy consumption for production are not common in Latin America; Mexico study (Chargoy 2009) referring specifically this common building product is highlighted. Peru and Colombia are unique, they are the only Latin American countries that still use coal as energy a main source of energy in the masonry industry (CAEM et al. 2015). This is done mainly to run the kiln and drying the final product. Other sources as firewood, sawdust, agricultural waste, coal, gas, tires, or used oil are used as well.

Peru reports water consumption values only for the clay and sand mixture [between 0.36 - 1.45 kg H_2O/brick] (reference King Kong from Peru), it depends if it is handmade (lower value) or mechanized (COSUDE); Argentina (Herrera 2014), refers to water for artisanal brick, as "a resource that enters from nature to the system", establishing a value of 2 kg H_2O/brick; Mexico refers a volume of drinking water of 2.5 kg H_2O/clay hollow block unit (Chargoy 2009).

Methodology

The study was developed using information provided by Arcillas de Colombia, a masonry building manufacturer (Figure 15-1), identifying, for clay hollow brick No 5 information (Table 15-1) the study roadmap (Figure 15-2), the processes (Figure 15-3) specifically raw materials, energy and water inputs and outputs in a first local inventory (Colombia) focused in referred product. Inventory allowed to define study at “cradle to gate” phase based on ISO 14040 (ISO/TC 207) and Functional Unit Technical Datasheet based on software SIMAPro v8 data requirement (Table 15-2).

Figure 15-1: *Arcillas de Colombia Location (Cogua, Cundinamarca, Colombia); source: authors.*

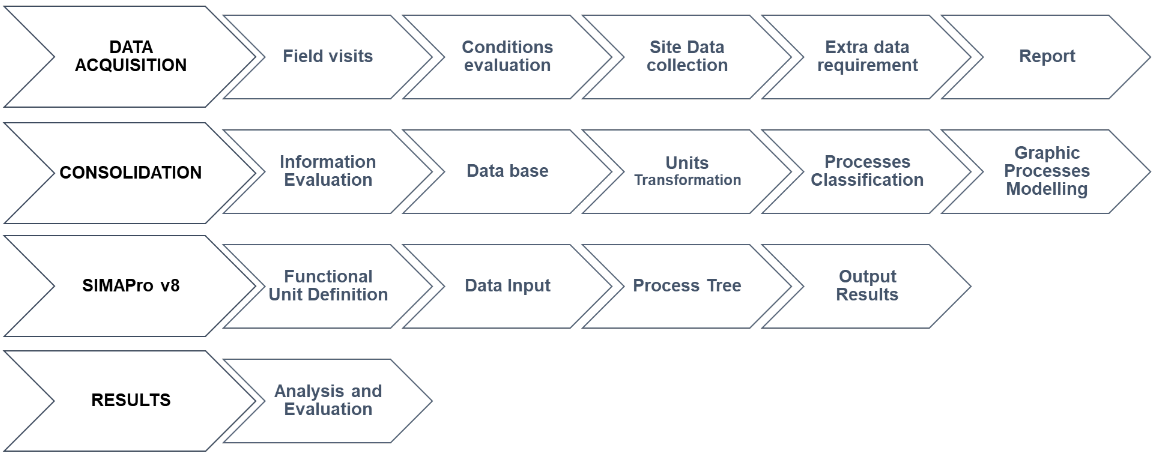


Figure 15-2 : *Project Roadmap; source: authors.*

Brick Features	
Dimensions	• Width: 9 cm • Length: 22 cm • High: 32cm
Composition	• Clay 70% • Sand-Silt 25% • Pre-consumer Content 5% • Water
Weight	• Initial 7 Kg • Dry 6,1 Kg • Baked 5,6 Kg

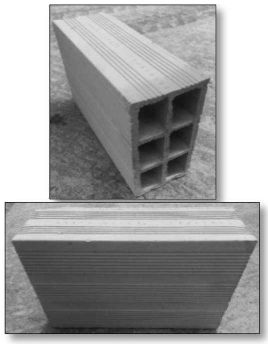


Table 15-1: *Clay Hollow Brick No. 5 Features; source: authors.*

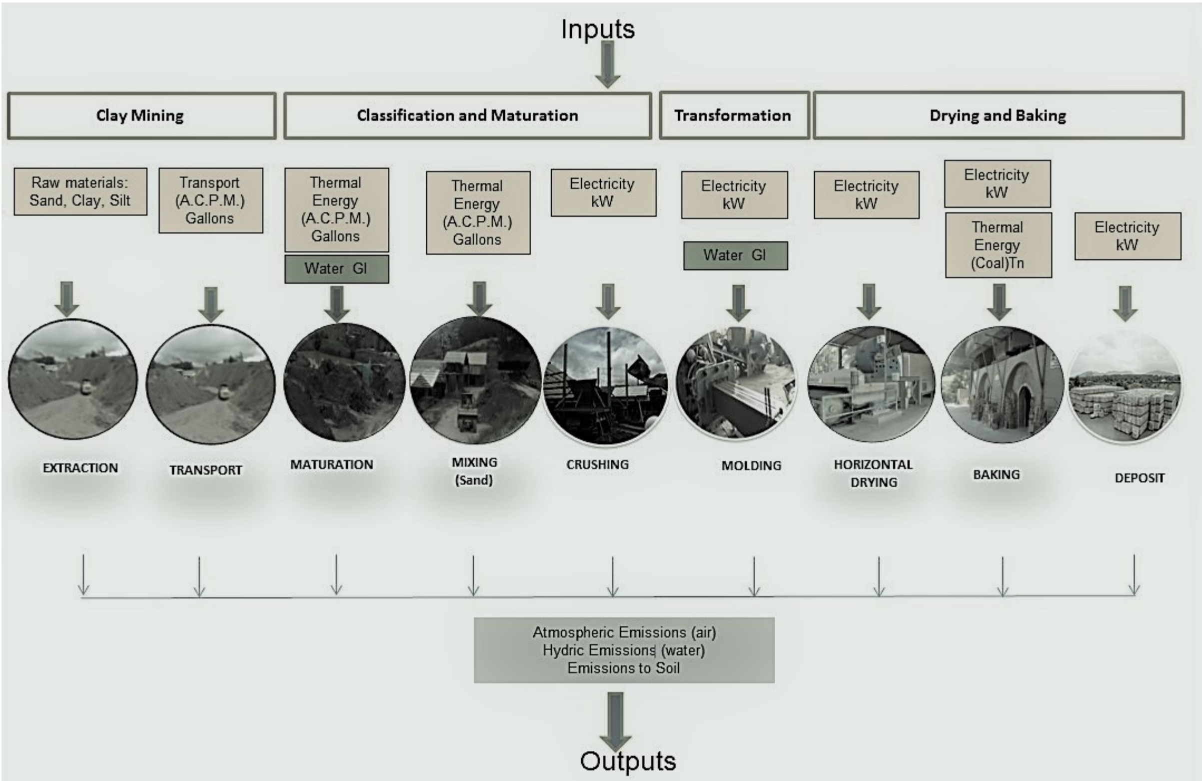


Figure 15-3: *Clay Hollow Brick No. 5 – Colombia Process Inventory; source: authors.*

Study Technical Datasheet	
Functional Unit	Non structural masonry unit (1) Clay hollow brick No. 5
Reference Flux	Efficiency:13 clay hollow bricks/ m^2 Useful life: 60 years in a building
Impact Category	Carbon Footprint (GHG) Water Footprint
Tools	SIMAPro v8 ECOINVENT WULCA - AWARE
Scope	LCA Cradle to Gate
Location	Cogua, Cundinamarca, Colombia

Table 15-2: *Functional Unit Technical Datasheet; source: authors.*

SIMAPro v8 as main tool, Ecoinvent version 3.0 as database, Cumulative Energy Demand V1.08 (CED) for energy demand, Water Stress Index (WSI) – AWARE WULCA for water demand and CML impact methodology -IA baseline V3.01 for environmental impact categories were used.

Results and Discussion

Greater energy flow and demand is concentrated at the clay extraction (mining) and its demand for fossil fuels such as diesel and oil. Highest energy consumption was (55%) at Benefit & Transformation phase, followed by cooking & drying consuming 45% from total energy required (Figure 15-4). The first clay extraction and second processing stages are linked to non-renewable energies of nuclear origin; on the other hand, the drying stage of the block is almost entirely committed to non-renewable energies of fossil origin due to the use of coal dryer. In our case, hydropower is the main source of national energy, so the results must be carefully interpreted.) It is worth noting that this evaluation is made based on the European energy matrix, where the supply of renewable energy systems varied and allow these results.

The highest impact flow related to the demand for water resources (Figure 15-5), also comes from the open clay extraction stage (84.8%) and secondly the clay processing (15.2%). Producer collects and use green water (rainwater) at production phase with a total of 0.3696 kg H_2O (rain)/unit, this value is comparatively less than that referred for Mexico (Chargoy 2009) of 2.5 kg H_2O (potable)/unit. The water supply must be highlighted, considering no water flow deviation or affectation, evidenced in a low demand established by SIMAPro v8. Considering that there is no comparison information for the extractive phase for the present study, the resulting generated by the software should be assumed as initially approximated to the reality of consumption in a mining extraction process, the weight of the resulting SIMAPro v8 for the demand for energy and water resources for the extractive phase must be considered significant.

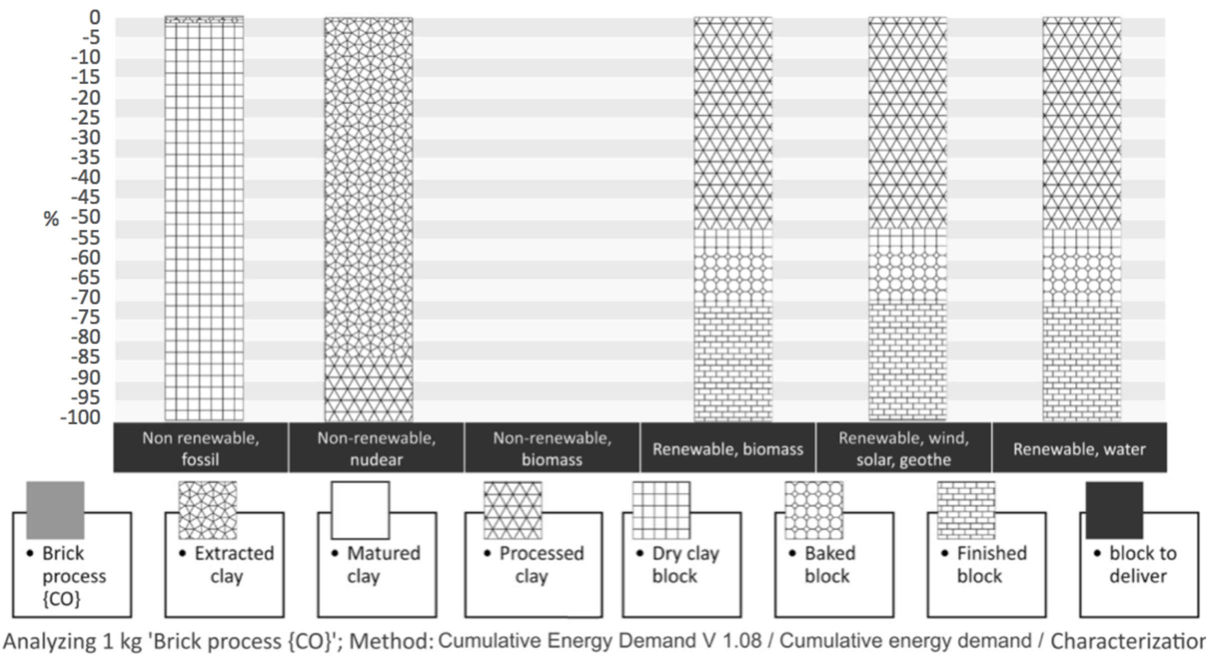


Figure 15-4: *Energy Demand; source: authors.*

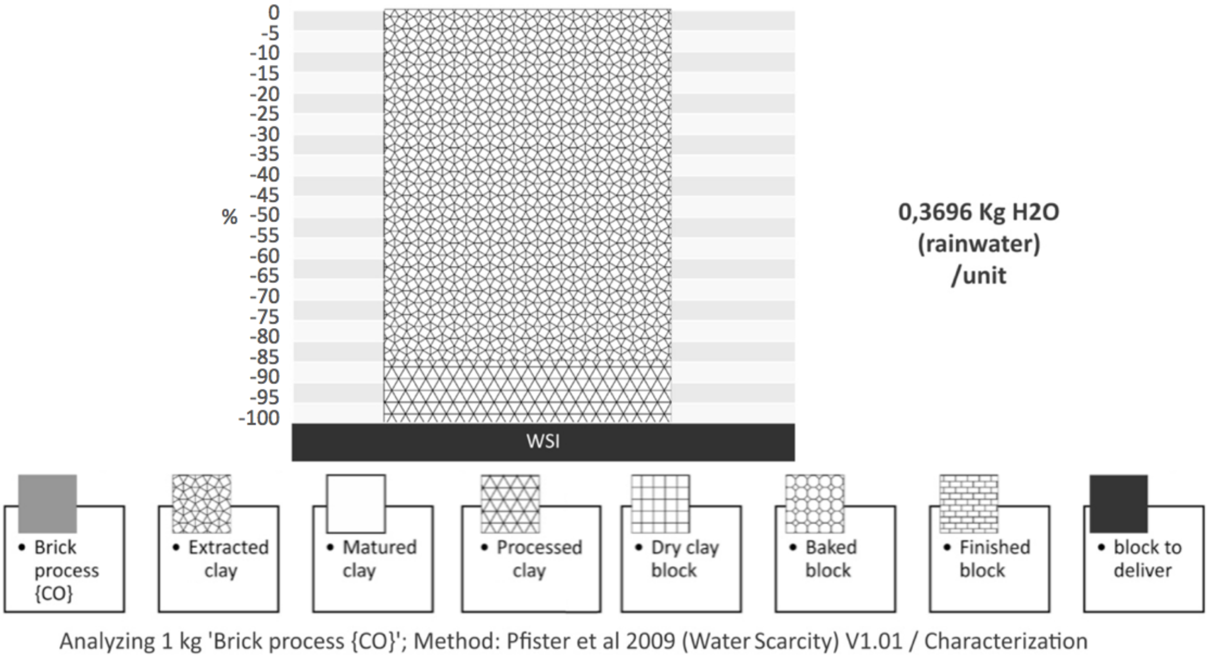


Figure 15-5: *Water Demand; source: authors.*

The global warming analysis shows a significant flow of impacts in the clay extraction stage (82%), clay processing (12.7%,) and the masonry blocks firing (4.7%). As in the previous figures and analyzes, a large portion of the responsibility for the impacts lied in the use of diesel as the main source of fuel, oil (in addition to heavy crude oil,)electricity, and natural gas and its residues. Producer emissions report for 2012 (CAEM et al. 2015), must be considered, with values of 16.89 t CO_2/y, associated with diesel fuel is used for backhoe loaders, forklifts, loaders and trucks, vehicles used at process plant, representing in 213,76 t CO_2eq of emissions by mobile sources. The reference study *does not* include information about consumption by mobile or fixed sources during the extraction phase; and that emissions are *not* discriminated by a specific product, but by total products. Considering that Clay Hollow Brick No. 5 represents 10.5% of the production, an emission for this product of 22.44 t CO_2eq can be estimated. SIMAPro v8, establishes a value of 21.35 kg CO_2/unit as emission, a value that compares to the one reported in Mexico (Chargoy 2009), of 1,179 kg CO_2, the value referred to in the present study is higher representative.

Comparing the results with Mexico (Chargoy 2009), the NOx value (among which NO_2 refers), is 0.0014 kg/unit NOx, a value that contrasts with the 1.62 kg/unit NO_2, and that considering the value of 0 for the NO_2 referred in 2012 (CAEM et al. 2015), an uncertainty is generated in the analysis. Greatest impacts as Global Warming Potential, acidification, photochemical oxidation and human toxicity, correspond to the extractive phase (Figure 15-6), highlighting that, in the baking phase, the acidification, photochemical oxidation and Global warming potential impacts are the following in relevance.

In general, the clay extraction stage shows the biggest impacts in almost all the categories, being clay transforming the subsequent. The baking phase has notable impacts, as photochemical oxidation, acidification and especially eutrophication, due to the use of coal which produces emissions of CO_2, CH_4, N_2O, CO, SOx, NOx, among others. The drying stage of the blocks has an almost totally related impact in the category of depletion of abiotic resources related to the use of fossil fuels and electricity as main source of power.

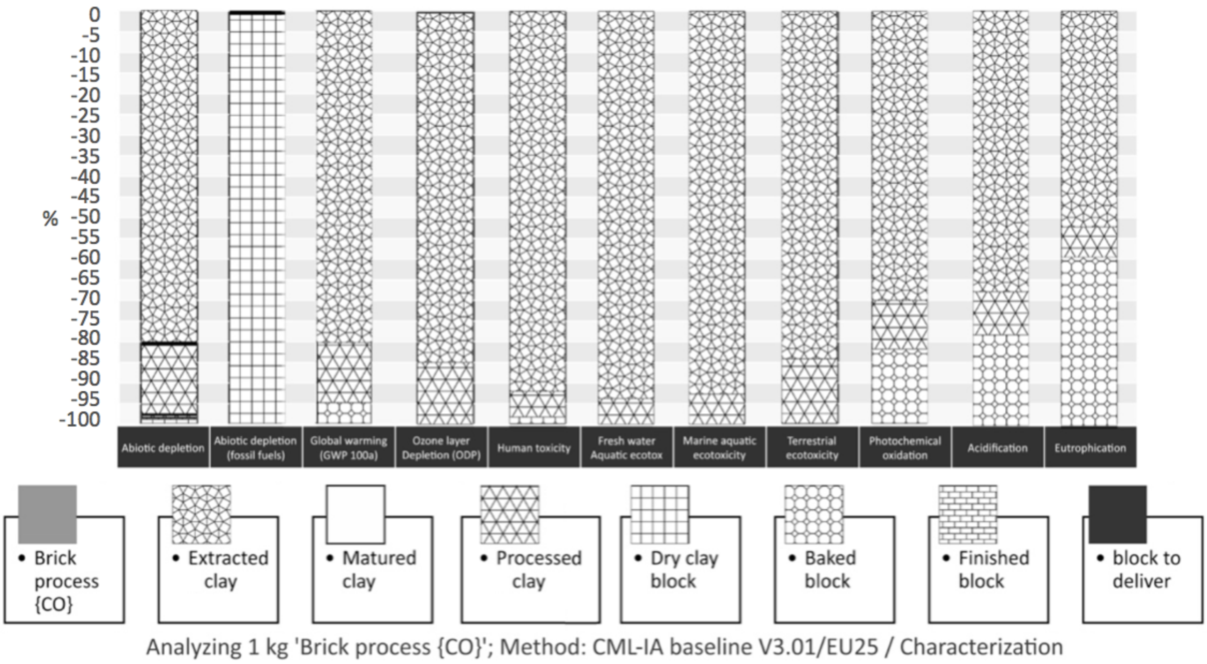


Figure 15-6: *Environmental Impacts Categories; source: authors.*

Conclusions

Mining (clay extraction) represents the highest levels of consumption of energy and water, causing other impacts activities.

Mixing, crushing, and molding are the activities second for high energy demand and impact.

In third place comes the baking activity. The most relevant categories are: Eutrophication, Acidification, Photochemical oxidation, Global Warming and Human toxicity.

This study provides arguments to enhance mining activities and public production policies formulation, that would accomplish 20% emissions reduction by 2030.

16. Bio-Inspired Solutions for Climate Responsive Sustainable Architecture

Avantika Srivastava, Tarun Kumar ✉, Vishal Mishra, Kriti Bhalla

Abstract

This paper studies natural organisms and plants along with their features that can be utilized to formulate better design-strategies for climate responsive buildings. The conventional buildings are often far away from the concept of sustainability. Bio-mimicry uses nature as a model, measure and mentor to formulate bio-inspired solutions. These bio-inspired solutions give us more unswerving building systems, responsive to climatic changes in the surroundings, thus reflecting bio-mimetic design as a sustainable paradigm. In this paper, few organisms and plants were closely observed, and their innate, behavioural and evolutionary characteristics were studied. Following which, a strategy was developed to design a framework that eventually aided us in emulating their properties and characteristics in the architectural design to give us more environmentally sustainable buildings. A group of 20 design students were asked to design a climate-responsive building with and without the help of the proposed framework. Preliminary observations show that the designs obtained with the aid of this framework are likely to be more sustainable and climate-responsive. Subsequently, an android application namely- 'PRAKRITI 1.0' was developed to aid the designers in developing biomimetic building design. Furthermore, a comprehensive database of various natural organisms and plants needs to be incorporated in the framework and 'PRAKRITI' Application to provide more creative, innovative and robust design solutions. Such bio-inspired design solutions would help us create climate responsive and sustainable buildings, which would be a part of future sustainable cities.

Keywords: Bio-Mimicry, Climate-Responsive Architecture, Bio-Inspired Buildings.

Introduction

The climate of a place remains constant and depends upon various geographical factors like altitude, distance from the sea and distance from the equator. However, expedited changes in the climate and harsher weather conditions have been recorded in the recent years (Hansen and Dale 2001). The root cause of these sudden climatic changes is various human activities. Exploiting the natural resources, deforestation, improper garbage disposal and land exploitation are some of the common human activities causing an imbalance to nature (Donner et al. 2007). In recent years the rate of development has increased drastically. Real-estate development rate has increased in today's ever-expanding cities but the conventional methods of construction often do not meet the criteria for an environment-friendly building (Ghaffarianhoseini et al. 2013). Therefore, there is a need to shift to new and greener techniques of design and construction that can deal with the problems of climate change.

Biomimicry is an approach that seeks sustainable solutions from nature by using nature as a model for various new techniques for construction and development. Nature has already solved many of the problems we are dealing with today; therefore, the basic idea is to take nature as a model, measure and mentor (Benyus 1997) to build more unswerving building systems, responsive to climatic changes in the surrounding, thus reflecting bio-mimicry as a sustainable paradigm. Understanding the living organisms in nature and the study of their origin, anatomy, morphology, physiology and behaviour has given us in-depth knowledge about the interaction between living and non-living organisms (Aziz and El Sherif 2016). From times immemorial, architects, designers and engineers have looked upon nature as an inspiration for various kinds of forms, techniques and functions. It is observed that organisms serve as perfect models having a mesmerizing harmony and proportion amongst their parts. Biomimetics (also known as 'biomimesis', 'biomimicry', 'biologically inspired design' are the words and phrases implying copying or adaptation or derivation from biology) is thus a relatively new field-of-study taking the mechanisms and functions of biological sciences to engineering, design, chemistry, electronics, and so on. However, people have looked to nature for inspiration for more than 3000 years (since the Chinese first tried to make an artificial silk) (Vincent et al. 2006). Innovative approaches to new building technologies and advanced computation tools have aided in designing environmentally responsive buildings.

The buildings that do not use mechanical cooling systems in desert-heat were designed by using ant nests as examples (Eastgate Building, Zimbabwe). In the apparel industry, the fabric that does not contain chemical pigment was developed after analyzing the relationship of the wings of the Morpho butterfly with light (Morphotex). These examples inspired-by-nature show that biomimicry has influenced the field of architecture, especially in form-development, structure-formation and texture-design (Tokman 2012).

Literature Review

Project	Location & Year	Description	References
The "algae house"	Germany 2013	● World's first example of a "bioreactor façade" ● The transparent surface containing tiny, growing algae, which shall control light entering the building and provide shade when needed. ● After enough algae grown they can be harvested and used to make biogas -a renewable energy source to supply the buildings	(BBC 2017)
The Eastgate building	Harare, Zimbabwe	Inspired by the way the insects create ventilated mounds, permeating them with holes over the surface Example of "passive ventilation" – buildings uses renewable energy from the environment around them in place of normal air conditioning and heating systems.	(BBC 2017)
Breathing Skins Project	Mandelba-chtal, Germany, Ongoing	● Inspired by organic skins that adjust their permeability to control the necessary flow of light, matter and temperature between the inside and the outside surrounding. ● It is a form of responsive architecture, the ever-changing pneumatic muscles allow a specific amount of air, light, and visibility according to the users' preference	(ArchDaily 2017)
Elytra Filament Pavilion	London 2016	● Exploration of how biological fibre systems can be transferred to architecture. ● Inspired by lightweight construction principles found in nature, namely "the fibrous structures of the forewing shells of flying beetles known as elytra. ● The pavilion's canopy is made up of 40 hexagonal component cells, each weighing an average of 45 kilograms.	(Doerstelmann et al. 2015)
Antarctic Port for tourism and Research	Antarctica 2014	● The project hypothesizes a point of arrival for the world's final frontier of development. ● The project employs biomimicry as a primary design tool, replicating the jagged asymmetrical edges of ice formations along the coast of the southern-ocean. ● The building snakes out of the water, ascending the face of the ice-covered continent and soars skyward with a tower clad in glass.	(ArchDaily 2014)

Table 16-1: *Existing examples of Bio-mimicry in Architecture.*

Methodology

The characteristics of different flora and fauna were studied that can help in designing a building, based on which a preliminary framework was created using morphological analysis. Biomimicry design matrix and a broad database of various natural organisms and plants were created and incorporated in the framework to provide more creative, innovative and robust design solutions and to improve innovation in the design of climate responsive buildings. A group of 20 design students were asked to design (conceptual planning) a climate responsive building with and without the help of the proposed framework in thirty minutes. These designs were evaluated against each other using the *weighted-mean* method. The same framework was used to develop an app named 'PRAKRITI 1.0', which takes design parameters as input and generate conceptual designs with respect to all parameters using the concept of biomimicry.

Results

Table 16-2 presents the analysis of features, form and functions of various flora and fauna which can be used for building design to generate innovative design ideas. Climatic factors, disaster analysis, and building design ideas with and without bio-mimicry for Bangalore city was done. Preferable weights were given to five different designing parameters namely- Technology (0.3), Sustainability (0.2), Cost (0.1), Aesthetics (0.2), Function (0.2). Climatic conditions were fixed as Bangalore climate for the proposed building design, which can be modified to other climatic zones as given in Table 16-7. Moreover, hazards due to different natural disasters for Bangalore city was reflected in Table 16-3. The morphology-based design framework for the design of climate responsive building is given in Table 16-4. While Table 16-5 shows the biomimicry-based design parameters. Design framework with biomimicry is the combination of table 16-5 and table 16-6. Finally, the conceptual designs obtained from Morphology-based design framework without bio-mimicry Ideas (Table 16-4, Table16- 5).

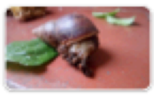
Name	Features	Form	Function	
Entada Rheedei Spreng	Stems can go up to 120m long and 40cm in diameter.	Thick stem are spirally twisted and angled 100m in height		
Snail Shell	The shape may vary depending upon the snail Hard	Solid spiral shape carried on back Single piece made of calcium carbonate	Structure protects the snail	
Honey comb		Columnar and hexagonal cells	Allow minimization of material used to reach minimal weight and max strength Least density High compression	
Spider web	Light weight structure Highly optimized High tension	Radial threads radiate out from the center of the web Spiral threads connect the radial threads together to form circular pattern	Catching Insects Robust and light weight Novel sensory structure	
Millipedes	Two pair of join legs and body parts segments	Distinct head and many repeated segments in body Each segment has two pair of legs	Segmented body allows the millipede to coil up into a ball. Hard exoskeleton	

Table 16-2: *Study on Different Flora and Fauna.*

Earthquake	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
Flood	Moderate	Low Risk Areas	High Risk Areas	High Risk Coastal Areas	Undetermined Risk Areas
Tornado	Prone	Not Prone			
Tsunami	Very Low Risk	Low Risk	Medium Risk	High Risk	
Volcano	Mid-ocean ridges	Sea-Floor Crust	No Volcano		
Cyclone	Prone	Not Prone			

Table 16-3: *Probable Disaster risks for Bangalore City.*

Building Envelope	Bricks	Concrete Blocks	Glass	Mud	Wood	Smart Material
Building Structure	Column & Beam	Load Bearing	Modular	Sub-Terrain	Mound	Tree House
Roof	Mangalore Tiles	Glass	Tensile	Truss	Concrete Slab	Thatched Roof
Opening	10%	20%	30%	40%	50%	60%
Construction Technology	RCC	Brick Work	Prefabricated	Modular		
Spatial Orientation	Radial	Courtyard	Villa	Liner	Clustered	
Building Environment	Forest	City	Rural	Suburbs	Snow	Mountain
Style	Vernacular	Conventional	Contemporary	Smart	Affordable	

Table 16-4: *Morphological Design Parameters for design of climate-responsive buildings*.

Organism	Dragon Fly	Spider	Entada Tree	Snake	Darkling Beetle	Weaver Bird
Eco-System	Ant Hill	Honey Comb	Borrow	Den	Corals	Nest
Behavior	Touch me not	Venus Flytrap	Sunflower	Green Leaf	Scorpion/ Bat	Starfish
Material	Calcium Carbonate	Spider Thread Fiber	Honey Comb (mud and wax)	Straws	Wood & Twigs	Mud & Sand
Form	Segmented	Cylindrical	Conical	Tensile	Hexagonal	Irregular

Table 16-5: *Biomimicry Design Parameters.*

Climatic Zones	Tropical	Sub-Tropical	Polar	Temperate	Arid	Mediterra nean	Mountain
Temperature	Hot	Hot & Dry	Hot & Humid	Moderate	Cold	Cold & Dry	Cold & Humid
Humidity	High	Optimum	Low				
Precipitation	High	Moderate	Low	Snow	Hail Storm	Foggy	
Wind Speed	High	Optimum	Low				

Table 16-6: *Climate Study of Bangalore City, India*

The various design parameters obtained from the analysis were evaluated using the weighted mean method. The results were obtained comparing conceptual designs formulated with and without the bio-mimicry integrated framework. The graph (Figure 16-1) below shows the results obtained from both the methods (Di: Design idea without Biomimicry framework; Bi: Design Idea with the bio-mimicry framework). It is obvious that biomimicry-based method combined with morphological analysis can give better and more sustainable building design ideas.

Finally, a software- 'PRAKRITI 1.0' (in the form of an android application) was developed to automate the ideation of design ideas through the framework (Figure 16-2). This app aid the designers in developing a climate-responsive building design; and is scalable enough to accommodate new features. Optimized functions are being brainstormed for a newer version of the app.

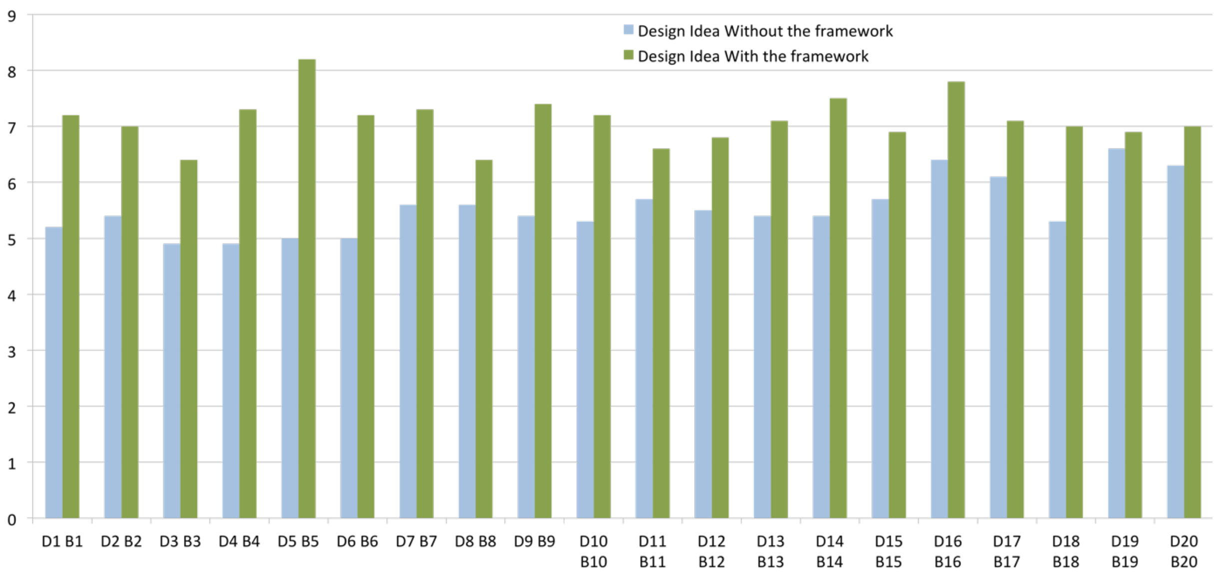


Figure 16-1: *Analysis of the Design Ideas with and without the framework.*

Figure 16-2: *Screenshots of PRAKRITI 1.0 Android Application*.

Conclusion

It was observed that the designs obtained with the aid of biomimicry integrated morphological framework were more sustainable and climate responsive as compared to designs without the framework. This framework needs to be tested further by including more variety of flora and fauna and extending the database. So, this android application can be further transformed into a fully-developed software with a comprehensive database. This broad database with a repository of features of many plants, animals and micro-organisms needs to be created to realize the full potential of bio-mimicry based design frameworks. As living species are known for their ability to adapt according to nature similarly bio-inspired building designs would adapt better to the changing climatic conditions. Such bio-inspired design solutions would help us create climate-responsive and sustainable buildings, which would be a part of future sustainable cities.

Part 3

Water and Regional Aspects

17. Transboundary Headwater Governance in Hindu Kush Himalaya: A Regional Cooperation Framework for Climate Change Adaptation, Water and Food Security and Peace in South Asia

Prakash C. Tiwari ✉, Bhagwati Joshi

Abstract

Hindu Kush Himalaya constitutes headwater of some of the largest transboundary basins of planet that sustain one-fourth global population dependent primarily on subsistence agriculture in South Asia. Climate change has stressed hydrological regimes of Himalayan headwaters causing substantial decrease in water availability and increasing frequency and severity of hydrological hazards and disasters. This may not only increase proportion of water and food insecure population in South Asia, but also have enormous regional implications for fundamental human endeavors ranging from poverty alleviation to climate change adaptation, and even to human security and peace in the region. A regional geo-political cooperation framework among riparian countries is therefore highly imperative not only for adaptation to climate change and disaster risk management; but also for peace and security in South Asia.

Study aims to: (i) investigate reasons for missing river-basin cooperation; (ii) explore geo-political constraints in initiating effective regional cooperation dialogue; and (iii) appraise mutual environmental and economic benefits of transboundary headwater governance. Comprehensive study of available literature and media reports, interpretation of people responses obtained through interviews, interaction with political leadership and government officials across Hindu Kush Himalayan countries formed the basis of this study. Study revealed South Asia is one of the most fragmented regions in the world, characterized by political tensions, armed conflict, political instability and economic imbalances. It was observed political transition, threats of internal and external security, and long standing conflictual inter-state dynamics are some of the important reasons for missing regional cooperation in transboundary water management and freezing hydro-diplomacy in the region. However, there are growing realization and recommendations by scientific community, intellectuals, regional and local institutions, NGOs and civil society organizations for transboundary water governance which would help in initiating regional cooperation for adaptive headwater governance in the region.

Keywords: Climate Change Adaptation, Disaster Risk Reduction, Deficit of Political Trust, Economic Cooperation, Hydro-Meteorological Information Sharing.

Introduction

The Hindu Kush Himalaya forms the tallest water tower of the world, where the mighty glaciers and forested mountain ranges constitute the headwater of South and East Asia (ICIMOD 2011). The region has some the largest glaciers of the planet and permafrost outside the Polar regions that constitute the source of some of the largest river systems of the planet (Biswas 2011). The Indus, Ganges and Brahmaputra rising from the glaciers of Hindu Kush Himalaya sustain one-fourth global population living in the densely populated plains of South Asia, mainly in Pakistan, India, Nepal, Bhutan, and Bangladesh (ICIMOD 2011). The regime of water resources in Himalaya is likely to change rapidly, with respect to discharge, volume and availability, primarily due to global climatic changes as well as increasing population pressure (Bandyopadhyay and Perveen 2002). Climate change has stressed hydrological regimes of Himalayan headwaters through higher mean annual temperatures, melting of glaciers and altered precipitation patterns causing substantial decrease in the availability of and access to water for drinking, food production and sanitation (Rasul 2014). This may increase proportion of water, food, livelihood and health insecure population in South Asia which includes some of the poorest people of the world primarily dependent of subsistence farming and with access to less than 5% of planet's freshwater resources (Karki and Vaidya 2010). Moreover, increasing rainfall variability and the rapid retreat of the Himalayan glaciers has rendered the entire South Asia vulnerable to a variety of hydrological hazards and disasters, such as floods, landslides, glacier lake outburst floods (GLOF) (Rahman 2009). During the recent years the number and intensity of hydrological disasters have increased in South Asian countries (IRDR) (Tiwari and Joshi 2012). This will have enormous regional implications for ongoing fundamental socio-economic development programmes ranging from poverty alleviation to environmental sustainability and climate change adaptation, disaster risk reduction; and even to human security and peace in South Asia (Shrestha et al. 2013).

A regional geo-political cooperation framework among all riparian countries is therefore highly imperative not only for climate change adaptation and disaster risk reduction; but also for security and peace in South Asia. However, importance of regional cooperation for adaptation to climate change has so far been not realized and exhibited by South Asian Countries. The study aims to: (i) investigate reasons and rationale for missing river-basin cooperation; (ii) explore geo-political constraints in initiating effective regional cooperation dialogue; and (iii) appraise mutual environmental and economic benefits of transboundary headwater governance in South Asia. Comprehensive study of available literature and media reports, interpretation of people responses obtained through interviews, interaction with political leadership and government officials across South Asian countries formed the basis of this study.

Transboundary Water Conflicts

Despite geographical and cultural similarities, South Asia is one of the most fragmented and disintegrated regions of the world (Karki and Vaidya 2010). The region is characterized by political tensions, armed conflict, political instability and socio-economic imbalances and disparities (Salman 2002). It was that observed political transition, threats of internal and external security, long standing conflictual inter-state dynamics and increasing deficit of political trust are some of the important reasons for missing regional cooperation in transboundary water management and for freezing hydro-diplomacy in Hindu Kush Himalaya (Nepal 2014). Viewing water of transboundary rivers from security perspective, increasing water demand, declining per capita availability of water, and the extent of dependence on water resources that flow in from the international borders are the main factors of cross-border water conflicts in South Asia (ICIMOD 2011). Bangladesh and Pakistan respectively receive more than 75% of their surface water supply from across their borders, mainly from India (Akanda 2013). Furthermore, although only about one-third of water supply to India originates outside its borders, yet almost 75% of the surface water particularly during dry winter and summer months in densely populated Ganges basin flows from Nepal (Biggs et al. 2013). These water resource inter-dependencies between Bangladesh, India, Nepal, and Pakistan in the Indus and the Ganga-Brahmaputr-Meghna (GBM) basins may further give rise to frictions and tensions over the governance of water resources in the region in times to come (Karki and Vaidya 2010). Nevertheless, the entry of China into the scene has further complicated the water sharing and management cconflicts in the region (Biswas 2011). India is particularly involved in conflicts as it shares international borders with all other countries of the region. Besides, India and Pakistan are facing internal security threats; whereas Nepal has been passing through political instability for long; and this is further complicating the hydro-politics in the region as each country is viewing its water resources through ‘security lens’ (Karki and Vaidya 2010). The Recent security issues between Pakistan and India has further complicated the situation.

South Asia being heavily populated is becoming a water-stressed region. The studies indicated that India, China, Bangladesh and Nepal are water-limited nations; where the annual water availability is quickly approaching the critical stress level mainly due increasing water demand and fast depleting of surface as well as groundwater sources. Water resource demand in India is expected to double and exceed 1.4 trillion m^3 by 2050 (Biswas 2011, Karki and Vaidya 2010). Recent development porogrammes in India in industrial, agricultural, sanitation, hygiene and drinking water sectors will further increase water demand. In the global picture, India is identified as a country where water scarcity is expected to grow considerably in the coming decades (Bandyopadhyay and Parveen 2002). Pakistan is already a water-stressed country, and is facing the greatest water crunch with 1000 m^3/person water supply (ICIMOD 2011, Karki and Vaidya 2010). The country is likely to fall below the minimum level in near future based on the rate at which water availability declined during the last 10 years in the country (Karki and Vaidya 2010). Bangladesh is subject to all kinds of downstream hydrological impacts. However, Bhutan is the only country in the region having large underutilized water resources that country might be able to develop without disrupting the hydrological regimes of the river systems (ICIMOD 2011). Moreover, rapid population growth, agricultural development and increasing industrialization could adversely affect the demand side; and on the other climate change likely to have a serious effect on the supply side of water resources management in South Asia. Since South Asian countries mainly fall within the major river basins of the Indus and Ganges-Brahmaputra-Meghna (GBM); and the extent to which water resources are shared would be an important indicator of vulnerability to competing interests among the nations in the region (Karki and Vaidya 2010).

The Basis and Rationale for Transboundary River Basin Cooperation

The preceding discussion clearly underline the urgent need to evolve a framework for regional cooperation among the countries in Hindu Kush Himalaya for managing water resources and hydrological disasters at basin level. According to the Fourth Assessment report of the Intergovernmental Panel on Climate Change the incidence and intensity of floods in the Himalayan region are expected to increase as a result of an increase in precipitation during the monsoon season and glacial retreat (IPCC 2014). This poses a challenge for reducing the vulnerability of the more than 1.3 billion people living in the major river basins downstream from the Hindu-Kush-Himalayan region. The overriding importance of climate change as a driver of environmental change makes it important to address disaster risk reduction and water-management concerns in a integrated manner at the catchment level. Such an approach is considered and recommended by both the United Nation (UN 2012) and IPCC (2014) to be an adaptive measure for climate change impacts and sustainable mountain development (Tiwari and Joshi 2012).

However in the Himalayan region, the problem lies in the implementation of such a strategy, because most of the Himalayan rivers are transboundary and flows across one of the most densely populated and geo-politically critical regions of the world. In view of this it is suggested that regional cooperation on water and disaster management can be facilitated by a perspective of regional economic cooperation that goes beyond the focus on water alone (ICIMOD 2011, Karki and Vaidya 2010). This perspective would be based on water as a natural resource of central focus, around which cross-border economic exchange, primarily trade, and the development of infrastructure to facilitate it, will also be promoted. The cooperation between India and Pakistan in the Indus river basin is considered as a good example of the situation being redefined to transform it into one of potential mutual benefit by enlarging the size of the pie rather than just dividing it (Crow and Singh 2000). The principal potential benefits of regional cooperation in water resources are: (a) sharing information for flood forecasting and development of early warning system, (b) storing water in upstream river basins for flood moderation, (c) storing water resources for increasing flow in dry seasons, (d) storing water for inland water transport, (e) harnessing water resources to generate hydropower, and (f) managing watersheds to help increase the quality and quantity of water available for irrigation and drinking water by downstream users (De Stefano et al. 2014).

The Opportunities for Regional Water Governance Cooperation

However, there is growing realization, demand and recommendations by scientific community, intellectuals, regional and local institutions, NGOs and civil society organizations for transboundary cooperation which would help in initiating regional cooperation for adaptive headwater governance in the region. Besides water, meeting the growing energy demand is the major challenge in rapidly urbanizing South Asia. This further provides an opportunity for enhanced regional cooperation in the region, particularly between India, Nepal and Bhutan. During the recent years, India has improved the opportunities for regional cooperation with Bhutan and Nepal on hydropower generation and marketing in Ganga and Brahmaputra catchments. This was facilitated by physical and the institutional developments in power sector in India. In the physical context, India developed hydropower power-grid inter-connections from the local level in the 1950s to the provincial level in the 1960s, and then on to the regional level in the 1970s and finally to the national level in the 1990s (Karki and Vaidya 2010). The Power Grid Corporation of India (PGCI) was established to take care of the development of transmission and power-grid inter-connections. The Power Grid Corporation completed: (a) the development of the national grid by interconnecting the five regional grids, (b) the establishment the national load dispatch centre, and (c) the modernization of the regional and provincial load dispatch centres. At the institutional level, India promoted the establishment of power trading companies, such as the government-undertaking Power Trading Corporation (PTC), to promote the power market in the region, particularly in Nepal and Bhutan. These physical and institutional developments have been quite successful in exploring cross-border sources of power for interconnections and trading, particularly in Nepal and Bhutan. Thus the rationale for long-term cooperation in energy are: (a) to take advantage of the potential for economies of scale as a result of large cross-border hydro-power projects set up primarily to address opportunities provided by India's increasing energy demand; and (b) to use cross-border hydro-energy for environmental and conservation benefits.

Conclusions

It was observed that long standing conflictual inter-state dynamics, threats of internal and external security, political transition and instability, increasing water-demand and growing political miss-trust are important reasons for missing geo-political process in transboundary water diplomacy in South Asia. However, there is growing realization among scientific community, academics, NGOs and civil society organizations for transboundary water governance which would help in initiating geo-political dialogues for adaptive headwater governance across Himalaya. Some countries in HKH region, particularly India and China have made significant progress in integrating with the global economy but, without integration and desired regional cooperation within the region due primarily to border dispute. This has wiped out several other comparative and competitive advantages such as common geography and low cost of production. Besides, geo-politics there are several other factors, such as lack of integrated transportation and communication which have seriously affected various efforts to foster regional cooperation in Hindu Kush Himalaya. Consequently, South Asia has remained the least integrated region in the world. Despite huge development potential, it has lagged behind all other regions in achieving minimal cooperation in environmental, economic, political, cultural and communication areas. As a result, the South Asian countries have been finding it difficult to resolve and address even their common issues of climate change, poverty reduction and disaster reduction.

However, climate change has provided a unique opportunity for the countries in South Asia to develop regional cooperation for integrated river basin governance for direct environmental and economic benefits of upstream communities as well as 1.3 billion population living in vast plains located in the downstream. In the changing context of the regional co-operation scenario brought about by climate change and economic globalization and their consequences for water-stress and hydrological risks, the importance of initiatives for timely management of transboundary rivers cannot be overemphasised. In the context of upstream-downstream linkages, it is necessary to consider the benefits of transboundary cooperation for coping with the events occurring in the catchments that lie across the borders. There is also an urgent need for transboundary cooperation in Hindu Kush Himalaya for collecting and sharing hydro-meteorological information to mitigate and manage the risks of climate change induced natural disasters. Further, transboundary river basin management need to be considered an integral component and framework for regional economic development strategy.

18. Rejuvenation of Lakes in Indian Cities: A Case Study for the Betterment of Wetlands in Bangalore

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Abstract

Pollution is defined as “to make something impure”. Water bodies, natural or man-made, are susceptible to pollution ranging from plastic waste disposals to urban and industrial sewage discharge. Until 1960, records show that there were 262 water bodies in Bangalore dotting its topography to impound runoff water so that citizens would always have an abundance of water to drink, irrigate their lands and for fishing. In recent times, the number of lakes in the city has dropped drastically and even the ones present are subjected to illegal encroachment, sewage, toxic waste apart from dumping of domestic waste, human and animal defecation. Few of the lakes now have a permanent froth, consisting of harmful bubbles on the surface that occasionally catch fire due to the presence of oils and chemicals (e.g. Bellandur Lake).

Samples from five lakes were tested for pH value, TDS and EC values. Further, the afore-mentioned lakes were assayed for change in area over a span of seventeen years (2000 to 2017). Based on the sources of pollution, a TRIZ-based ‘Morphological Analysis’ was carried out to propose various technological and bio-inspired solutions for the betterment of these lakes and its ecosystem.

It was interpreted from the study that lakes near industrial areas (i.e. Varthur and Bellandur lake) were more polluted than the other lakes (i.e. Hebbal lake and Sankey Tank). This study infers that city sewer lines and industrial waste are the broad sources of water pollution. Moreover, illegal encroachment of lakes due to increasing urbanization has taken a heavy toll on these dying water-bodies. Various preliminary conceptual models based on technological and bio-inspired approach were proposed, which needs to be comprehensively developed and further tested in the future.

Keywords: Rejuvenation, Lakes, Wetlands, Water-Pollution.

Introduction

Water is considered a purifier and is holy in many ancient cultures and faiths. Many religions glorify the existence of particular water bodies that are considered holy: River Ganga in Hinduism, Jordon River in Christian Churches, Zamzam Well in Islam, among many others (Wikipedia 2017). It is an established fact that famous early civilizations configured around different forms of water-bodies such as the lakes, rivers and thus commencing the River Valley Civilization, starting with the Mesopotamian Civilization to the Egyptian Civilization (Yevjevich 1992). The water-body served as the inhabitants’ key source of livelihood. With an approximated 71% of Earth’s surface blanketed with water, only 0.013% are present in the form of lakes, freshwater lake 0.007% and saline water 0.006% (U.S. Department of the Interior & U.S. Geological Survey 2016). A brisk increase in urbanisation and population has placed the existing lakes in danger (Thippaiah 2009). Water is said to be the chief medium which influences climate change in the Earth's ecosystems and as a result the physical and human environments too (Government of India 2015).

India

India, the peninsular land of rich culture and great ancestral history, is also home to diverse natural landscapes. It experiences the tropical weather with monsoon rains dominating most of the months and serving as the main source of water with annual precipitation of 4000 Billion Cubic Meters (BCM) (Government of India 2015, Iyer 2009). The country experiences five major climatic conditions over its geographical expanse: Hot and dry, warm and humid, composite, temperate and the cold climate concentrated in the northern-most part of the country (Bureau of Energy Efficiency 2009).

Bangalore: City of Lakes?

In the tropical southern states of India, Bangalore (12.9716° N, 77.5946° E), Karnataka, is a metropolitan city having a Moderate Climatic condition due to which it is often referred to as "City of gardens", "City of Lakes", "Pensioner's Paradise" and recently "Silicon Valley of India" (Patil 2010). According to the *census of India*, Bangalore is the fifth largest metropolitan city in India (Gowda and Sridhara 2007, Chandramouli 2011). The city has grown and is still growing into an Information Technology hub and has marked itself on the atlas.

Bangalore Lakes: History and significance as Urban Water Bodies

History of Lakes

At an elevation of 920m, Bangalore cannot host major rivers flowing through the city, which is a potential cause for water scarcity in the city. Foreseeing this problem, the 16th Century ruler *Hiriya Kempe Gowda*, created several water tanks in the city interconnecting each other by means of surface canals (Parisaramahiti (ENVIS Centre Karnataka) 2017, Tekur 2004). The nearest major rivers to Bangalore is Cauvery River, Vrishabavathi River and Arkavathi River, of which only Cauvery River water, 100 kilometres from Bangalore, is serviceable for drinking as the other two rivers mainly carry untreated sewage and industrial and household waste (Government of Karnataka 2017). Bangalore was estimated to have 400 odd tanks- including small, medium and large tanks- dotting the topography of Bangalore, all of which thrive on rains during the monsoon months. This solved the problem of water scarcity as the water from the tanks was utilised for drinking, irrigation, recharging ground-water and prevention of urban floods (Iyer 2009, Parisaramahiti (ENVIS Centre Karnataka) 2017, Thippaiah 2009). Now, Karnataka along with five other Indian states constitutes for 62% of the total land area under tanks and ponds. Also, Karnataka and four other Indian states contribute to more than half of country's inland water bodies (Ministry of Water Resources: Government of India 2014).

Lakes as Urban Water Bodies

Tanks and lakes have a difference by virtue of which tank water is usually used for daily purposes whereas lake water is not used for our daily needs. In this paper, the terms 'lakes' and 'tanks' have been used interchangeably. Apart from the pleasant vistas and a variety of biotic life they offer, lakes and other surface water collection prevent the episodes of floods due to monsoons, prevent sediment load, provide drinking water and help in recharging of groundwater to maintain a healthy groundwater table (Gowda and Sridhara 2007). The aquatic ecosystem attracts several colourful migratory birds, creating splendid views for passersby (Bharathi 2010). The lake ecosystem also ideally provides favourable conditions for the co-existence of a variety of fishes along with other lentic life forms, thus forming bio-indicators of a healthy lake ecosystem (Benjamin et al. 1996, Rajashekara and Venkatesha 2010). The close proximity between each lake propagates micro-climate effects into the neighbourhood dwellings and contributes to the pleasant nature of Bangalore climate.

Effects of population explosion on lakes

The pollution of water bodies, in Bangalore City, started as early as 1883 in Ulsoor Lake by the dumping of untreated/partially treated sewage, soon after which the lake was deemed unfit for consumption (Parisaramahiti (ENVIS Centre Karnataka) 2017). The above-mentioned means of pollution have not only led to drinking water scarcity in the city- making water a costly affair (Thippaiah 2009) - but have also resulted in the, diminishing of the lakes from 400 odd numbers to 262 and now standing at approximate 71 lakes in urban Bangalore (Parisaramahiti

(ENVIS Centre Karnataka) 2017, Thippaiah 2009). Due to the limited capacity of the city sewage treatment plant, only 33% of the generated sewage is treated while the rest is directly let into the water bodies thereby forming a point source for pollutant entry (Central Pollution Control Board 2005). Human defecation by the local slum settlement residing around the lake combined with animal defecation has changed the original chemical composition of the lake leading to eutrophication, causing the death of several fish breeds (Benjamin et al. 1996).

With the increase in built space, with no consideration for the natural drainage pattern along the topography, and growing population of the Information Technology (IT) hub, illegal attempts at lake encroachment have gone unnoticed by the authorities (Kothari 2013). Urbanisation results in 105% of concretisation of the land area available, irrespective of wetlands. In his study, Thippiah (2009) has stated that 519 acres of the lake have been encroached, as of 2009 report from the Forest Department. Another factor liberally contributing to the pollution of water bodies is the trade and chemical effluents from the many industries that have made Bangalore their home (Ramachandra and Solanki 2007). The surface runoff due to precipitation and storm-water accumulation gets collected in lakes along with surface sand and mud with adsorbed chemicals; plastic and paper waste; defecation of animals; and other naturally or artificially found compounds on the ground, which has potentially altered the chemical composition of the lake.

Filamentous algae, algal blooms and macrophytes are indicators of pollution in the aquatic ecosystems. Algae develop due to the presence of adequate Nitrogen and Phosphorus in the water, ample sunlight, pH and temperatures; while turbidity and agriculture are variants on which growth of macrophytes depend on (Kissoon et al. 2013). The turbidity of the lake plays a vital role in determining the quantity of Dissolved Oxygen (DO). Increase in turbidity of the lake, and surface cover of macrophytes and hyacinths leads to lesser penetration of sunlight through the water surface, this affects photosynthesis process of the algal matter, soon after which they die and kick-start the process of decomposition. Decomposition of bacterial matter uses up oxygen as a primary element, leaving the lake with significantly less amount of dissolved oxygen (DO) (Mahapatra et al. 2011).

Pollution of Bangalore Lakes

The feeble efforts put forth by the governing body have not benefitted the dying lakes. Few lakes have been leased to private organisations in Bangalore due to the lack of funding by the Karnataka Government for the lake rejuvenation and maintenance. The long-term lease has been advantageous for the private organisations that have encroached the lake area and commercialised the spaces around (Jain 2007). The diminishing lakes have caused noticeable effects in Bangalore starting from the apparent climatic change, with every year seemingly warmer than the previous year (Ramachandra and Kumar 2010). The reduction in the greenery and the birth of more and more buildings around the lakes has caused Bangalore to hit an all-time high of 37.2 Degree Celsius. The increase in temperature over the last decade has been attributed to the decrease in vegetation and water bodies (Ramani 2016).

The steady growth in information technology (IT) hubs has given rise to an increase in population and infrastructure for commercial as well as residential use. This expansion in quantity of buildings has been a contributing factor in the depletion of natural vegetation and natural surrounding within city limits.

Materials and Methods

The water samples were collected from five (5) lakes within Bangalore city, viz. Hebbal Lake, Sankey Tank, Chinnapannahalli Lake, Varthur Lake and Bellandur Lake; in accordance with the standard protocol; and tests for Total Dissolved Solids (TDS), pH, Electric Conductivity, were conducted with the water samples in a laboratory setup. The samples were collected from the surface of the water that is accessible from the boundary of the lakes. The qualitative and quantitative observations were noted in the below tabular column (See Table 18-1).

Varthur Lake and Bellandur lake are situated near industrial centres of the city, whereas Sankey Tank, Hebbal Lake and Chinnapannahalli are situated alongside residential settlements.

Further, the afore-mentioned lakes were assayed for change in area over a span of 17 years (2000 to 2017). The lakes were viewed through satellite imaging from *Google Earth Pro* and the changing areas were monitored using the *history-timeline tool* and marking of boundaries. The recorded-area data were noted in the interval of four years from 2000 to 2017(except the last period of 2016-2017). A TRIZ-based 'Morphological analysis' (Altshuller 1999) was carried out to propose various technological and bio-inspired solutions for the betterment of these lakes and its ecosystem.

S. No.	Lake Samples	TDS	EC	pH
1.	Sankey Tank	197	387	7.84
2.	Hebbal Lake	500	-	7
3.	Chinnapannahalli Lake	737	1478.3	6.8
4.	Varthur Lake	577.6	1146.7	6.65
5.	Bellandur Lake	573.3	1165.52	6.53

Table 18-1: *Water Quality Characteristics of Bangalore Lakes.*

Results and Discussion

It is observed that the catchment area of most lakes has been declining over 2000-2017. It was interpreted from the study (see table 18-1) that lakes near industrial areas (i.e. Varthur and Bellandur lake) were more polluted than the other lakes (i.e. Hebbal lake and Sankey Tank). Augmented built spaces also result in higher rates of the felling of trees. A study of the area of these five lakes at an interval of five years from 2000 to 2017 is tabulated below (in Square Metre). Some of the lakes like *Bellandur* lake and *Varthur* lake show a constant decline in the area due to illegal encroachment and insufficient monitoring (as shown in Table 18-2); while Hebbal lake shows seasonal variations in its area. Trees maintain balance in our ecosystem by contributing to the moisture content in the air, which triggers the precipitation from the clouds in the locale. A lesser number of trees results in lesser humidity in the air which in turn reduces rainfall over the area. This again poses a threat to the tanks that essentially thrive on rainwater. Treating the lake alone will not benefit the lentic ecosystem due to a continuous flow of wastewater from the city.

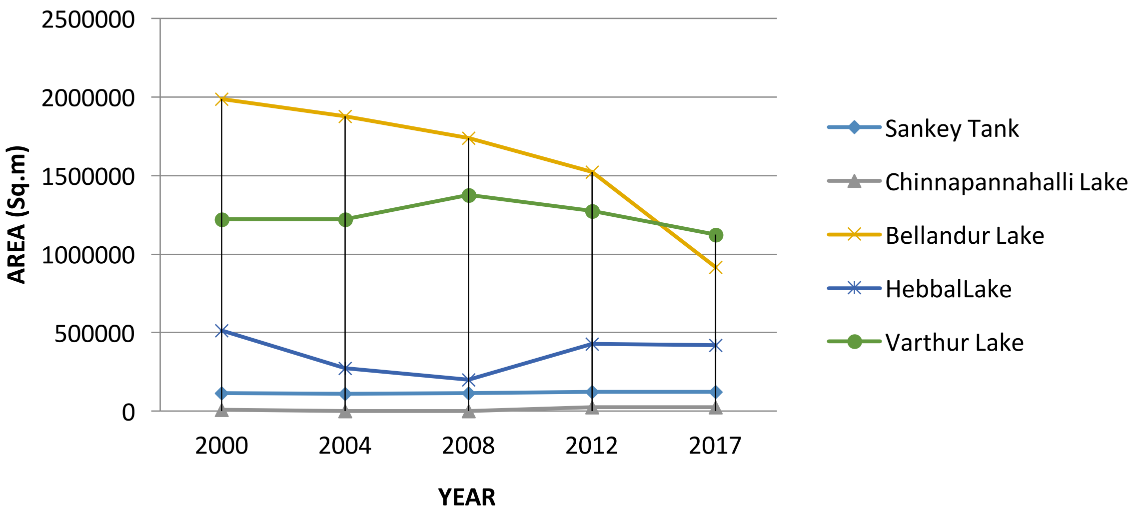

Figure 18-1: *Varying Areas of Lakes (Sq.m) in the interval of four years.*

A sewerage ring surrounding the lakes having an inlet(s) from the catchment areas around the lake and an outlet(s) connected to the sewerage network could prevent pollution from run-off water from the surrounding areas. Apart from treating the system of lakes, the surrounding with which the system interacts also needs an upliftment from the current conditions. Furthermore, after a TRIZ-based brainstorming session, various technological and bio-inspired solutions were proposed as given in the next section.

	Lake	**Area (Sq. Meters)**				
		2000-2004	**2004-2008**	**2008-2012**	**2012-2016**	**2016-2017**
1.	Sankey Tank	116,745	109,850	114,992	123,806	122,765
2.	Ulsoor Lake	411096	346205	261342	358817	353956
3.	Chinnapannnahalli	8788	608	409	26,300	25,562
4.	Bellandur Lake	1,987,488	1,877,001	1737528	1521800	915,667
5.	Hebbal Lake	511,968	273,750	199917	427788	421621
6.	Varthur	1223258	1221066	1377118	1275528	1125635

Table 18-2: *Declining area (in Square Meter) of Bangalore lakes 2000-2017 (Interval took as five years).*

Proposed Solutions

Technological Solutions

Satellite-based GPS System to map the boundary of the Lakes:

An Arduino-based GPS system (Fig. 18-2), achieved using Arduino UNO Rev 3, was designed to keep track of the area of the catchment area. Any reductions in the form of encroachments would be notified through the GPS System. This digital intervention monitors and maintains the original catchment area. This system intends to provide the real-time 3-d position (latitude, longitude, altitude). It uses asterism of satellite and ground stations to compute the position.

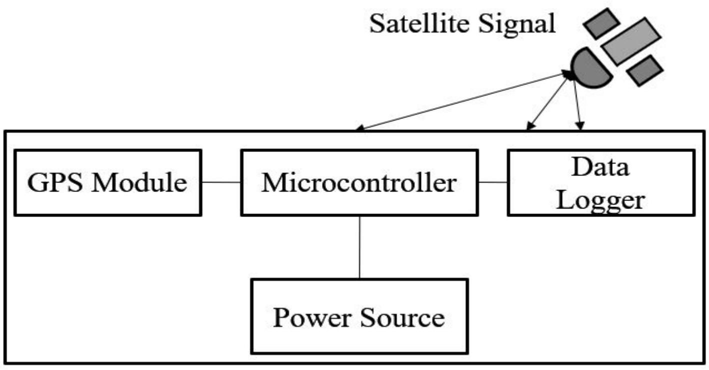

Figure 18-2: *Schematic diagram of the GPS Mapping system.*

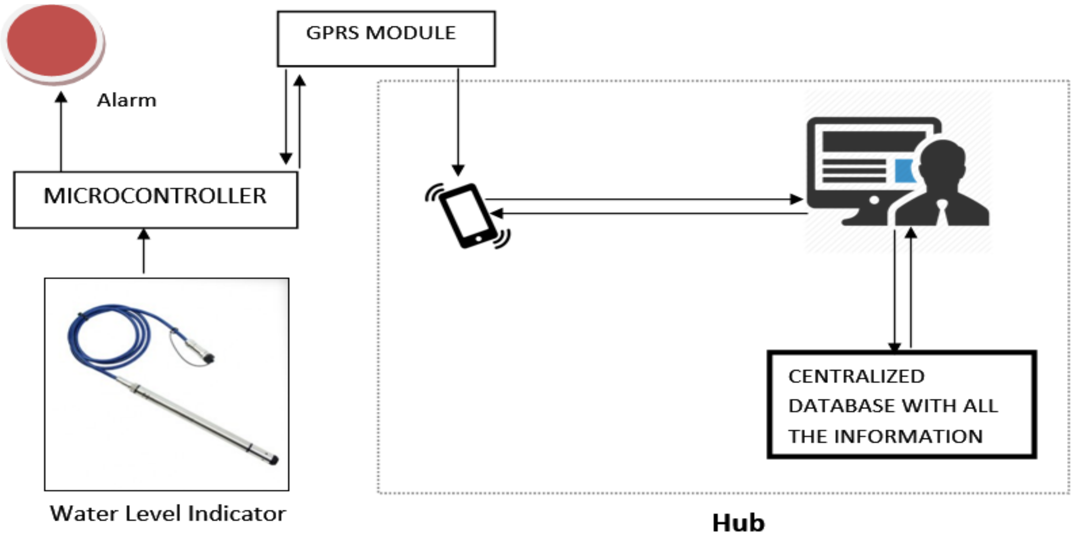

Figure 18-3: *Schematic diagram of a Water level monitoring system for lakes.*

Mobile-App based Water level monitoring and Centralized Database:

A GPRS based water level monitoring is conducted with help of a Mobile-App and a centralized database is maintained for all the lakes in case of water shortages and flooding (Fig. 18-3).

Bot-based autonomous cleaning system monitored using mobile application:

This method of cleaning is used after the water body has been polluted with contaminants. The bot-based autonomous cleaning system does the following activities:

- De-silting of lake-bed
- De-weeding of invasive species
- Brushing of plastic waste to the boundary

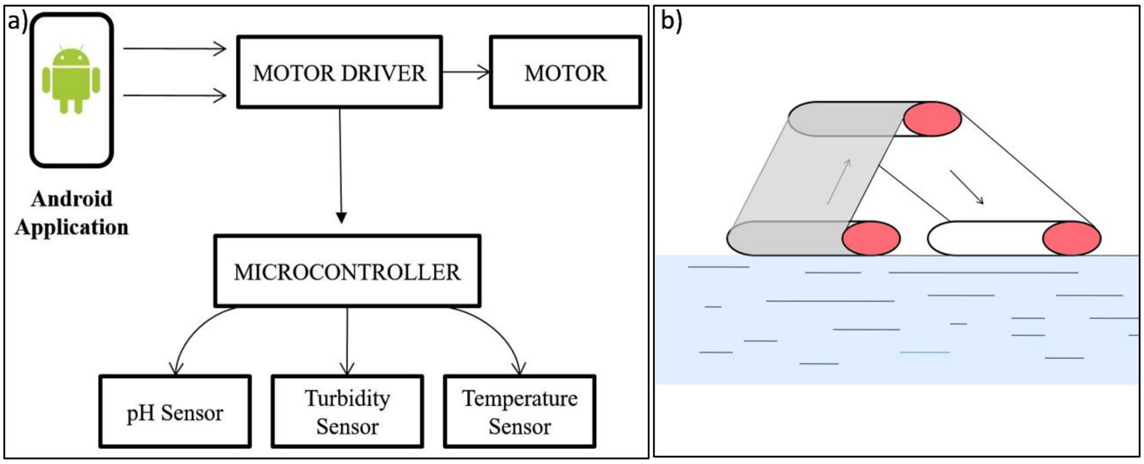

Figure 18-4: *Bot-based autonomous cleaning system- a) Schematic b) Conceptual diagram.*

	PROBLEMS	SOLUTION	BIO-INSPIRATION
1.	Lake Ecosystem Management	Provision of Buffer-green Zones around lakes .	Beavers Dam- Check Dams Flamingo- Stilt Construction Capillary System: roots of trees- Water absorption strip
		Flood prediction system	Mapping of neurons- Inputs, Hidden layer, Outputs
2.	Water Pollution Management	Sewage Water Treatment Plants at Point Sources (Apartments and Industries)	Brain-neural Networks- Drainage Systems
3.	Algal blooms and low dissolved oxygen content	Creation of motion on the surface of water by means of native water bird	Diffusion in the Alveolar membrane in lungs-gas exchange surface
4.	Surface run-off into lakes	Sewerage ring around the lake boundary	Naturally occurring swales

Table 18-3: *Bio-inspired Solutions based on TRIZ based 'Brainstorming Session.*

Bio-Inspired Solutions

While dealing with a problem related to the ecosystem, it is best suited to have biological and natural solutions to help better the ecosystem conditions. Based on TRIZ (teoriya resheniya izobretatelskikh zadatch, or "theory of the resolution of invention-related tasks") based 'Morphological Analysis', the above tabular solutions (see Table 18-3) was arrived with pointing out bio-inspired solutions inspired by nature. Lake ecosystem management, Water pollution management, Algal blooms and low Dissolved oxygen, Unregulated Surface water run-off were the major problems areas addressed by these solutions as given in Table 18-3.

Conclusions

It was interpreted from this study that lakes near industrial areas (i.e. Varthur and Bellandur lake) were more polluted than the other lakes (i.e. Hebbal lake and Sankey Tank). This study infers that city sewer-lines and industrial waste are the broad sources of water pollution. Moreover, illegal encroachment of lakes due to increasing urbanisation has taken a heavy toll on these dying waterbodies. Various preliminary conceptual solutions based on technological and bio-inspired approach were proposed, which needs to be comprehensively developed and further tested (on a larger urban-scale) in the future. A sewerage ring surrounding the lakes and planting trees along their boundaries would serve as a support to the lentic ecosystem and its microclimate. And lastly, a comprehensive urban-level lake-restoration plan incorporating technological(autonomous) and bio-inspired solutions need to be formulated to save the dying lakes of Bangalore City.

19. Stepwells: Reviving India's Cultural and Traditional Water Storage Systems

Meenakshi Piplani ✉, Tarun Kumar

Abstract

Water has been foreseen to be the cause of the next great global crisis. India has 18% of the world population but only 4% of the world's water resources. This brings us to the important issue that India may lack overall long-term availability of replenish-able water resources.

India is characterized by diverse ecological and cultural regions inhabited by the people. For centuries, a traditional construction for harvesting rain in the arid regions of India, stepwells, has helped people overcome water scarcity in the dry seasons. Stepwells, also known as '*Baolis*' and '*Vav*' in Hindi, are large subterranean stone structures built to provide water for drinking and agriculture. This study explores these traditional water systems in light of their potential to address the current water crisis in India and as artifacts of cultural heritage. Stepwells of the lost ancient Indian city of Hampi in Karnataka were studied. Furthermore, studies of various stepwells across India were conducted, to develop an understanding of their social and historical importance. The case studies show that the timeless grandeur of stepwells is unmatched but most of them have fallen into neglect and have become dumping grounds for adjacent urban communities.

Finally, the study proposes solutions for the rejuvenation of these man-made groundwater reservoirs for sustainable water consumption. These stepwells can also be turned into major tourist attractions and social interaction hubs in the form of parks, '*melas*' and '*Haat-Bazaars*' (Traditional Commercial Centers). This would also effectively generate revenue for maintaining them, one of the major challenges in its upkeep. Thus, the stepwells can be enlivened to improve aesthetics of the urban fabric while serving as solutions to the problem of depleting water resources for a growing population. Furthermore, it would also be instrumental in conserving the cultural heritage of various Indian traditional settlements.

Keywords: Stepwells, Cultural Heritage, Water Resource Conservation.

Introduction

Water is a vital resource for human survival, which is an irrefutable truth. The knowledge of its importance and its need has sparked war and peace (Chakraborty and Serageldin 2004). One-third of the world's population is living under conditions of physical water scarcity, due to unprecedented rates of population rise and water use per capita in several areas of the world (Vörösmarty et al. 2000, Alcamo et al. 2003, Oki 2006, Matti et al. 2010). Millions of people in India are devoid of sufficient water resources, as the nation supports a confounding 18% of the world's population with 4% of the world's water (Dhawan 2017). In general, this is occurring due to many reasons such as social water scarcity and physical water scarcity (Matti et al. 2010).

India is a multi-cultural, multi-linguistic and multi-racial nation that carries with it a plethora of representations of its glorious history in art, music, dance, language, and architecture. These expressions in various forms are living museums of the socio-cultural heritage of her people. Several of them are water-related monuments that serve users for their religious, aesthetic, recreational and utilitarian needs (Jain-Neubauer 1999, Ruggles and Silverman 2009, Shubhangi and Shireesh 2015). They include, stepped temple ponds as in *Modhera*, Gujarat, ritual platforms called *'ghats'* on river banks, such as in Benares, and on lakes in Udaipur, Rajasthan; large artificial lakes as in *Sarkhej* in Ahmedabad; ornamental pools as in Red Fort in New Delhi and below ground level stepped water-wells, commonly found in western India

(Jain-Neubauer 1999). Among these, the stepwell is one of the most beautiful testaments to the distinct and rich architectural and cultural heritage of India (Lautman 2013).

Stepwells

The term "stepwell" defines a subterranean water-related monument which consists of a water-well and a downward stairway leading from ground level to the underground water aquifer. They were created to collect water that precipitated during India's torrential Monsoon and made it available in the dry months, especially crucial in the arid regions of Gujarat and Rajasthan; where water lay hundreds of meters beneath (Lautman 2013). Remarkably, the stepwells date back to the 3rd millennium BC in India, an uninterrupted tradition that went on for centuries, attaining the peak of its glory in the 11th and 12th centuries overlapping the peak of traditional Indian architecture (Jain-Neubauer 1999, UNESCO 2014). It was an incredible honor to commission a Stepwell; one-fourth of them are said to have been commissioned by women, in connotation with the life-giving aspects of water, and the activity of seeking water, often performed by women (Jain-Neubauer 1999, Lautman 2013).
Stepwells dot the Indian subcontinent from the northern-most and central regions of Delhi, Uttar Pradesh and Madhya Pradesh along Rajasthan, Gujarat, and Maharashtra, the western peripheries to the south in Tamil Nadu, Karnataka and Telangana (Pathak and Kulkarni 2007, Lautman 2013, Shubhangi and Shireesh 2015, Parasa 2018).

Figure 19-1: *View of Adalaj Stepwell, Gujarat Karnataka. (Gujarat Tourism 2008).*

Figure 19-2: *View of Pushkarni, Hampi.*

Sustainability and Tradition

Some stepwells were vast open depressions as wide as 35m, while some have a more gradual descent of steps, in passageways, intricately embellished, along with storeys that lead to the deepest parts of the stepwell (Cox and Grainger 2008, Shubhangi and Shireesh 2015). The passageways, stone pillared pavilions, and the underground storeys were non-religious edifices that provided respite from the tropical heat to travelers and villagers (Cox and Grainger 2008, Lautman 2013). The embellishments and sculptures portrayed in detail all sorts of carvings about battles, mythical creatures, deities and ordinary activities like women churning butter, combing their hair; some also depicting erotic acts (Cox and Grainger 2008, Bhatt 2014). They were often built adjacent to temples or contained shrines. Under the rule of the Mughal Empire, they continued to be constructed by Hindu artisans and used for performing ablution before entering the mosques. Stepwells fell into disuse in the 19th century under the rule of the British Raj, whence they were declared as unhygienic and prohibited from use, and replaced with taps and pumps to deliver water to rural areas.

Stepwells were life saviors of crops and man alike in the toughest geo-climactic regions of India (Das 2002, Bhatt 2014). Indeed, they combined social, religious and functional purposes. The water that was used only for drinking purposes, therefore, had to be kept clean and unpolluted. The water was hauled up using buckets from the ground level. Although the other water bodies would succumb to the high rates of evaporation in summer, the narrow stairway leading to the depths of the stepwell was barely touched by sunlight, thereby, some amount of water would always be present in the well throughout the year. The steps were present to allow access to diminishing levels of water in all seasons (Wilhelm 2013). The water was well-fed into the lowest level of the well, the basin, through a small opening, in a unidirectional flow, thus maintaining a recharged reservoir of groundwater (Jain-Neubauer 1999). Many of the wells in Rajasthan possessed an important geological feature, which was that they were strategically linked to perennial underground water streams or channels. These wells prove to be life-changing in the barren landscape of Rajasthan, with rural folk maintaining a positive outlook on water sourced from there, as they were venerated in the past. Thus, as groundwater resources are depleting across India now, at alarming levels with drying up of rivers and the consequences of climate change that are upon us, it seems imperative that India's time-tested traditional water harvesting systems are revisited and revived.

Materials and Methods

Case Studies

The objective of this study is to probe into the various stepwells found in India and to study them. Data collection was performed on analysis of stepwells from online repositories, newspaper articles, journals, and books. The primary study was conducted by an examination of stepwells in Hampi, Karnataka, India, a part of the *Vijayanagara* Empire (14th century AD) and the stepwell in Meenakshi Amman temple, Tamil Nadu, India.

Analysis and Tabulation

The paper abridges the characteristic features of stepwells by taking typical examples of stepwells, according to geographic regions in terms of its dimensions, depth, function, the material used for construction and the period of construction of the stepwell. It also proposes potential uses of these stepwells to enhance economic, social and environmental gain in those regions. A SWOT analysis (strengths, weaknesses as well as external opportunities and threats) of the proposed methods for their revival is also conducted to evaluate their suitability in the given contexts.

Results and its Interpretation

Primary Case Study: Stepwells of Hampi

The primary data was obtained from observations of the stepwells present in the temple-town of Hampi (352.4 km/232.4 mi north of Bangalore city) in the interiors of the state of Karnataka. Hampi occupies an area of 26 sq. km. In the period of AD 1336-1570, *Pampati* (now known as Hampi) became one of the centers of the revival of the Hindu religion, art and architecture as evident from the myriad megaliths in stone; some profusely carved that were erected during this time. King *Krishnadevaraya*, one of the most popular characters from Indian folktales, oversaw the inception of various royal buildings and enclosures in the city. Among them, stepwells can be found near temples, inside royal enclosures of the Queen, as public baths and adjacent to places of the celebration of Hindu festivals (as in the Durga Mandapa, Queen's enclosure, Hampi).

A total of 8 stepwells found within Hampi, Karnataka were studied. These stepwells illuminate certain key observations in their characteristic features. It was seen that 6/8 stepwells were supplied by water from external channels of stone masonry that carried water from nearby water bodies (such as the *Kamlapur* Lake) as the stepwell had a masonry base and thereby, the stepwell was not in direct contact with the soil underneath it. The vast Public Bath measuring 40 m in length, 15 m in width and only 4.5m in-depth located in the Royal Enclosure was fed by water from covered stone channels that circumvent the bath and open into the stepwell through a cavity, allowing water to fall into it. The stepwell was equipped with outlets to drain out the water and was elevated 5 m above the ground level. Religious rituals that are performed prior to entering a temple, such as washing of feet, often require running water as opposed to still water. Hence, we can deduce that the stepwell was used for performing religious rituals of cleansing prior to entering sacred or holy places. The presence of hard bedrock at shallow depth blocks ease of access to an extensive water table in the peninsular region of India that is spanned by the Deccan Plateau. This condition led to the evolution of its functions, construction materials and water collection strategies over centuries.

Literature Case Study

The stepwells of Hampi and the stepwell of the Meenakshi Amman Temple of Madurai, share similar characteristics in terms of depth of well, a method of water collection, function, constituent construction materials and culture. Further analysis from studies of stepwells in Hullikere and Lakundi regions of Karnataka reveal common features with the instances from the primary case studies. The literature study of typical examples of stepwells present in parts of North, West, Central and East India reveal several significant differences in comparison to the stepwells of Southern India. These stepwells tend to be at least 4 to 5 stories deep (about 12m-15m). They are connected directly to groundwater aquifers and often, can be found without an accompanying place of worship adjacent to them.

The analysis and acquisition of data regarding the local nomenclature of the stepwell in that geographic region, location, ruling dynasty that commissioned the stepwell, time period of the commission, the dimensions, shape, functions, construction material and any special characteristics of the stepwells have been recorded and tabulated in Table 19-1.

Thereby, after this study of stepwells from different parts of India, a definition has been formulated to properly determine the characteristic features that constitute a stepwell. A ‘stepwell’ is a term that refers to a subterranean monument that is stepped and has the capacity to hold and store water in a traditional and sustainable manner. There are two types of stepwells based on their capacity to store water:

I. Stepwell with a masonry base
II. Stepwell without a masonry base

The stepwells with a masonry base are also known as ‘stepped tanks’. They are commonly found in Southern India, where the water table can be found at greater depths due to the hard rock of the Deccan Plateau on which it lies. These stepwells are charged by water channels that feed it from lakes and other water reservoirs nearby. Moreover, they are almost always found beside places of worship like Hindu temples to assist in the cleansing of hands and feet before entering the holy place (Stepwell at Meenakshi Amman Temple, Madurai, Tamil Nadu). These stepped tanks have also been used as ‘baths’ for the public (Public Bath at Royal Complex, Vijayanagara Empire, Hampi, Karnataka) and for the Queen (Octagonal Bath, Hampi, Karnataka). These ‘baths’ were fed with water and after the bathing activity, it must have been drained out. Stagnant water would be unable to fulfill the purpose of bathing.

	South Indian			North Indian
Nomenclature	Pushkarni, Kalyani, Kund, tirtha			Baori, Baoli, Bavdi
Dynasty/Area	Chalukya	Hoysala	Vijayanagara	Delhi
Name	Muskin Bhanvi	Hullikere Stepped Tank	Pushkarini	Gandhak-ki-Baoli
Location	Lakkundi, Karnataka	Hullikere, Karnataka	Hampi, Karnataka	Mehrauli, Delhi
Period	Kalyani Chalukya Period (10^{th} century)	NA	14^{th} century	Period of Iltutmish (1210-1236) or the 13^{th} century
Dimensions (length) (breadth) (depth)	20m	20m	15m	6m
	10m	7m	15m	10m
	15m	2.5m- 3m	5m (above water) + 2m	15m-20m (5 storeys)
Function	• Rites of consecration • Ritual cleansing • Deemed to have sacred water from Ganges	• Rites of consecration • Ritual cleansing • Deemed to have sacred water from Ganges	• Rites of consecration • Ritual cleansing • Deemed to have sacred water from Ganges	• Sacred shrines in Hindu Context • Mosque next to stepwell serves for ablution before prayers
Material	Stone	Stone	Black schist stone blocks	Brick and Stucco
Special characteristics	Adj. to Manikeswara Temple, Cut into virgin rock	Not adjacent to a temple	Contained water in Summer season	Water is known to contain sulphur (*Gandhak* in Hindi) Contains water in Monsoon, Mosque located adjacent

Table 19-1: *Classification of typical examples of stepwells of Southern and Northern regions of India.*

	Western Indian			Eastern Indian	Central India
Nomenclature	Vav, Kuvo, Barav, Vaav				
Dynasty/Area	Modhera	Maharashtra	Rajasthan	Odisha	Madhya Pradesh
Name	Rani- ki- Vav	Baramotichi Vihir	Chand Baori	Rock-Cut Stepwell	Bijamandal Temple Step-well
Location	Patan, Gujarat	Satara, Maharashtra	Abhaneri, Rajasthan	Khandagiri and Udaygiri Jain temple and caves, Odisha	Vidisha, Madhya Pradesh
Period	11^{th} century Bhimdev I (1022 -1063) CE	17^{th} century	860 AD Nikumbha Dynasty	10^{th} century AD	8^{th} century AD
Dimensions (length) (Breadth) (depth)	64m	40m	54m	5m	
	20m	15m diameter	54m	4m	
	27m	34m	33m (13 storeys)	NA	NA
Function	• Used as sources of drinking water • Venue for Indian festivals and rituals • Act as cool retreats • Sacred shrines	• Used for administrative purposes • Royal family holds meetings with council of ministers	• Used as sources of drinking water • Socializing and bathing • For worship of the water-related avatars of Vishnu and Shiva	NA	NA
Material	Stone	Black stone	Stone	Rock-cut	Stone
Special characteristics	Multi-storied, carved niches, motifs of Vishnu avatars. UNESCO world heritage site. Attached to a 30km long tunnel used as an escape route 50 years ago	Accommodates the throne of the king that opens to two galleries to hold council meetings ;Looks like a dug-out shivling	Opposite to temple of Harsha Mata, goddess of joy and happiness Jharokhas (windows) meant to house the royal family are present on one side of the stepwell	One of the oldest known stepwells. Almost bereft of any ornamentation.	Motifs of Buddhist mythology

Table 19-2: *Classification of typical examples of stepwells of Western, Eastern and Central regions of India.*

On the other hand, the stepwells of North, West, and East India contain water from the underground water table. This water is considered sacred, pure and healthy enough to rid of ailments by local villagers as in, Rajasthan and Gujarat. These stepwells were used to satisfy the thirst of traveling nomads and villagers. Some stepwells (such as *Gandhak-ki-baoli*) are known to possess special healing qualities in their water. Due to the soft fertile soil in the plains, the stepwells could go several meters deep to access groundwater reserves of water.

Revival Strategies

However, these stepwells have now become culturally decadent and hygienically unsuitable as they're being used as spaces for disposing of waste. Plastic bottles, wrappers, and other urban waste can be found lying at the bottom of the stepwells without a masonry base, stagnating in water. After due consideration and analysis of the local culture, climate, environment, social and economic context, revival strategies have been recommended that rejuvenate and retrofit stepwells into modern urban cityscapes. Parks, walking plazas, *melas*[25] and *haat bazaars*[26] are some of the space design strategies recommended to restore the stepwells. A SWOT (strengths, weaknesses, opportunities, and threats) analysis of these suggestions has been conducted and recorded in Table 19-3.

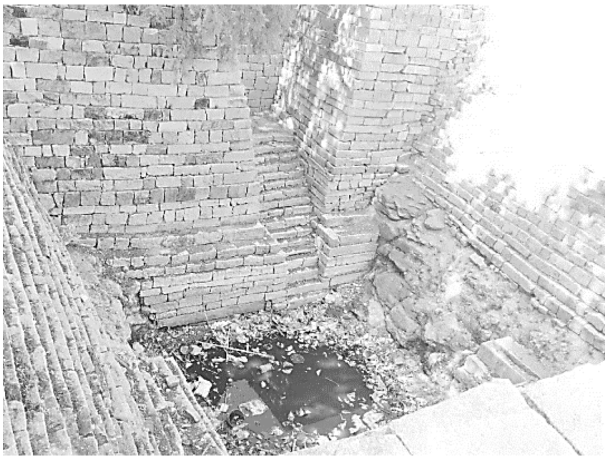

Figure 19-3: *A littered stepwell at Hampi, Karnataka, India.*

[25] Used to refer to 'gathering' or a 'fair' in India

[26] an open-air market that serves as a trading venue for local people in rural areas and some towns of Nepal, India and Bangladesh

Typologies of Stepwells	Strengths	Weaknesses	Opportunities	Threats
Parks	• Prominent feature of the park. • Evaporative cooling brings down the temperature. • Historic value addition. • Vistas of water landscape.	• Management of surface water runoff to be ensured.	• Hosting forest and park retreats of historic significance. • Indicative of water table levels and create public awareness. • Potential to irrigate surrounding flora.	• Lack of initial seed fund to establish landscape around the stepwell. • Lack of incorporation of indigenous flora , leading to soil degeneration. • Improper landscape design . • Threat of water borne diseases when not maintained.
Melas	• Creates a need for maintenance. • Local employment generation. • Improved social interaction. • Augment local economy. • Historic value addition.	• Increased waste generation • Safety measures to be adopted to keep accidents in check.	• Fortification of stepwells with guard rails for protection • Organizing festive events to create a socio- cultural identity. • Generation of revenue from *melas* for maintenance.	• Lack of initial seed fund to clean the stepwell. • Absence of governing bodies for organized revival. • Destruction of monument due to increased footfall. • Threat of water borne diseases when not maintained.
Haat Bazaars (Traditional Commercial Centres)	• Will ensure maintenance. • Local employment generation. • Improved social interaction. • Augment local economy. • Historic value addition.	• Increased waste generation • Safety measures to be adopted to keep accidents in check.	• Fortification of stepwells with guard rails for protection • Organizing festive events to create a socio- cultural identity. • Generation of revenue from commercial stalls to revive and maintain the stepwell	• Absence of governing bodies for organized revival. • Destruction of monument due to increased footfall. • Threat of water borne diseases when not maintained.
Plazas (walking plazas)	• A cultural promenade for tourists and local inhabitants with stepwell as the anchor element. • Open air amphitheater for light, sound and water shows • Augment local economy.	• Increased waste generation • Safety measures to be adopted to keep accidents in check.	• Fortification of stepwells with guard rails for protection • Organizing festive events to create a socio- cultural identity. • Generation of revenue from commercial stalls to revive and maintain the stepwell	• Lack of initial seed fund to revive the stepwell and establish the cultural center around it. • Absence of governing bodies for organized revival. • Threat of water borne diseases when not maintained.
Religious Uses	• Construction of temples of spiritual awakening to assert the sanctity of the monument. • To be used for cleansing rituals prior to entering the temple. • A gathering place for spiritual discourse.	• Awareness of safety and hygiene precautions.	• An opportunity to create an inclusive gathering place for all religions centered around the stepwell • Improve communal harmony in India	• Separatist attitudes in conflict with communal harmony • Absence of governing bodies for organized revival. • Threat of water borne diseases when not maintained.

Table 19-3: *SWOT (strengths, weaknesses, opportunities, and threats) analysis of various stepwell revival strategies that have been suggested.*

Conclusions

Stepwells provide a key solution to using water in a sustainable way while preserving the culture and enhancing India's urban and rural spaces. This study examines the types of stepwells based on their geographic location, functions, craftsmanship and historic significance. The stepwells studied illustrate that they have fallen into disuse as a water resource and almost entirely absent in the historic cultural scene of India. They were found in those regions of India that experience high to extremely high water stress which reinstates the need for a revival of traditional water storage systems. Therefore, this paper proposes revival strategies that not only conserve them as a heritage water body but also offer a community space which is pointedly lacking in most cities, forcing people to frequent only malls or stay confined to their residential communities. They will prove to be tranquil additions to parks and plazas as well as lively water shows in carnivals. In rural areas, they will sustain the populace with their sanctified water during times of water duress and can play an important role in improving water self-sufficiency.

Part 4

Metals, Minerals, and Materials

20. Why Does Material Efficiency Stay in the Shades of Energy Efficiency?

Marlene Preiß ✉, Christian Haubach, Mario Schmidt

Abstract

The efficient utilization of raw materials has become a crucial topic for more and more companies in order to assure their existence and competiveness. Therefore, the German federal state of Baden-Württemberg has commissioned the Institute for Industrial Ecology (INEC) at Pforzheim University along with other partners to compile and evaluate a 100-company case study on resource efficiency in the state's manufacturing industry. While many studies on energy efficiency in industries have been published (Schulze et al. 2016), empirical studies on material efficiency and their expectable saving potentials are scarce. So far, empirical research has not adequately reflected the importance of material efficiency in the manufacturing industry although the subject is of high relevance; since material costs constitute about 40 % of costs whereas energy costs only make up about 2 %.

The evaluation and comparison of the completed case studies revealed a strong interlinkage between energy and material usage; or more precisely, that an increase in material efficiency is the precondition for various energy efficiency improvement options. Another common scheme within the case studies was the observation that successful resource efficiency measures require cross-functional and interdisciplinary teams within and beyond the companies. Technology adoption or innovation which was often necessary for an increase in material efficiency could only be realised in close collaboration with equipment manufacturers.

Keywords: Operational Resource Efficiency, Material Efficiency, Barriers, Drivers.

Introduction

Resource efficiency has continued to gain importance on a global level. At the 41st G7 Summit in 2015 in Germany, the Group of Seven founded the G7-Alliance on Resource Efficiency as a platform for the exchange of best practices examples in collaboration with different stakeholders (Presse- und Informationsamt der Bundesregierung 2015).

On a national level, German federal states have set up different strategies to tackle the future demand of resources. The government of Baden-Württemberg, a state in Southern Germany known for producing and exporting high-tech products throughout the world and also holder of the highest share of GDP in European manufacturing, has adopted a resource efficiency strategy (Ministerium für Umwelt, Klima und Energiewirtschaft 2016).

The resource efficiency strategy of Baden-Württemberg comprises different courses of action. One area of action is material and energy efficiency in companies for which an Alliance for more Resource Efficiency has been founded. The alliance includes members from politics and economy. One important measure of the action field is the project "100 companies for resource efficiency" aiming to compile and evaluate 100 successful examples from the manufacturing industry in Baden-Württemberg. The companies are expected to report detailed and reproducible information on their savings due to resource efficiency measures.

Although companies benefit from energy efficiency measures, different studies have identified a so called Energy Efficiency Gap in the course of implementing energy efficiency measures (Hirst und Brown 1990). This phenomenon indicates that the reduction of energy costs is not the decisive factor; rather several factors interplay in the day-to-day business operation to hamper the implementation of energy efficiency measures.

To accelerate the implementation of resource efficiency measures in companies, it is necessary to analyze barriers that inhibit their implementation. Besides creating transparency on barriers, the identification of success factors for increasing operational resource efficiency is also beneficial in order to deduce recommendations for actions within companies.

Background, the companies and methods

Theoretical background

The Energy Efficiency Gap, as well as the drivers and barriers that interact around it have been extensively studied (e.g. Blumstein et al. 1980, Trianni et al. 2013, de Groot et al. 2001, Painuly and Reddy 1996, Weber 1997). Researchers have investigated barriers and driving forces towards company energy efficiency in different countries and industries often in energy intensive sectors not only in large enterprises but also in small and medium-sized enterprises (SMEs).

Barriers to energy efficiency measures are economical barriers, which can be market barriers or individual barriers, and behavioral or organizational barriers (Sorrell et al. 2000). The categorization of Sorell et al. (2000) was tested for overlaps and gaps by Cagno et al. (2013). Besides economical, behavioral and organizational barriers, they identified technology-related, information-related and ability-related barriers as well as a lack of awareness as a barrier. Brunke et al. (2014) basically picked up these categories, but further differentiated between internal and external origin.

Often identified barriers are capital availability, high investment costs, and hidden costs, that are linked or are consequences of an intervention in the process other priorities as well as a lack of time and information (Rohdin and Thollander 2006, Thollander et al. 2007, Ren 2009, Fleiter et al. 2012).

Similarly, the identified drivers can be categorized into economical, information-related, behavioral and organizational, and external success factors (Thollander et al. 2013). Main drivers are increasing energy prices, people with real ambitions, customer demands, environmental image of a firm, commitment of management and a long-term energy strategy (Rohdin et al. 2007, Thollander and Ottosson 2008, Venmans 2014, Wentemi Apeaning and Thollander 2013).

While the barriers and drivers for energy efficiency in companies have been studied in-depth, the barriers and success factors for material efficiency in companies despite their significant share in the cost structure of manufacturing industries have been widely unconsidered. Only Biebeler (2014) identified financial restrictions, technical problems, lack of personal, insufficient information and organizational problems as barriers. Drivers are high volatile material prices, competition advantages through higher quality, customer demand, negotiated environmental and sustainable agreements, improved marketing, as well as material scarcity and a high uncertainty of supply. Besides hard facts that are obvious like costs and diminishing natural resources, soft facts can also influence the implementation of efficiency measures. Soft facts such as a green corporate culture, flat hierarchies and a flexible organizational structure were studied regarding energy and material flow management by Schwegler et al. (2007).

The appearance of drivers and barriers and their effect on decisions regarding energy efficiency can be explained by different theories. In terms of the decision theory, the decision maker is confronted with a conflict of aims between the different alternatives; an alternative has to be chosen with regard to the priority of aims. According to the stakeholder theory, different stakeholders in- and outside the company like customers, competitors or managers influence the decision. Decisions on energy efficiency measures are often characterized by principal-agent situations likewise, according to transaction cost theory the costs linked to gathering information, evaluation of alternatives and finally the implementation of a new technology hamper resource enhancing measures.

The companies

For the project, 103 measures within Baden-Württemberg were selected; the number of companies, however, amounts to 117 due to examples in which measures were realised jointly or in a cooperation of more firms. The companies cover a wide range of industrial sectors. In some cases complete value chains are represented. The manufacturing of fabricated metal products and the manufacturing of machinery and equipment hold the highest share with 23 % and 19 % respectively. They are followed by the manufacturing of chemicals and chemical products with 7 % and the manufacturing of motor vehicles, trailers and semi-trailers with 6 %. The detailed distribution can be found in Table 20-1. Of the total number of companies, about half (53 %) is made up by large companies. The other half consists of SMEs of which small companies account for 20 % and medium sized companies for 27 %. Compared with the population of Baden-Württemberg, large companies are overrepresented whereas small enterprises are underrepresented.

Sector	
Manufacture of basic pharmaceutical products and pharmaceutical preparations	3
Manufacture of chemicals and chemical products	8
Manufacture of motor vehicles, trailers and semi-trailers	7
Manufacture of fabricated metal products, except machinery and equipment	26
Quarrying of stone, sand and clay	2
Manufacture of textiles	5
Manufacture of other porcelain and ceramic products	3
Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics and synthetic rubber in primary forms	4
Manufacture of machinery and equipment	25
Manufacture of products of wood, cork, straw and plaiting materials	3
Manufacture of paper and paper products	3
Manufacture of furniture	2
Electricity, gas, steam and air conditioning supply	2
Manufacture of electrical equipment	6
Manufacture of food products	3
Other manufacturing	3
Manufacture of coke and refined petroleum products	1
Manufacture of basic metals	4
Manufacture of computer, electronic and optical products	4
Waste collection, treatment and disposal activities; materials recovery	3
Total	*117*

Table 20-1: *The participating companies differentiated by sector.*

Methods

In over 100 cases, the barriers and drivers towards the implementation of a resource enhancing measure could be studied under unique circumstances. This suggested a comparative case study design. For this sort of approach, the kind of action, the type of saved material, the participation of external consultants as well as the collaboration with other companies were analysed. The measures were classified according to the technical options for implementing material efficiency suggested by Allwood et al. (2013).

Additionally the companies filled in a questionnaire covering the motivation, opportunity and ability to implement resource efficiency measures. For this purpose, Likert-Scales were used.

The knowledge of methods and measures for enhancing resource efficiency was also investigated.

Results

The four most popular approaches among the companies to increase resource efficiency are process innovations with 30 %, followed by energy concepts with 27 %, process optimization (26 %) and the closing of material loops with 24 %. In about 70 % of the cases, the companies implemented one individual measure whereas in the other 30 % they combined several measures.

Regardless of company size and sector, material and energy efficiency are strongly interlinked. An increase in material efficiency often leads to various energy efficiency improvements. In 41 % of the cases, the measure led to an increase in material efficiency, in 17 %, it led to an increase in energy efficiency and in 42 % of the cases, it led to a combination of both where the increase in material efficiency also leads to increased energy efficiency. Regarding the type of saved material, metals, products of the chemical industry, and plastics are ranked as top three.

Allwood et al. (2013) suggested six technical options for implementing material efficiency: light-weight design, reducing yield losses, diverting manufacturing scrap, re-using components, longer-life products and more intense use. With 61 %, almost two thirds of the cases can be assigned to the option reducing yield losses, 30 % to diverting manufacturing scrap and 22 % to light-weight design. Re-use of components accounts for 7 % of the cases, more intense use for 6 %, and longer-life products for 1 %.

The main driver of resource efficiency measures are competitive advantages such as cost reduction, and increased productivity. Associated social and environmental benefits are either additional drivers or highly appreciated side-effects.

For SMEs, the lack of personnel resources for comprehensive resource efficiency projects is a major barrier. They do not have a sufficient workforce to gather and evaluate information about their own processes and available technologies. Almost 50 % of the small companies and 34 % of the medium-sized companies were supported by consultants.

In the run-up to a resource efficiency measure, its implementation is often hindered by the fear of decreasing process stability or product quality, which corresponds to hidden costs. Companies shy away from encroaching on established processes. Contrary to energy efficiency, off-the-shelf solutions for the specific application in material efficiency are scarce.

Therefore, a major success factor for the implementation of resource efficiency measures is cooperation within and beyond the company. Within the company, cross-functional teams ensure a smooth implementation without nasty surprises. Beyond the company, the close collaboration with machinery and equipment manufacturers helps to find perfect solutions for a specific application. In general, cooperation is pivotal for the accomplishment of innovative solutions.

Another significant success factor is process knowledge and understanding. The better a company understands its own processes; the easier and smoother changes can be undertaken. Moreover, an excellent process understanding helps in the identification of inefficiencies. The definition of reduction goals by the top management often triggers an analysis of the processes resulting in the identification of inefficiencies, pioneering the implementation of new technologies and changes.

Conclusions

Process understanding is a significant success factor. It is dependent on well-educated employees, as well as their continuous training and education. Especially for small companies in rural regions, it is difficult to recruit and keep young professionals. Besides the general shortage of personnel, this is probably one of the reasons why SMEs have a higher propensity to rely on external consultancy. A noteworthy strategy could be the offering of free or subsidized consultancy programs to assist SMEs. Furthermore, companies frequently have to

deal with a lot of bureaucracy when it comes to the implementation and application of new technologies; in these cases the existing regulations hinder the realization of new measures.
Companies should try to involve their customers and suppliers into resource efficiency considerations. An examination of the whole supply chain and the related processes will lead to a better solution; due to existing interactions a process should not be considered isolated. Otherwise, the optimization of one process might lead to a decrease in the efficiency of a connected process or the inefficiency is shifted to another area in the supply chain. The research of Gemünden (1999) on innovations led to similar conclusions. They argue that bigger innovation steps are achieved, if companies collaborate. Ideally, each side should provide two promoters, one with hierarchical power and one with object-specific knowledge.
The idea to gather and publicize best practice examples in order to raise awareness and to show role models of company resource efficiency is without a doubt good. But the study is carried out in an already highly industrialized region where a high interest in resource efficient production already exists. However, the leverage effect would likely be higher, if the examples were spread to newly industrialized countries or used to deduce recommendations and strategies to promote sustainable production in these countries. Since a lot of production is shifted to emerging nations, it would be ecologically worthwhile to help to raise awareness for resource efficiency, where resource efficient principles of operation are not yet applied and high environmental standards are not fulfilled.

21. On the Metal Contents of Ocean Floor Nodules, Crusts and Massive Sulphides and a Preliminary Assessment of the Extractable Amounts

Anna Hulda Olafsdottir ✉, Harald Ulrik Sverdrup, Kristin Vala Ragnarsdottir

Abstract

The metal contents of ocean floor nodules, crusts and massive sulphides was estimated and an assessment of their commercial extractability were conducted. The metals considered were iron, manganese, copper, nickel, cobalt, molybdenum, platinum, gold and silver. We found that significant metal amounts are located mainly in 5 regions of the world's oceans. Most of the tonnage of the studied metals are located at great depth, involving huge technological challenges. Only a smaller fraction (5-25%) of the detected amounts can be considered to be extractable under the most favourable of conditions. We found that the land-based metal resources appear to be more readily available for extraction. Despite huge optimism in the field, no profitable commercial operation has yet been started. It seems that based on an ore grade to metal price evaluation, that only cobalt or silver would perhaps be interesting on a commercial level.

Keywords: Ocean Seafloor Resources, Mining, Cobalt, Copper, Nickel, Molybdenum, Silver.

Introduction

There is a concern for the long-term sustainability of metal supply to the world, therefore mining the ocean seafloors have been proposed. Many authors have highlighted risks of resource depletion looming (Alonso, Frankfield, and Kirchain 2007, Bardi 2014, Meadows, Meadows, Randers, and Behrens 2004, Ragnarsdottir, Sverdrup, and Koca 2012, Sverdrup and Ragnarsdottir 2014). Metals on the seafloor (Manganese nodules, cobalt crusts, massive sulphide deposits) sometimes suggested as a calming message against metal resource scarcity concerns, a "solution-to-all-worries". We would like to inspect a bit closer how realistic this message is, and attempt to substantiate this to tonnage numbers for realistic extractable amounts. We have assessed the land-based resources extensively (Sverdrup and Ragnarsdottir 2014), and thus, the time has come to ask if there is some substance in mining the ocean seafloors and how much metal can we reasonably well expect to get out of it. Nodules are found on the deep ocean floors, cobalt crusts are associated with volcanism and seamounts, and massive sulphides with deep-sea brines, and deep sea hydrothermal wells associated with tectonic division lines, such as the mid-Atlantic Ridge.

Scope

To preliminarily assess the amount of extractable resources available on the seafloor in relationship to the resources available on land for some key infrastructural and technology metals; Iron, manganese, copper, nickel, cobalt, molybdenum, platinum group metals (PGM), silver and gold. We would consider the impact of setting different assumptions on the technical feasibility of actually doing the extraction from the Ocean floor, using literature descriptions of the available and potential future technology. The results will be used for helping set the right input resource sizes for iron, manganese, copper, nickel, cobalt, molybdenum, platinum group metals, gold and silver in the WORLD 6 model being developed by the authors (Ragnarsdottir et al. 2012, Sverdrup, Koca, and Ragnarsdottir 2015).

Methods

We made a literature review and extracted data from the published studies, assessments and evaluations. We compiled estimates of technically extractable amounts from the oceans, grading the resources according to estimated extraction costs and degrees of extractability. We made simple mass balances in tables and overview tables, using extractability estimates to gain recoverable resources from metal detected from any type of deposit. We focused on three types of deposits:

1. Manganese nodules on the main sea floor
2. Cobalt crusts on submerged seamounts
3. Massive sulphide deposits associated with black smokers and deep sea hydrothermal activity along mid-ocean ridges and tectonic separation- and subduction-zones

Figure 21-1 indicates the approximate location of the occurrence of ocean floor nodules, of cobalt crusts and of massive sulphide deposits (The map was modified after Boschen et al. (2013).) We used earlier land resource estimates by the authors for these metals (Alonso et al. 2007, Bardi 2014, Berger, Singer, Bliss, and Moring 2011, Ragnarsdottir et al. 2012, Sverdrup, Koca, and Ragnarsdottir 2013, Sverdrup, Olafsdottir, and Ragnarsdottir 2017a, Sverdrup and Ragnarsdottir 2014, 2016, Walther 2014)

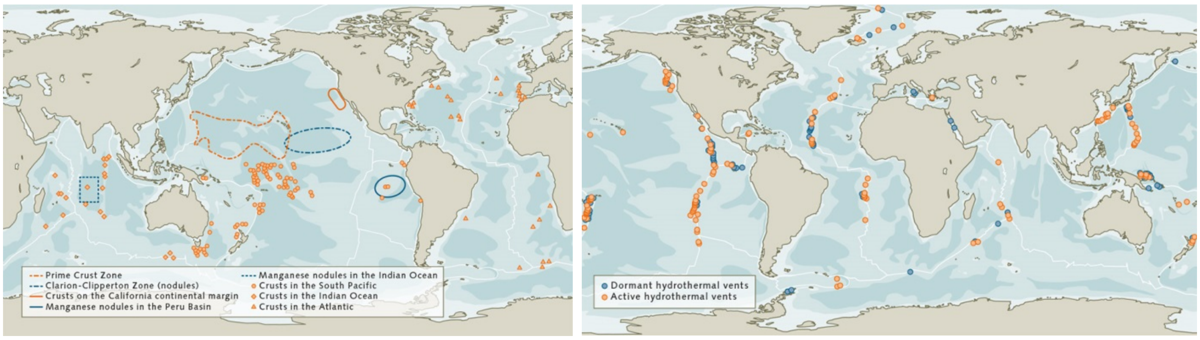

Figure 21-1: *Detected locations of ocean floor nodules, cobalt crusts and massive sulphides. As can be seen from the maps, these can be found in specific areas of the world's oceans, depending on their geological history. Figures from World Ocean Review 3, Maribus GmbH, Hamburg 2014, after Hein et al. 2014, 2015, and World Ocean Review 3, Maribus GmbH, Hamburg 2014, after GEOMAR (World Ocean Review 3 after Hein et al., 2014, 2015).*

Materials and data sources

A number of articles was reviewed the amount of resources and their locations in the World's Oceans: (Allsopp et al. 2013, Berger et al. 2011, Hoagland et al. 2009, Mudd, Weng, and Jowitt 2013, Schmidt 2015, World Ocean Review 3 after Hein et al. 2014, World Ocean Review 3 after Hein et al. 2014). Table 21-1 shows a general relationship between ore grade, the approximate production cost and minimum supply price to society, as well as the impact of price on the recycling in market supply adapted after (Phillips and Edwards 1976, Sverdrup et al. 2015). The cost estimates were generalized and approximated by the authors using literature data. The metal resources were stratified according to such an extraction cost scheme on the ocean floor. Hannington, Jamieson, Monecke, and Petersen (2014), Heinberg (2005) and Beaudoin et al. (2014) made efforts to estimate the size of the deposits and their average contents (ore grades). Roberts (2012) assesses the location and amount of metals in sulphides. Many samples have been taken from the sea floor. How well they actually cover the territory is only known on an overview level. We estimate that this is still sufficient for a preliminary estimate. Table 21-1 shows the general relationship between ore grade, the approximate production cost and minimum supply price to society for mining on land. We have added the approximate extraction cost for deep-sea mining and extraction as well. Figure 21-2 shows the development of copper ore grade with time (Data compiled by Sverdrup, Ragnarsdottir, et al. 2014 and Sverdrup, Olafsdottir, et al. 2017a). Most ores mined today have a copper ore grade of 1% or lower, whereas ocean floor massive sulphides have ore grades from 3-15% copper content.

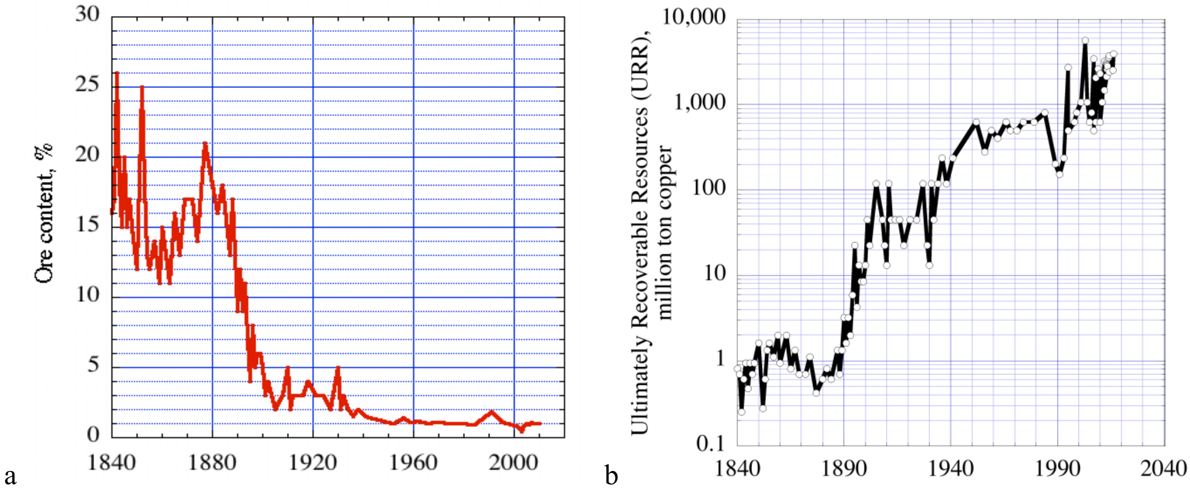

Figure 21-2: *Development of copper ore grade with time Diagram (a) shows the decline in ore grade observed for land-based copper deposits. Diagram (b) shows how the size of the recoverable copper resource is converging on round 4 billion ton of copper. This is what the human society can expect to be able to extract, and what it will have to make the best of.*

Ore grade	Metal content %	Metal content g/ton	Extraction yield, %	Land extraction cost, $/kg	Ocean floor extraction cost, $/kg	Land energy need, MJ/kg
Rich	40-5	400,000-50,000	100	4-15	15-28	30
High	5-1	50,000-10,000	99	15-28	28-50	33-64
Low	1-0.2	10,000-2,000	98	28-50	50-100	120-160
Ultralow	0.2-0.04	2,000-400	91-95	50-100	100-160	400-600
Extralow	0.04-0.01	400-100	80-91	100-160	160-400	700-1,100
Trace	0.01-0.002	100-20	75-80	160-400	400-1,200	3,000-20,000
Rare	>0.002	20-4	55-75	>400	>1,200	>20,000

Table 21-1: *General relationship between ore grade, the approximate production cost and minimum supply price to society (Adapted after (Sverdrup, Koca, and Ragnarsdottir 2014a, Sverdrup et al. 2015, Sverdrup, Koca, and Ragnarsdottir 2017a, Sverdrup and Ragnarsdottir 2014, Sverdrup, Ragnarsdottir, and Koca 2014b).*

Diagram (a) shows the decline in ore grade in the land-based ultimately recoverable resource for copper. Several other metals (For example iron, nickel, zinc, gold, lead, molybdenum or platinum group metals) show similar patterns. Copper contents in nodules and cobalt crusts are normally lower (Table 21-2) than land-based ores at present, the content in massive sulphides are substantially higher. At the same time, the land-based ultimately recoverable resources of metals like copper, zinc and lead are converging on a fixed and finite number. The land-based resource is somewhere between 3.5 and 4 billion ton of copper (Figure 21-2b). In deep-sea mining, the mining extraction operation and actual hauling the material up and processing it out at sea cause larger costs than similar operations on land. Waste management will also be more expensive if the serious environmental damage is to be avoided. Most ores mined today have an or grade of 1% or lower (Figure 21-2), whereas ocean floor massive sulphides have ore grades from 3-15% copper content. The different types of metal resources are found at different depths in the oceans;

1. Manganese nodules on the sea floor are found from 1,800-4,000 meter depth
2. Cobalt crusts on submerged seamounts are found on 400-4,000 meter depth
3. Massive sulphide is found on 800-3,500 meter depth in connection with hydrothermal activities, but some deep trenches develop warm salt brines such as in the Red Sea.

These factors all combine to make the mining operations technically challenging and expensive. The southern and northern polar regions are, at the moment, blocked because of challenging ice conditions and the rough environment. The Southern Seas are also largely blocked because of their storm-infested very deep waters and risks of sea-ice. Part of the Penrhyn area in the Pacific Ocean is host to some of the largest coral reefs on the planet, and large-scale mining in significant parts of the area may not be such a good idea from an environmental point of view (Allsopp et al. 2013, Beckmann 2004, Smith and Heydon 2013).

Area	Size	Density	Amount	Fe	Mn	Cu	Zn	Ni	Co	PGM	Au	Ag
	mill. km^2	kg/m^2	billion ton	% weight						g/ton		
Deep sea nodules												
Clarion-Clipperton	9.0	2.3	21	18	22	0.2	0.4	0.4	0.5	5	1	10
Peru Basin	4.5	10	45	18	22	0.2	0.4	0.4	0.5	5	1	10
Penrhyn	0.75	25	19	18	22	0.2	0.4	0.4	0.5	5	1	10
Atlantic	0.20	25	4.8	18	22	0.2	0.4	0.4	0.5	5	1	10
Indian Ocean	0.75	5	3.8	18	22	0.2	0.4	0.4	0.5	5	1	10
Cobalt crusts												
Northeast Pacific	9.0	0.84	7.55	17.8	22.9	0.2	0.4	0.5	0.8	3	20	200
Southwest Pacific	4.5	0.7	3.2	18.1	21.7	0.1	0.2	0.5	0.8	3	20	200
Penrhyn	0.75	0.7	0.53	14.5	20.9	0.2	0.4	0.4	0.5	2	20	200
Atlantic	0.20	0.7	0.15	15.0	20	0.2	0.4	0.4	0.5	2	6	200
Indian ocean	0.75	0.7	0.53	17.0	22.3	0.23	0.4	0.5	0.6	2	20	200
Massive sulphides and brines												
Pacific CC+PB	13.5	0.22	3.000	10	0.2	3.5	13	0.1	0.7	1	3	150
Penrhyn	0.75	1.25	1.000	10	0.5	8.5	7	0.1	0.7	1	3	80
Atlantic	1.50	1.3	2.000	10	0.5	8.5	7	0.1	0.7	1	3	80
Indian Ocean	0.75	0.3	0.250	10	0.5	0.9	4	0.1	0.7	2	2	100

Table 21-2: *Area cover, metal ore density and contents of different metals in the different nodules, crusts and massive sulphides on the ocean floor. The estimates are very approximate.*

Area	Fe	Mn	Cu	Zn	Ni	Co	Mo	PGM	Au	Ag
	Million ton							Thousand ton		
Nodules										
Clarion-Clipperton	6,000	5,990	226	452	274	44	12	15	52	520
Peru Basin	8,145	9,765	450	900	587	94	26	30	104	1,040
Penrhyn Basin	3,420	4,180	203	406	247	40	10	15	48	480
Atlantic	864	1,056	10	20	62	10	3	4	12	220
Indian Ocean	1,080	1,078	41	82	49	8	2	-	1	10
Sum	19,509	22,069	930	1,860	1,219	196	53	64	217	2,270
Crusts										
Northeast Pacific	1,344	1,714	7.4	1.8	32	50	3.5	12	2	17
Southwest Pacific	2,870	3,668	15.8	4.0	68	107	7.7	24	4	34
Penrhyn	77	111	1.2	2.4	2.1	2.7	0.3	2	-	2
Atlantic	2	27	0.4	0.6	0.5	0.7	0.8	0.5	-	0.5
Indian ocean	90	118	1.3	0.4	2.2	2.9	0.3	3	-	2
Sum	4,383	5,636	26.7	9.2	104.5	163.3	12.6	41.5	6	55.5
Sulphides										
Pacific	300	150	60	405	6	21	21	6	60	600
Penrhyn	100	50	20	49	2	7	7	2	20	200
Atlantic	200	10	170	140	4	14	14	4	40	400
Indian Ocean	25	12	5	10	0.5	2	2	-	5	50
Sum	625	222	85	604	12.5	44	44	12	125	1,250

Table 21-3: *Estimated seafloor presence of metal resources, before assessment of technical extractability. The estimates are very approximate.*

Results

The results have been compiled in a series of Tables 21-2 to 21-4. Table 21-2 shows the area cover, metal ore density and contents of different metals in the different nodules, crusts and massive sulphides on the ocean floor. Table 3 shows the estimated seafloor metal resources, before assessment of technical extractability. Table 21-4 shows the estimated seafloor metal resources, coming to an assessment of technical extractability. We found that significant amounts are presently located in mainly 5 limited regions of the oceans for all the metals considered, two areas in the Pacific Ocean, One in the Atlantic Ocean and one in the Indian Ocean. Most of the tonnage of the interesting metals in nodules and black smokers are located at great water depth, from 1 km to more than 4 km depth, involving huge technological challenges. Only a smaller fraction (5-25%) of the detected amounts can be considered to be extractable under the most favourable of conditions (Allsopp et al. 2013, Mudd et al. 2013).

Area	Fe	Mn	Cu	Zn	Ni	Co	Mo	PGM	Au	Ag
		Million ton						ton		
Sum nodule	19,509	22,069	930	1,860	1,219	196	53	63,000	217,000	2,270,000
Sum crusts	4,383	5,636	27	9	105	163	13	41,500	6,000	55,500
Sum sulfides	625	222	85	604	13	44	44	12,000	125,000	1,250,000
Sum	24,517	27,727	1,042	2,473	1,337	403	110	116,000	348,000	3,505,000
Considering different extractability in the total picture of all extractable metal resources. The URR estimates are very approximate.										
Ocean, 25%	6,129	6,932	261	618	334	100	26	29,000	87,000	876,300
Ocean, 5%	1,226	1,386	53	124	67	20	6	5,800	17,400	175,260
Land	340,000	5,600	4,030	2,676	300	32	80	210,000	150,000	3,700,000
How much metal resources do we have on land and ocean floors? The estimates are very approximate										
URR low	341,226	6,986	3,823	2,800	367	52	86	215,800	167,400	3,900,000
URR high	346,129	12,532	4,291	3,294	634	132	106	229,000	237,000	4,576,000
% on land	99-98	81-41	98-96	96-81	82-49	62-24	94-79	97-91	90-66	87-95

Table 21-4: *Estimated seafloor metal resources, coming to assessment of technical extractability. The estimates are approximate.*

Discussion

Despite optimism in the field, no profitable commercial operation has yet been started. Considering the difficulty of mining, it seems that based on an ore grade to metal price evaluation, that only cobalt or silver would perhaps be interesting on a commercial level, with by-products of copper, gold, perhaps also molybdenum and nickel. There are few assessments of how much of the detected seafloor deposits that can actually be extracted. Many reports and prospects available are optimistic stories about new technologies aimed at potential investors and shareholders, and these do not constitute an objective assessment of real extractability. The extractability estimates in the scientific literature vary from 5% (Mudd et al. 2013) to 25% in the most optimistic views (Allsopp et al. 2013, Beckmann 2004). We have taken 5-25% as the minimum to maximum range. For iron (1-2% of the total resource is located on the sea floor), manganese (19-59% of the total resource is located on the sea floor), copper (2-8% of the total resource is located on the sea floor), molybdenum (6-21% of the total resource is located on the sea floor), PGM (3-9% of the total resource is located on the sea floor), gold (10-34% of the total resource is located on the sea floor), silver (13-42% of the total resource is located on the sea floor), the contribution from seafloor extraction will never be significant for any longer time. The resources on land for these metals are far larger than what is extractable from the sea floors. There are similar proportions for zinc and lead, however, these have so low market price at present that they do not support any deep-sea floor mining operations with the present cost situation. For some metals, the global fraction of the resources located on the ocean floor is significant; Manganese (19-59% of the total extractable resources in the ocean floor), cobalt (38-76% of the total extractable resources in the ocean floor), nickel (18-51% of the total resource is located on the seafloor), gold (10-34% of the total resource is located on the seafloor) and silver (13-42% of the total resource is located on the seafloor). This has been listed in Table 4. Considering the importance of cobalt, silver and nickel for production of new advanced technologies, the ocean floor resources provide interesting and significant backup resources for future global supply. It has been speculated about mining Rare Earth metals and phosphorus from the ocean floors, but at the moment, these are traded at prices where an extraction operation would be very far from profitable. Extractions from ocean floors are subject to the same consideration as is valid for the extraction of low-quality reserves and exotic sources of oil, a concept called EROI (Energy Return On Investment). For rare metals and materials, we would have the same limiting indicator; Utility Return On Investment (UROI). When the benefit from extracting the resource is less than the cost, energy use, effort and environmental damage cost, then it will not be extracted. If ocean floor mining is profitable or not in the future, depend completely on the future raw material prices and how the demand will develop in the time to come. To be able to pay for the extraction costs, as well as to do this in a manner that is not destructive to the oceans, several things are still needed. Firstly, the technology available at present is technically capable of extracting the ore, but at a high price so far. The technology has seen significant advances in the recent years. Secondly, many reports discuss the potential environmental impacts of ocean floor mining (Allsopp et al. 2013, Beaudoin et al. 2014, Beckmann 2004, Smith and Heydon 2013, World Ocean Review 3 after Hein et al. 2015). Unless special precautions are taken, significant impacts may be expected on marine ecosystems and water quality. Much work remains to ensure that the mining can be done environmentally sound and without causing irreversible damage to marine ecosystems and without causing deleterious damage to physical structures. This homework has definitely not been done yet, and the industry should use the time to solve this issue, rather than protesting against not being allowed to cause damage to nature.

Conclusions

The role of significant new resources for metals on the ocean floor to replace land supply seems limited for most metals. For some of the main metals in society (iron, copper, platinum group metals, gold, silver), the extractable amounts seafloor resources are significantly smaller than those on land and more expensive to extract. For some of the key technology metals in short supply and with small extractable resources, the ocean resources may be an interesting and significant source of metal. The metals cobalt, nickel and silver may be in this category, with additional side products of gold, copper or perhaps molybdenum and platinum group metals. There is a lot of manganese nodules available, but the manganese price is at present low, and would not pay for the effort to harvest them and to extract the manganese. The extraction of these resources may be commercially viable for the metals identified above, and they may under certain conditions contribute significant amounts to the total supply. Considering the difficulty of mining, it seems that based on an ore grade to metal price evaluation, that only cobalt or silver would perhaps be interesting on a commercial level in the near future.

22. Transforming Phosphogypsum Waste into Products with Market Value

Ron Zevenhoven ✉, Victor Morales-Floréz, Alberto J. Santos, Luis Esquivias

Abstract

Vast amounts of phosphogypsum (PG) which is a by-product of phosphorous acid production from apatite rock using sulphuric acid, are deposited in large piles at many locations worldwide. PG materials are added at rates of the order of megatonnes (Mt) per annum. Recognising these PG piles to be a problem and a threat to the environment resulted in the development of technologies aiming at transforming these piles into useful products. The sheer amounts of PG material to be processed and the available markets for products make it necessary to use a portfolio of approaches.

Researchers from Spain and Finland have investigated methods for converting PG into a precipitated calcium carbonate (PCC) and other products. While process conditions and equipment can be practically identical (similar near ambient temperatures and pressures, in aqueous solutions), the use of either ammonia and CO_2, or sodium hydroxide in the conversion processes can result in ammonium sulphate and calcium carbonate, or sodium sulphate and calcium hydroxide, which can bind CO_2, subsequently. Thereby, besides PG valorisation, large amounts of CO_2 can be also fixed into carbonates, thus, contributing to carbon emissions control strategies. Other waste streams have been successfully tested as possible reactants for converting PG such as soda-rich liquid waste from the aluminium industry. Important is the presence of rare earth elements and radionuclides in the PG, requiring special treatment while recovering materials with large market value. Aiming at products with high purity, the removal of phosphorus from PCC product may be necessary.

This paper summarises the work and findings that led to a joint approach towards processing 120 Mt of PG deposited at the salt marshes on the Tinto – Odiel estuary at Huelva, Spain, which was declared a UNESCO Biosphere in 1983. The various process routes are outlined and the quality/purity and amounts of products obtained are quantified. Finally, some projections on development towards large-scale implementation and commercialisation are given.

Keywords: Phosphogypsum, Waste Processing, Precipitated Calcium Carbonate (PCC), Valuable Sulphate Product, Carbon Dioxide.

Introduction

The production of phosphoric acid, H_3PO_4, from apatite or fluoroapatite rock can be summarised through the following chemical reactions:

$$Ca_3(PO_4)_2(s) + 3H_2SO_4(l) + 6H_2O\ (l) \rightarrow 2H_3PO_4(l) + 3CaSO_4{\cdot}2H_2O(s)$$

$$Ca_5(PO_4)_3F(s) + 5H_2SO_4(l) + 10H_2O\ (l) \rightarrow 3H_3PO_4(l) + 5CaSO_4{\cdot}2H_2O(s) + HF(l)$$

This results in large amounts of gypsum by-product, $CaSO_4{\cdot}2H_2O$, known as phosphogypsum (PG). Estimates for annually produced amounts worldwide are in the order of 250 megatonnes (Mt). Most of this PG is deposited in large stockpiles around the world. The amounts used in agriculture or construction, adding up to ~ 15%, are limited due to the high concentrations of pollutants and sometimes also high levels of radioactivity. Radiation doses resulting from using PG are, however, negligible compared to doses from natural sources (Saadaoui et al. 2017). Overall, PG receives increasing attention as a source of raw materials, including rare earth elements, REEs. Being a calcium-based industrial by-product, PG is interesting from a carbon-capture and utilisation, CCU, viewpoint as well: one tonne of PG can react with ~250 kg CO_2 to produce a calcium carbonate, $CaCO_3$, with significant market value, besides other products.

This has the potential to bind up to ~ 75 Mt CO_2 annually (Mattila and Zevenhoven 2015).

Thus, PG processing that results in calcium carbonate combines the urgent challenges of reducing solid waste amounts and lowering CO_2 emissions to the atmosphere while producing materials with market value. Finland and Spain are or have been stockpiling significant amounts of PG. Researchers in Huelva, Seville and Cádiz, in southern Spain, have suggested process routes for converting the feedstock into materials with market value, by primarily using other industrial by-products as reactants. Special attention goes to the U-Th series radionuclides found in PG deposited at Huelva. In Finland, research in Turku has resulted in a process route to obtain precipitated calcium carbonate, PCC. These activities are described below, driven by a need to implement a portfolio of methods with different feedstocks and resulting products in order to avoid flooding the market by a single products stream.

Phosphogypsum processing in Spain and Finland

Phosphogypsum stockpiles

The situation in Spain, at the south coast city of Huelva, with a ~ 120 Mt deposit area very close to the city at the salt marshes on the Tinto – Marismas del Odiel estuary calls for urgent action. The Marismas del Odiel estuary was declared a UNESCO Biosphere in 1983. Between 1968 and 2010, besides PG from the Huelva's fertilizer industrial facility, smaller amounts of other industrial wastes and by-products have been deposited in this area as well, see Figure 1 (left). One risk to consider is the seismic activity, fearing a repetition of what is known as the Great Lisbon 1755 earthquake and tsunami; another hazard is the high radioactivity level of the deposited material which may be transferred to the surrounding hydrosphere.

Figure 22-1: *Deposits of phosphogypsum: at Huelva, Spain, covering ~ 1200 ha (left)* [27] *and near Siilinjärvi, Finland, covering ~ 60 ha (right)* [28].

Because of the concentrations of As and Cd, the Huelva PG is a hazardous waste according to European Standards (Macias et al. 2017).

In Finland, a small and a larger deposit exist at Uusikaupunki (now closed) and Siilinjärvi (in operation since 1979, adding ~ 1.5 Mt PG annually to an existing stockpile of ~ 55 Mt), respectively. For the latter see Figure 22-1 (right). However, it is not considered necessary to take similar measures in Finland as planned in Spain.

[27] Source picture: http://www.huelvahoy.com/wp-content/uploads/2016/07/Fosfoyesos-en-Huelva.jpg

[28] Source picture: http://media.tivi.fi/ponlltlplv-1463133534/incoming/dqetp0-kipsikasa.jpg/alternates/LANDSCAPE_640/kipsikasa.jpg

Process concepts work in Spain

Two process concepts developed in Spain base on the use of either alkaline soda (NaOH) or an aluminium-rich liquid waste for converting Huelva PG (> 95%-wt gypsum) into calcium carbonate PCC, and other products. Both concepts make use of aqueous solutions and operate at or near to ambient temperatures and pressures.

The first process concept, shown in Figure 22-2 (left), has been developed the furthest and has been patented under the name of 'Captura CO_2' (Captura CO_2 2017). Through this process, PG is dissolved in aqueous solution of NaOH, reacting to dissolved Na_2SO_4 and a precipitate of slaked lime, $Ca(OH)_2$, two products that can be separated by filtration (see the equation below representing the transformation):

$$CaSO_4 \cdot 2H_2O\ (s) + 2NaOH\ (aq) \rightarrow Ca(OH)_2\ (s) + Na_2SO_4\ (aq) + 2H2O(l)$$

Using CO_2, the slaked lime can be carbonated to produce calcium carbonate ($CaCO_3$) (possibly via weathering under atmospheric CO_2) while solid Na_2SO_4 can be obtained by evaporating the water. Trace elements (e.g. Cr, Ni, Pb, As, Cd) and radionuclides such as Th, U end up primarily in the ~ 90%-wt pure carbonate while high purity Na_2SO_4 is obtained. This process route can convert 120 Mt PG with 55.2 Mt NaOH and 30 Mt CO_2 into valuable products. More detail is given by Cárdenas-Escudero et al. (2011) and Contreras et al. (2015).

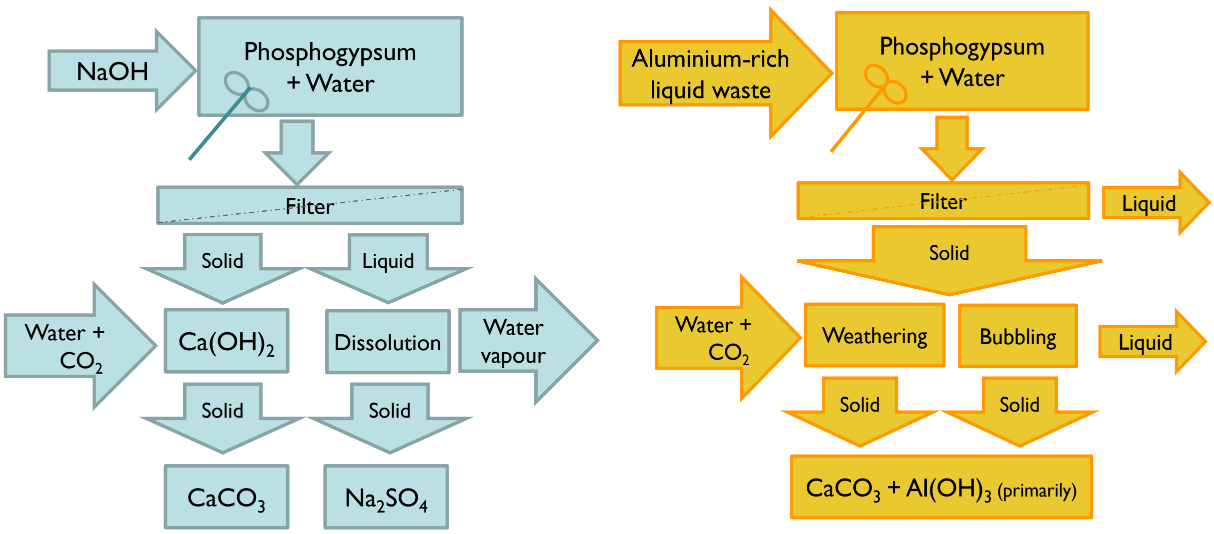

Figure 22-2: *Process concepts for PG conversion using alkaline soda (left) and aluminium-rich alkaline waste (right), respectively.*

The second concept developed more recently in Spain uses an alkaline soda-rich waste stream from the aluminium anodising industry. As an intermediate, katoite or $Ca_3Al_2(OH)_{12}$ is formed, which can be carbonated with pure CO_2 or via weathering with atmospheric CO_2:

$$3CaSO_4 \cdot 2H_2O(s) + 6Na^+(aq) + 12OH^-(aq) + 2Al^{3+}(aq) \rightarrow 3Na_2SO_4(aq) + Ca_3Al_2(OH)_{12}(s) + 6H_2O(l)$$

$$Ca_3Al_2(OH)_{12}(s) + 3CO_2(g) \rightarrow 3CaCO_3(s) + 2Al(OH)_3(s) + 3H_2O(l)$$

Again, trace elements end up mainly in the $CaCO_3$ product. This process route can convert 120 Mt PG into 73 Mt katoite that can further react with 20 Mt CO_2 into valuable products. It is worth noting that available amounts of the aluminium-rich alkaline waste to be used in this process are limited. More detail is given by Romero-Hermida et al. (2017).

Process concepts work in Finland

Fearing a limited market for Na_2SO_4 in Finland, a process concept using PG (from Siilinjärvi, > 97%-wt gypsum) aims at producing PCC and ammonium sulphate, $(NH_4)_2SO_4$. The latter finds a large market as fertilizer. (It can be also used as a flux salt for extraction of magnesium from silicate rock as the first step of CO_2 mineral sequestration, for example as in the so-called "ÅA routes" (e.g Zevenhoven et al. 2017) that bind CO_2 in magnesium (hydro) carbonates. Note, though, that in these "ÅA routes" the ammonium sulphate is eventually recovered and recycled.) Ammonia (NH_3) is used as reactant besides CO_2, in a process that uses aqueous solutions and operate at or near ambient temperatures and pressures:

$$CaSO_4{\cdot}2H_2O(s) + CO_2(g) + 2NH_3(aq) \rightarrow CaCO_3(s) + 2NH_4^+(aq) + SO_4^{2-}(aq) + H_2O(l)$$

$$2NH_4^+(aq) + SO_4^{2-}(aq) \rightarrow (NH_4)_2SO_4\ (s) + H_2O(l)$$

For 120 Mt PG, their reaction with 31 Mt CO_2 and 24 Mt NH_3 would produce 92 Mt ammonium sulphate, 68 Mt PCC and 14 Mt water. [29]

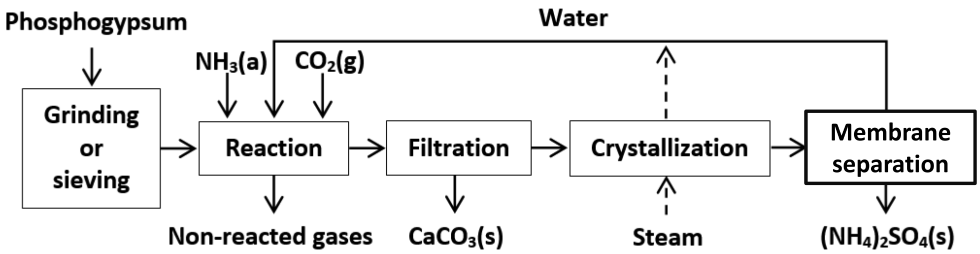

Figure 22-3: *Process schematic for PG conversion using carbon dioxide and ammonia (adapted after Mattila and Zevenhoven, 2015).*

Specific for the work in Finland, see Figure 22-3, is the possibility to produce a PCC with a pre-selected crystallinity. At ambient conditions ~20°C typically spherical vaterite is obtained; longer reaction times (and some excess of CO_2 feed) results in rhombohedral crystals, while scalenohedral PCC is obtained via a slight temperature increase to ~45°C – see Figure 22-4.

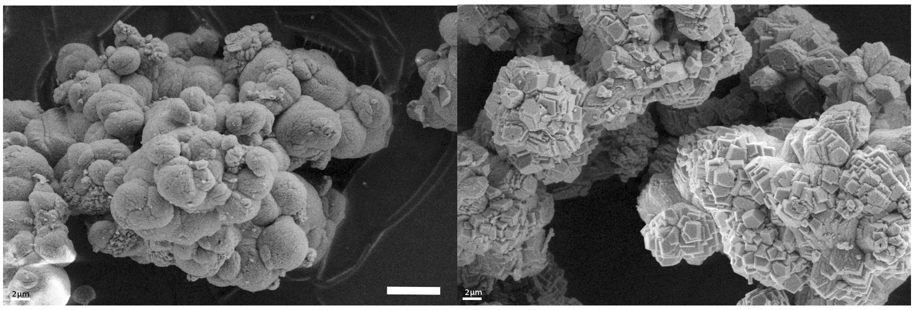

Figure 22-4: *Spherical vaterite (left) and rombohdral calcite (right) produced from PG (Mattila and Zevenhoven, 2015). Note the white scale bar that stands for 2 microns in both images.*

Neutral pH values were obtained by controlled feed of CO_2 and ammonia which also minimises losses of free, dissolved ammonia. PG conversion levels > 95% and PCC purities > 90%-wt were obtained, with trace elements including several REEs (Nd, Ce) and lanthanides (La, Pr, Sm, Gd) transferred largely into the PCC. More detail is given by Mattila and Zevenhoven (2015).

[29] This can be compared to a current annual production of 0.4-0.5 Mt NH_3 in Spain – see http://empresite.eleconomista.es/Actividad/AMONIACO/

For the recovery of ammonium sulphate, membrane separation methods are being tested (in conjunction with work on magnesium silicate rock carbonation) – see e.g. Koivisto and Zevenhoven (2017). This work on PG carbonation builds on experiences with the (patented) slag2pcc concept that is being developed in Finland for production of PCC from steel converter slag (Mattila and Zevenhoven 2014, Said et al. 2016). Note that converting gypsum using ammonia and carbon dioxide is a conventional method for large-scale production of ammonium sulphate.

The way forward

With several process route options including the Captura CO_2 concept, development and scale-up of a process unit is the next step, to be soon followed by a unit that can process several Mt of PG annually - for a scale of 4 Mt PG per year this implies 500 t/h ~ 140 kg/s. Experience with scale-up of the slag2pcc process in Finland will be of use in Spain, Huelva, for PG processing. One hurdle to take into account is finding the amount of (cheap) needed waste or chemicals that contain the NaOH or other alkalinity needed. Flooding the market with cheap products can be avoided by using several different routes which all operate at or near ambient conditions using aqueous solutions: presumably a single process unit can handle different chemical feedstocks besides PG.

Processing solid waste stockpiles will nonetheless have an impact on the environment. By-products and wastes will be generated that must be disposed of: for example, the radionuclides that may be obtained from the PG in a concentrated form. A good overview on the environmental footprint of the suggested processes can be obtained using a life cycle assessment (LCA), showing the impact of seemingly harmless features like water use (e.g. Mattila et al. 2014). Especially for rare earth metals and radionuclides, separation methods must be studied in more detail. Also, recovery of small amounts (< 1%-wt) of phosphorous from the PG deserves attention. For recovery of dissolved salts from water, membrane methods can be considered, being (much) more energy efficient than methods such as solvent evaporisation.

Conclusions

Phosphogypsum can be processed using routes that bind CO_2 while transforming (large amounts of stockpiled) solid waste into valuable carbonate and sulphate materials. This gives several windows of opportunity for processing the 120 Mt PG stockpiled in Huelva, Spain. Several process concepts using different reactants, preferably alkaline industrial wastes and by-products open up routes to various valuable products, lowering the risks of flooding markets with low-value material.

Precipitated calcium carbonate (PCC) with a chosen size, quality and morphology can be produced through several process routes, paying attention to the reduction and control of impurities. Especially for rare earth metals and radionuclides, separation must be studied in more detail. Also, the recovery of small amounts (< 1%-wt) of phosphorous from the PG deserves attention. A next step is a project framework (for example funded through the European Commission Horizon 2020 program) for development and scale-up of a process unit to be able to process larger amounts of Mt PG annually.

Abbreviations

CCU	Carbon capture and utilisation
LCA	Life cycle assessment
Mt	Megatonnes, Million tonnes
PCC	Precipitated calcium carbonate
PG	Phosphogypsum
REE	Rare earth element

23. Rare Earth Metals Recycling from E-Wastes: Strategy and Perspective

Ajay B. Patil ✉, Rudolf P.W.J. Struis, Albert J. Schuler, Mohamed Tarik, Andreas Krebs, Werner Larsen, Christian Ludwig ✉

Abstract

A robust and economically viable technology is under development for the recycling of technologically important rare earth (RE) metals from end-of-life lamp fluorescent powder (FP) e-waste. This is one of the first efforts to recycle RE from municipal e-waste components to arrive at commercially promising individual RE elements that are knowingly difficult to separate. The process technology addresses the management of strategically important RE resources as also identified by the Swiss Federal Office for the Environment (FOEN), the EU and the USA department of defence. The methodology to separate Y, Eu, and Tb each to >99% purity from the metal-digested FP waste involves cheap mineral acid for metal digestion and extractive (liquid-liquid) separation protocols with ligands (extractants) under specific conditions. The developed technology has potential for scale up to industrial level, for manifold re-use of extractant and organic phase, as well as for recovering RE metals from other e-waste. The technology is complimentary to the lamp shredding machinery developed and marketed by the project partner (Blubox 2018).

Keywords: Recycling, Rare Earths, Critical Raw Materials, Solid E-waste, Separation.

Introduction

Rare earth elements (REEs) comprise 17 elements (i.e., Y, Sc, La-Lu) exhibiting special optical, magnetic and physical properties. They have extended the technological limits of the conventional electronics. This resulted in the advent of smart technologies in the energy, transportation, medicine, diagnostics, advanced defence and space applications. Due to such strategic and advanced uses of the REEs, the European Union and the USA department of defence declared them as critical raw materials with potential supply risk (Baldé 2014, Zepf 2013, Yoon 2016). Ever increasing use of such raw materials is resulting in stockpiling of valuables in the e-waste in landfills; hence poses a major resource management concern. Due to the lack of reliable and economically feasible processing technology, the recovery of such raw materials is not undertaken in Europe or in other developed countries. In primary mining production the majority of the EU and the USA based companies are outcompeted. The major process difficulties in the production or recycling of secondary raw materials are mainly due to difficult separation between the REEs (Dupont 2015, Hatanaka 2017) and their dilute content in waste streams; therefore, their recycling is not addressed by conventional hydrometallurgical methods. As it comes to their mining, one can also have a balance problem (stockpiling of unwanted minerals during the mining of desired ones) that is also not addressed nowadays. Most research groups focus on material flows and technical investigations for the mining of REEs. The diversity and inhomogeneity of e-waste make REE recovery very challenging. The separation technology should also be robust and allow the recycling of high-grade REE materials from e-waste.

Recycling process

To accomplish hydrometallurgical operations on solid e-waste streams, it is first necessary to do the mechanical shredding or segregation. In present work, the mechanical shredding of end–of-life lamps was done using the BLUBOX process (Blubox 2018) operated by the hazardous waste recycler Sovag Veolia, Rubigen, Switzerland (Sovag 2018). Our recycling process involves digestion of the fluorescent powder (FP) in acid medium, wet chemical steps for purification purposes, as well as, liquid-liquid extraction steps using suitable ligands and extraction conditions with each REE targeted.

Digestion

The fluorescent power was digested under different mineral acid conditions to evaluate optimal leaching conditions regarding the major different phosphors (Figure 23-1) and REEs (Table 23-1). With Table 23-1, the leaching efficiency for selected REEs (% recovery) were calculated by comparison with quantitative REE composition data (ICP-OES) for FP digested in acid in a microwave furnace operated under high temperature and high pressure conditions. The latter results are considered maximum extractable REE amounts from the lamp e-waste studied. The different phosphors have been isolated as HALO ($Ca_{10}(PO_4)_6FCl$:Sb,Mn), YOX ($Y_2O_3:Eu^{3+}$), and LAP ($LaPO_4$:Tb,Ce) for further hydrometallurgical operations to separate individual REEs.

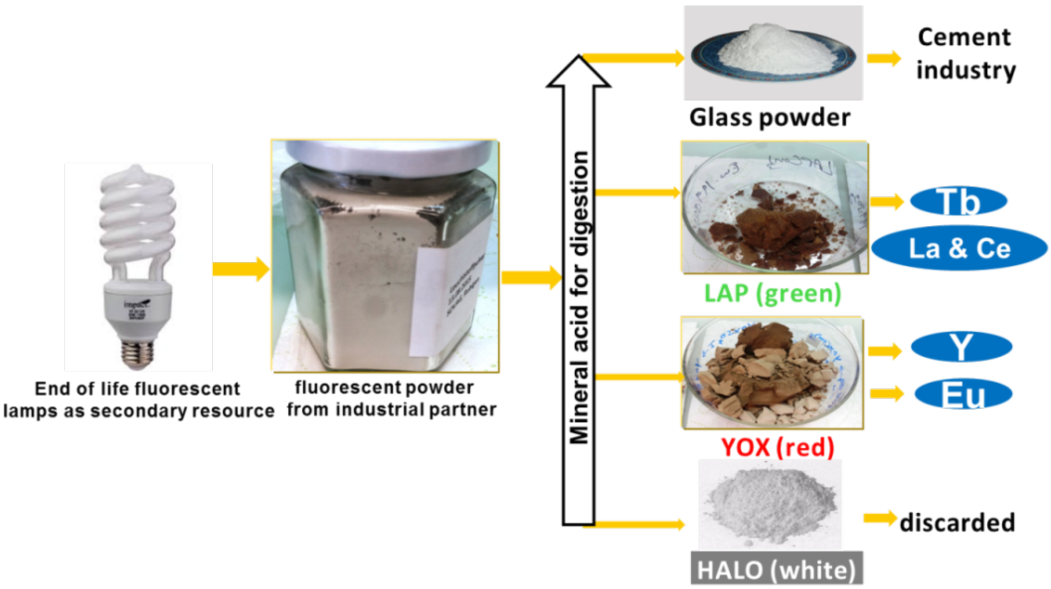

Figure 23-1: *digestion scheme for the FP e-waste and targeted pure REE products.*

RE element	Total amount (mg) obtained from 100 g FP after sequential leaching	Maximum amount (mg) expected from the 100 g FP batch	% Recovery
Ce	735	727	>99
Eu	559	521	>99
Gd	148	268	55.1
La	1212	1142	>99
Tb	419	438	95.6
Y	10030	10426	96.2

Table 23-1: *Leaching efficiency for different REEs from the developed digestion process.*

Separation process of individual REEs from digested FPs

The liquid-liquid extraction approach was exploited for cleaning the digestion leachate to achieve the individual pure REEs. At present, three different extraction procedures were developed at PSI and rendered 99%-pure Y, 99%-pure Eu and 99%-pure Tb and each along with promising economics in 1, 56, and 25 extraction stages, respectively. The 99% purity value was calculated from RE-trace metal based analyses of extraction / separation experiments using ICP-OES (with further validation by ICP-MS) and should not be confused with the leaching efficiency (% recovery) values shown in Table 1 for digestion experiments.

Major highlights of our developed recycling process are, (1) the cost effective method to leach and purify the Tb metal as it is one of the most expensive REEs and not recovered so far, (2) the reduction on the processing costs given by re-using the water-immiscible organic fluids, and principally also the extractants, in the respective liquid–liquid extraction steps (Strauss 2017, Tan 2015, Tunsu 2016, Dupont 2015, Van Loy 2017, Hatanaka 2017). Moreover, also the digestion acid can be re-used several times with the digestion of the FP.

Conclusions

A cost effective recycling process for Y, Tb and Eu rare earths with commercial acceptable purities has been developed. The FP waste has been exploited successfully as potential secondary resource for some critical or very valuable REEs. The process takes care of the waste and resource management of an unexplored segment of municipal e-waste stream. Our strategy to digest the FP from e-waste in mineral acid followed by metal specific extraction stages was successful in achieving desired purities of individual rare earths. The developed process was filed for patent application (Patil 2018). The process can be exploited / expanded further in securing other REE-containing e-wastes, such as in permanent magnets (Hippenmeyer 2016).

Part 5

Sustainable Resource Management – Personal Views and Insights from the Private Sector

24. Environmental Reporting, Between Strategic Management and "Greenwashing"?

Claire Kwiatkowski ✉, Jesús Alquézar Sabadie

Abstract

Environmental reporting as part of Corporate Social Responsibility reporting (CSR) is one of the governance tools increasingly used by companies to measure, analyse and communicate on their ecological information. The rules and standards governing their environmental reporting are in constant evolution. They provide a framework for companies to consider non-financial aspects as business opportunities and consequently to integrate them into their strategic management via virtuous practices, which make possible the creation of value in a range of forms such as economic and financial, intellectual and productive as well as social and environmental.

However, as a genuine communication tool which is published and made available to external stakeholders, environmental reporting may also contain "greenwashed" information. The objective of this paper is to analyse the environmental reporting of French companies quoted on the CAC 40 and to assess the meaningfulness of their published information. The results of the study show that companies have developed a range of practices to improve their environmental performance as shown in their reporting. Some can be classified as practices aiming at internalising environmental externalities, while others lead to a phenomenon of "externalisation" of those externalities (e.g. sub-contracting or rental). It demonstrates the need to make the standards more precise, both in terms of the scope and even the objectives of reporting. This would involve developing a natural capital and ecosystem services accounting system.

This article also reviews the different initiatives to integrate the value of nature in the accounting systems of both businesses (micro level) and countries (macro level) and their possible inter-linkages.

Keywords: Greenwashing, Sustainable Communication, Valuation Techniques, CSR, Extra-Financial Performance.

Environmental reporting as a strategic management tool

Protecting the environment is part of the societal challenges that we have to address more intensively this century. Climate change, increasing pollution of the earth's resources or depletion of biodiversity and raw materials have an effect not only on ecosystems but also on food, health, the economy and even on geopolitical stability. This explains why the environment has arrived at the top of our political priorities as demonstrated by the signature of important international commitments such as the COP 21 Paris agreement[30] and the Sustainable Development Goals (SDGs)[31] in 2015. Those commitments set goals and objectives that have to be translated into concrete actions at national level implying monitoring and reporting obligations and involving a large array of actors such as local authorities, citizens and companies.

Companies are very important players in enabling the transition towards a greener society because they can shape new and more sustainable production and consumption patterns. They are integrating more and more environmental considerations into their strategic management and have developed a number of tools and practices in favour of its protection.

[30] http://unfccc.int/paris_agreement/

[31] http://www.un.org/sustainabledevelopment/

Environmental reporting is one of the governance tools increasingly used by companies to measure, analyse and communicate on their ecological information. It is part of Corporate Social Responsibility (CSR), and so also includes reporting on social aspects in companies. According to the KPMG Survey of Corporate Responsibility Reporting in 2017, 60% of worldwide companies use CSR reporting. However, the main motivation to use CSR reporting is to comply with legal obligations. This is notably the case in France where the “Grenelle II” Law[32] of 2010 makes compulsory for companies with more than 500 employees or having a turnover of more than EUR 100 million, to publish every year a social and environmental report, which is the equivalent of the CSR report found in the Anglo-Saxon system. According to the implementing provisions, reporting should be verified by an independent third-party body, which should certify the presence of the information as well as its fairness. The Law also imposes some specific reporting themes. All these provisions show that the French legislator wants to make environmental reporting an important corporate management tool containing information that is authentic, accurate, comprehensive and auditable.

More recently, the European Union (EU) adopted in 2014 a Directive on the Disclosure of Non-Financial Information[33] requiring that European companies of more than 500 employees include non-financial statements in their annual reports from 2018 onwards (based on the 2017 period). Thanks to this Directive, the number of companies using CSR should increase in Europe over the coming years.

As regards the motivation to impose CSR on companies, the EU Directive mentions that this reporting will help with “managing change towards a sustainable global economy by combining long-term profitability with social justice and environmental protection”. The EU Directive recognises that non-financial reporting is a tool to influence the sustainability of the global economy. Environmental reporting raises awareness of companies about their environmental performance allowing them to take action in response. The impact assessment accompanying the proposal of the Directive highlighted the role of stakeholders mentioning that stakeholders are very interested in social and environmental information produced by private companies and that they would like to see more commitment from those actors towards sustainability. It gives the impression that stakeholders, by their preferences, could influence businesses' management to serve greater objectives of common interest (Szabo and Sorensen 2015).

There are different reporting standards such as the ones proposed by the Global Reporting Initiative (GRI)[34], the ISO 26000 norm[35], the OECD[36] or the UN Global Compact[37]. Even if those methods are applicable only on a voluntary basis, they provide a framework for companies to consider non-financial aspects as business opportunities and to consequently integrate them into their strategic management. Doing so, would make possible the creation of value and confirm the assumptions underlying the EU Directive.

Taking into consideration environmental dimensions in businesses' activities through environmental reporting can bring three types of value:

- **Environmental value**: environmental reporting allows for better control of environmental aspects within the company. The environmental benefits are shown in the reporting themselves: CO_2 emissions, waste generation, recycling rate, waste water treatment, etc.
- **Financial and economic value**: environmental reporting allows for better identification of avoidable costs for a company. Those costs can concern raw materials or “end of pipe” costs, reputational or legal costs. Reducing those costs will increase businesses' profits.

[32] https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000022470434
[33] http://eur-lex.europa.eu/legal-content/FR/TXT/?uri=CELEX:32014L0095
[34] https://www.globalreporting.org/
[35] https://www.iso.org/
[36] http://www.oecd.org/corporate/mne/
[37] https://www.unglobalcompact.org/

Environmental reporting also allows for observation and monitoring of the financial performance linked to environment. It is a tool that facilitates the creation of solutions, their diffusion and their monitoring. Beyond cost reduction, environmental reporting highlights opportunities (e.g. selection of new raw materials or new channels of distribution, making possible the creation of new business models). Environmental reporting also makes possible the diffusion of good practices that could be used by other businesses.

- **Intellectual, productive and social value**: environmental reporting is a communication tool that can improve the image and reputation[38] of a company. It inspires trust in stakeholders who can have a preference to invest in or to buy products of a greener company. It is a tool allowing benchmarking between companies and therefore providing comparative advantages. Indeed, there is a growing demand by customers and even investors for greener goods or services (Pérez et al. 2016).

To seize the opportunities offered by an efficient management of the environmental aspects of their activities, companies need to integrate them in their strategic management and align their practices – so creating a virtuous circle of environmental actions (Figure 24-1). This is confirmed by Flash Eurobarometer 426 entitled "SMEs, resource efficiency and green markets"[39] which states that 87% of European SMEs are taking actions to be more resource-efficient, the first motivation is cost saving (68%) followed by the environment being integrated in the company's top priorities (39%).

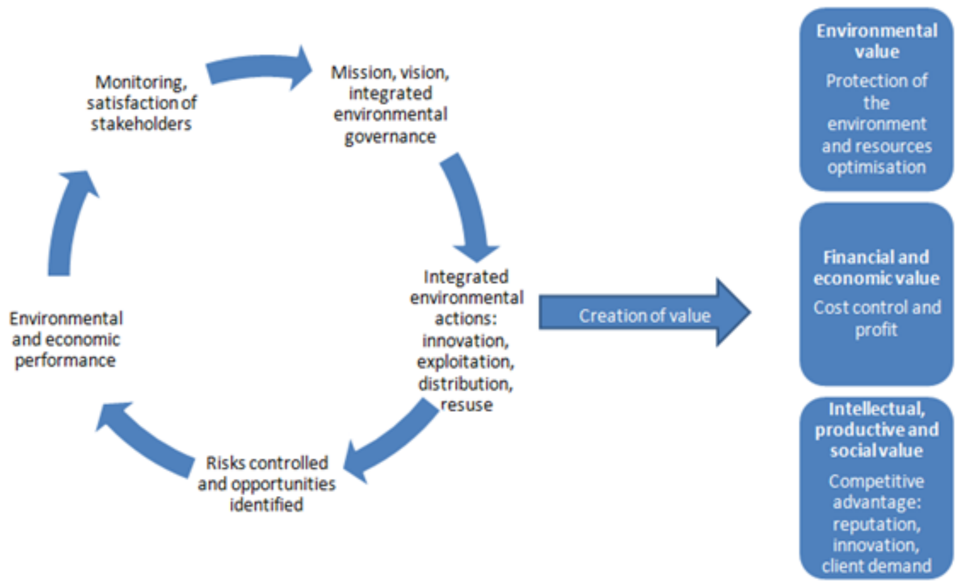

Figure 24-1: *Virtuous cycle of environmental actions and value creation; source: authors.*

Environmental reporting is therefore a highly relevant management tool for companies because it helps them to analyse, monitor and communicate their environmental performance. Depending on the standards, environmental reporting contains quantitative and qualitative information on pollution, use of resources, biodiversity protection, climate change but also information on the internal environmental policy implemented by companies or the commitment of stakeholders (such as suppliers). The intention is to monitor all internal and external impacts along the value chain of companies. Environmental reporting therefore is very promising.

A salient characteristic of reporting is that it should be published as it then becomes a genuine communication tool for companies. However, they could then be tempted to publish flattering

[38] According to Eurostat's Community Innovation Survey 2014, reputation is the first motivation for companies to introduce eco-innovation.

[39] http://ec.europa.eu/COMMFrontOffice/publicopinion/index.cfm/Survey/getSurveyDetail/instruments/FLASH/surveyKy/2088

information on their ecological performance because the perception of stakeholders and the reputation of companies are important drivers of businesses' activities. The next section tries to assess the meaningfulness of the environmental reporting and to answer the following question: Does environmental reporting contain "greenwashed" information (Lyon et al. 2015)?

Environmental reporting: information or "greenwashing"?

This section analyses the content of the environmental reporting produced by the French companies quoted on the CAC 40. According to "Grenelle II" Law, these companies should produce yearly social and environmental reporting[40]. The analysis is based on the reporting for the period 2015.

As a general observation, the environmental reporting of companies is typically ten pages in length and contains mainly narrative or qualitative information. All firms state that they have developed a corporate environmental strategy (which is more or less clear as regards the objectives). Because the companies belong to various economic sectors, it is observable that the fields of reporting are very different from one company to another, making impossible any comparison of reporting or even indicators between companies. To comply with the reporting themes imposed by "Grenelle II" Law, most of the enterprises use concordance (or correlation) tables between their own reporting priorities and the themes imposed by law. It can also be seen that the same indicator can be used to comply with more than one theme of reporting showing once again the multi-dimensional aspect of the environment, which makes it difficult to measure. The selected indicators are also very different from one company to another and rely on different methodologies, reporting parameters and values (absolute, relative or pro-forma).

All reports have been verified by an independent third-party body who has certified the presence of the information required by law. However, it was not possible for any of the companies to give a complete assurance of fairness. This shows once again that environmental indicators are very difficult to verify and can be subject to different interpretations.

It is interesting that in all cases, companies have declared an improvement of their environmental performance from one period to another (except for a few indicators). This could confirm that environmental reporting is an incentive to identify and address environmental issues but it can also indicate that the reporting information can easily be presented in a flattering way.

The study shows that companies have developed various practices to improve their environmental performance in the reporting. Some can be classified as practices aiming at internalising environmental externalities, while others lead to a phenomenon of "externalisation" of those externalities.

One of the main responses of companies to address environmental issues are technological (e.g. evaporator to obtain solid waste) or organisational improvements (e.g. waste sorting). In this case, they internalise the externalities and try to limit their impacts. However, those measures are very often expensive for private businesses as they imply high R&I expenditure or the purchase of new equipment. However, those measures do not lead to "greenwashing".

The environmental reporting also refers to some practices that lead to a phenomenon of "externalisation of the externalities", which gives the impression that the ecological performance of companies has been improved from one period to another. Those practices modify the parameters of reporting, for example, in the case of subcontracting or rental: the ownership of the externality is transferred to another actor whose activities are no longer mentioned in the reporting. Carbon credits can be considered as an example of "externalisation

[40] All the reporting is available on the Internet

of externalities". With the creation of a "market" of tradable emission permits, companies are entitled to buy extra-credits that give them the right to make more emissions (Field and Field 2002). There is also a voluntary market where companies can buy credits in investment funds which in return finances de-carbonisation projects (e.g. reforestation). Emissions related to de-carbonisation projects are usually highlighted in the reporting.

Another case of externalisation of externalities is legal re-characterisation. This happens when a product is legally re-characterised and so it no longer meets the definition of waste, for example. Consequently, the product is no longer counted as waste and this shows up in an improvement of the environmental performance of a company. Of course, those practices are not implemented by companies solely with the objective of improving their reported performance but are part of larger strategic decisions. However, they are mentioned in the environmental reporting with the effect of improving it.

Another mean to improve the content of the reports is the legitimacy offered by external entities (Berrone et a. 2015). The information contained in environmental reports is very difficult to understand and to interpret. This is why companies communicate with labels, their rank in surveys or indexes proposed by non-financial rating agencies. All of those tools are proposed by external organisations, who provide an external legitimacy to the enterprise. However, are those external tools very relevant and do they reflect the actual environmental performance of a company? If we look closer, for example at the indexes proposed by non-financial rating agencies, we realise that the methodology and the criteria used can be very different. In some, one company out of three could be part of the index – and this does not look very selective. In addition, some indexes do not reward the efforts made in terms of pollution reduction, they only refer to companies with the lowest emission rate (very often the services sector).

Not all practices and tools mentioned above have been implemented by companies with the sole objective to improve their reporting. However, they contribute to biasing of the information communicated to stakeholders who could in return have an incorrect perception of the environmental performance of a company or of its green commitment. An effect of "greenwashing" can be induced from this information, even if it is not necessarily intentional.

This analysis demonstrates that the environment is very difficult to measure and that legal provisions are not sufficient to lead to meaningful reporting (Braam et al. 2015). It shows the need to make precise the standards, the scope and even the objectives of the reporting and highlights the opportunity of developing an environmental capital and ecosystem services accounting system, which could ultimately give a monetary and financial value to the environment. If the environment was integrated in financial accounts then it would make easier the interpretation and comparison of reports.

Environmental valuation as a solution?

The idea of integrating the value of the environment into the measurement of nations' wealth is not new. It is perceived as a way to protect nature. For some economists, the depletion of natural capital and ecosystems services should be made visible to countries and should therefore be given a price. Stiglitz et al. (2009), for instance, pointed out the limits of current growth indicators such as GDP that do not include a fair appraisal of the sustainability of a country. National accounts should include other assets such as the environment, human capital and social cohesion.

The idea of environmental accounting is the subject of numerous studies and works. In 2016, the European Commission provided the following definition: "Natural capital accounting is a tool to measure the changes in the stock of natural capital at a variety of scales and to integrate the value of ecosystem services into accounting and reporting systems" (European Commission 2016). This definition suggests that environment has a double value: one related to its natural capital and the other related to the services generated by nature.

When referring to worldwide accounts, the most prominent reference is the System of National Accounts (SNA). The UN's System of Environmental-Economic Accounting (SEEA) provides a global framework to link environmental and economic accounting that is consistent with the SNA. The SEEA includes a Central Framework (CF) and an Experimental Ecosystem Accounting (EEA). The SEEA-EEA complements the SEEA-CF. It focuses on accounting for ecosystem services (flows) and assets (stocks) in physical and monetary terms (Science for Environment Policy 2017). The SEEA-EEA is largely based on guidelines that still require further development, in particular on valuation (United Nations et al. 2014). It constitutes a first step towards an environmental accounting, but remains very general and it is still not mandatory for countries.

The international initiative TEEB (The Economics of Ecosystems and Biodiversity) promotes environmental valuation, to prove its economic benefits and to evaluate the costs related to ecosystems degradation. In 2012, TEEB for Business was created. It was renamed the Natural Capital Coalition in 2014. TEEB provides a classification of ecosystem services[41].

At business level, the two most important frameworks are proposed by the Natural Capital Coalition and the World Business Council for Sustainable Development (WBCSD). However, the same comment applies to them: they are not compulsory and contain mainly guidelines. Environmental valuation remains the main issue to be addressed in the future but it raises the question of defining valuation criteria that would represent an incentive for both countries and businesses.

The Global Nature Fund (2014) provides an overview of valuation techniques (Table 24-1).

Techniques	Description
Market prices	Production and distribution costs, sales prices Mainly applicable to goods
Treatment costs avoided	Costs related to the degradation of ecosystem services Should be calculated by experts
Productivity	Data on production function
Replacement costs	Costs of replacing an ecosystem service by technology
Hedonic prices	Difference in prices that can be attributed to the different ecosystem qualities. The calculation is rather complex.
Contingent valuation	Value of preferences of users
Benefit transfer	Valuations from studies on similar sites

Table 24-1: *Overview of valuation techniques.*

The table shows once again the difficulty to give a value to nature. Some of the techniques are very complex and would not be easily applicable by all companies as they require the expertise of scientists or experts. Giving a monetary value to the environment remains an artificial exercise that will anyway require the intervention of public authorities as regulator. However, further research and experimentation is needed to understand the pros and cons of the different techniques, and then to better include and apply them in standards or regulation.

Disclaimer

This paper reflects the views only of the authors; neither the European Commission nor any person acting on behalf of the Commission is responsible for the use which might be made of the following information. The responsibility for all conclusions drawn from the analyses lies entirely with the authors.

[41] Provisioning services, regulating services, habitat or supporting services and cultural services

25. Decision Support Methodology for Designing Efficient and Sustainable Recycling Pathways

Guilhem Grimaud ✉, Nicolas Perry, Bertrand Laratte

Abstract

As the end of life becoming more and more complex recycling systems encountered many difficulties in valuing all the materials contain in each product. This involves not only recovering a large number of materials but also doing so with the minimal environmental impact. Although the benefits of recycling are well established, the industrial processes need to be designed in regard with their environmental impacts. That why recyclers need robust assessment tools to make the right choices during the design of recycling processes. This evaluation work should enable them to choose the right recycling solutions for a wide range of end of life products. In this article, we present how we develop a methodology for evaluating the performance of recycling processes during their design phase. This methodology is our answer to help optimise the recycling of multi materials products based on the evaluation of the sustainability performance of the processes chosen.

Keywords: Industrial Design, Environmental Technology Verification, Life Cycle Assessment, Life Cycle Cost.

Introduction

The rise of the world population and its life conditions go hand in hand with the growth of energy and raw material consumption as well as the steady growth of CO_2 concentration in the atmosphere. The consumption growth comes with an increase in the amount of waste produced annually (EUROSTAT 2015). The demand for primary resources is not sustainable long term. It is therefore vital to find industrial solutions to maintain standards of living equivalent while also decoupling resource use and demand (Schandl 2015). The circular economy offers a partial answer to resource depletion (McDonough and Braungart 2012). Recycling is inherent in the circular economy strategies that why industrial companies look for stepping recycling rates up. To do so they implement product centric End-of-Life (EoL) solutions using closed loop recycling (Rebitzer et al. 2003). Those strategies show good environmental performance but a specific EoL requires a suitable and efficient supply chain to reach the recycling plant. The different steps of an EoL scenario are shown on the Figure 25-1. Also, as the motivation is mainly economy, the generalisation of closed loop recycling is slowed down (Butterworth et al. 2013, Gahleitner 2015, Lavery and Pennell 2012).

For waste that is not recycled in closed loop it is necessary to adapt the recycling pathway. Yet the recycling pathways are multiple and it is important to determine the best path according to different categories of indicators and not only financial performance.

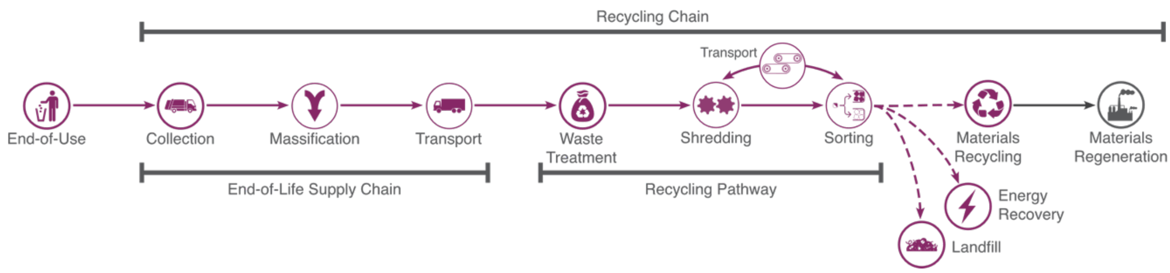

Figure 25-1: *Main steps of the End-of-Life chain including recycling pathway.*

MTB company, an international manufacturer of recycling technologies and a recycling operator in France, has launched a sustainability strategy. The aim of the strategy is to reduce the environmental impact of its industrial activities. To do so, MTB started to evaluate its environmental performance with evaluation tools such as Life Cycle Assessment (LCA) and Mass Flow Analysis (MFA). The first evaluation has been realised on an aluminium recycling process using only mechanical separation process instead of smelting. Results show the advantages of mechanical processes (Grimaud, Perry, et al. 2016a). Based on these results from environmental evaluations, MTB implemented corrective measures to increase its environmental performance level (Grimaud, Perry, et al. 2016b).

Beyond optimising recycling pathways in operation, these results also helped us to guide the research for new recycling processes which have been designed to be more sustainable (Grimaud, Laratte, et al. 2017). All these steps help to enrich the company's own knowledge, but the evaluation process is long and requires strong stakeholder involvement at each assessment step. To systematise this new practice and provide data relevancy to decision makers, a methodology was needed to integrate the Life Cycle Management (LCM) approach in MTB design phase.

Methodological framework

Segmentation of recycling processes

The recycling pathways are mostly based on common elementary technologies. The elementary technology selection and order have a strong influence on the overall performance of the recycling chain (UNEP 2011). This assembly achieves the targets of purity and quality specific to processed wastes, the performances largely depend on the pathway rather than technological innovations (Fisher 2012). So, the assembly choices of common sub-processes are one of the key points to design efficient recycling pathways. The Figure 25-2 shows different pathways for the same waste recycling pathway. The technologies used and the streams vary with recycling process choices. We have determined that recycling processes can be classified in 3 types (Heiskanen 2014): shredding, separation and transport. In addition to these 3 families of process unit, there is the flow unit family.

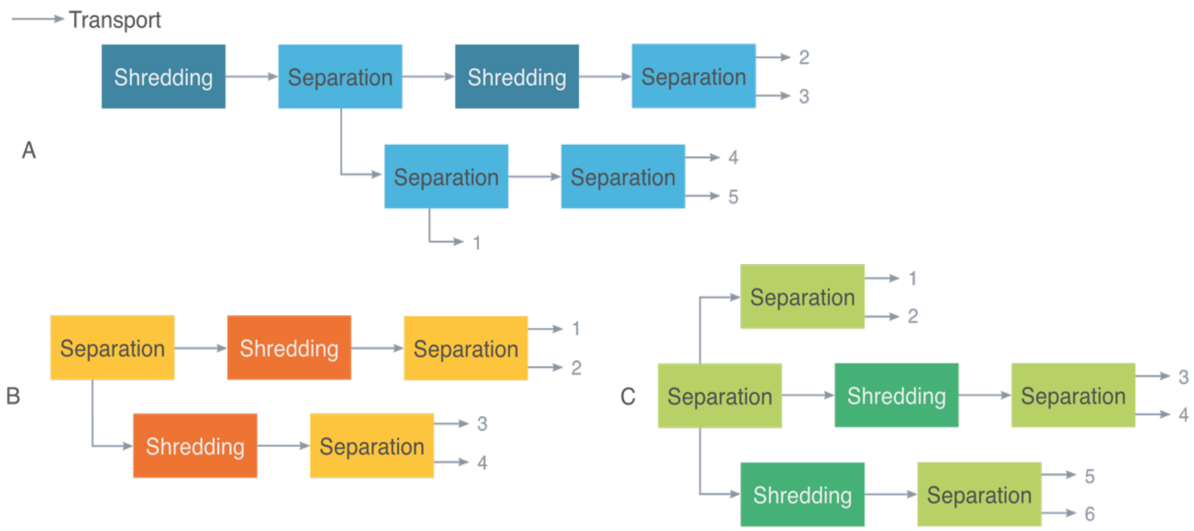

Figure 25-2: *Presentation of pre-recycling processing alternatives for the same waste.*

Unit process database

To support the evaluation, we launched the construction of a database for recycling processes. This database includes technical, environmental and economic dataset. On the one hand, for each data a part of the values is fixed, they are invariant data regardless the type of transformation performed by the unit process. This is mainly the impact of manufacturing, its price without the options or the weight of the equipment. On the other hand, in addition to these fixed values, the engineering team can set value adjusting unit process to customer need. These are the operating variables. These actions will have a direct effect on the performance of the recycling pathway. Each unit process and its associate in/output flows can be modelling as shown on the Figure 25-3.

Figure 25-3: *Modelling of a recycling pathway step with a separation unit process.*

To define the technical characterisation of each unit process, we have chosen to implement the Environmental Technology verification (ETV) protocol (European Commission 2014, European Commission 2016). The main steps of the ETV program are given on Figure 25-4. The whole ETV verification steps combine together last 8 to 18 months (European Commission 2012). In comparison, the average designing time for a recycling pathway is between 3 and 6 months. Although ETV verification time is too long for designers, the program provided general requirements, allowing to develop a self-assessment framework (Grimaud, Perry, et al. 2017).

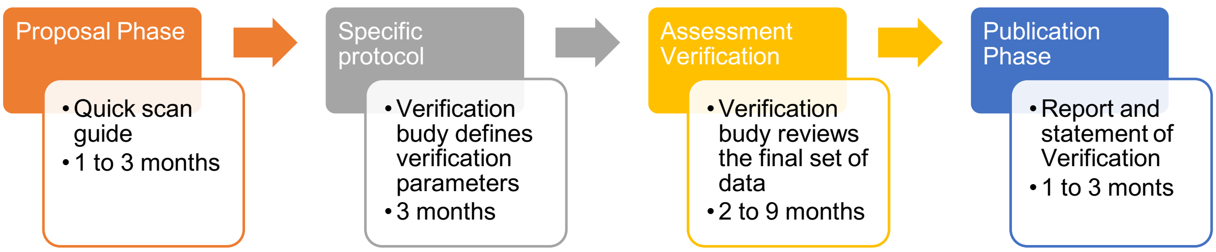

Figure 25-4: *Main steps of the European Environmental Technology Verification process*

For the 3 families of unit process, the Table 25-1 gives the associate operational details and the technical characterisation define using the ETV program. For each specific unit process, technical characterisation will help to define the most suitable process for each purpose of the recycling pathway step.

Type	Operational Details	Characterisation
Shredding	Type of technology (constraint) Cost of purchase Material losses Capacity	Reduction rate/Fineness
Separation	Type of technology (constraint) Cost of purchase Material losses Capacity	Effectiveness/Separation quality
Transport	Type of technology (constraint) Environmental characterisation Cost of purchase Material losses Capacity	Flow rate
Elementary flow	Flow composition Physical properties Input or Output Market price	Purity

Table 25-1: *Variables and characterisation for recycling each unit process family.*

Results

Step by step evaluation methodology

To support our assessment methodology and provide a coarse result in early design phases to promote sustainable solutions. The methodology can be divided into several key steps. First, with the specifications and the customer need the general framework can be built. This step allows to determine the specific constraints, delays and costs of the project in order to draught the initial specifications. In the continuity, the customer provides his main orientations for the recycling process purpose. The customer defines purpose and objectives for the recycling pathway. And the engineering team validate or not main orientation of the recycling chain. From this orientation, the engineering team starts working on the recycling pathway proposal. The aim is to provide: treatment synoptic definition, selection of the main steps, choice of technological bricks.

According to the recycling chain synoptic, for each step of the recycling pathway, MTB commercial team needs to select the appropriate technology and thanks to the expertise from MTB engineering team the operating variables are selected. It is from this point that the database makes it possible to calculate the unit performances. This calculation is made according to the general settings, the specific flow information and the variables. At the end, a synthetic evaluation of the global process and unit steps is provided to allow discussion.

Unit process performance calculation

The technical performance indicators are oriented towards the capacity of the pathway to recycle the waste, so each unit process is described by 3 indicators. The calculation of these rates is made according to the standard (International Standard Organization 2002).

- Recycling rate
- Recovery rate
- Landfill rate

For the economic dataset, data is easily accessible through the information provided by manufacturers and recyclers feedback. The Life Cycle Cost (LCC) analysis is used to determine the economic performance of each unit process. The LCC methodology used to consider both the costs of each system in addition to the profit from recycled materials sales.

But we do not include the costs of the environmental impact (Office of Acquisition and Project Management 2014). The economic performance is described by using 3 results:

- Initial investment costs
- Operating costs (cost per ton)
- Profit from recycled materials sales

On the contrary, environmental data are rare and not available in the current LCA database (ELCD, Gabi, Ecoinvent). Inventory data remains to be collected and assessed to build a strong dataset. Our team has started to build an environmental database for recycling processes. In order to present the results of environmental performance with one inventory indicator and two impact factor indicators (using ILCD methodology (JRC - Institute for Environment and Sustainability 2012)):

- Total energy consumption
- Climate change
- Non-renewable resource depletion

Discussion

The decision tool provides aims to help the design team to implement more sustainable recycling pathway. It is not a matter of providing a comprehensive assessment for each recycling pathway during the design phase, but it is to communicate to industrial customers performance indicators in addition to economic indicators. These additional performance indicators should allow designers to propose optimisation on recycling pathways and give a quantified result of the improvements. With an iterative approach, designer could optimise flows and processes to limit impacts.

Although recycling lines are not new, industrial optimisation has not been fully conducted (Martínez Leal et al. 2016). The unconstructive approach, the complexity of waste and the lack of control over incoming flows limit the drafting of theoretical principles. The increasing interest in waste recycling and the evolving regulations in force steer the waste sector to adopt an increasingly industrial approach. To accompany this transition, it is a question of advancing the design methods with specific tools.

Conclusion

Even though plenty of technical options exist for developing products recycling, the recycling solutions selecting motivations are too often led by the pursuit of profit growth which leads to a greater inefficiency (Allwood et al. 2011). By communicating additional performance indicators, we are convinced that this approach can evolve. And that new issues will be introduced in trade negotiations for recycling pathway.

As a next step, we need to build a sufficiently complete and robust database to support the evaluation of recycling pathway. This approach must be enriched in the future. It is also required to facilitate the improvement of the quality of results during the refining process variables and input parameters.

Acknowledgments

The authors want to thank MTB Recycling and the French National Association for Technical Research (ANRT) for the funding of the PhD study (CIFRE Convention N° 2015/0226) of the first author.

26. Transportable Versus Centralized Recycling Plant: Environmental and Cost Assessment

Guilhem Grimaud ✉, David Ravet, Bertrand Laratte, Nicolas Perry

Abstract

The purpose of the study is to determine the environmental and economic balance between the collection of wastes and their transport to a centralized recycling plant versus the displacement of a recycling plant near the waste source locations. Two systems are compared in this study with economic and environmental Life Cycle Analysis (LCC and LCA) tools. On the one hand, the study demonstrates environmental benefits for transportable recycling plant in comparison with waste collection. On the other hand, the results show the economic advantages of such solution. Transportable recycling solutions seem to be a good answer to solve waste logistic issues, both from an economic and an environmental point of view.

Keywords: Circular Economy, Recycling, Life Cycle Assessment, Life Cycle Cost.

Introduction

In previous Life Cycle Assessment (LCA) we demonstrate the significant contribution of upstream waste logistic (Grimaud et al. 2017). In the case of electrical cables recycling, transport to a centralized recycling plant represents at least half of the total environmental impact. Beyond the LCA results MTB Recycling has been able to identify ways to improve the recycling pathway (Grimaud et al. 2016). To further reduce the environmental impact of cables recycling, MTB started to review the overall recycling pathway and not just the industrial processes. First, the logistic routes were optimized, and the filling rates of the collection trucks were increased. However, these solutions only provide a partial answer. MTB therefore launched the challenge of designing a transportable recycling solution capable of achieving the same level of purity as its existing centralized plant but with a lower throughput. Instead of bringing the waste to the recycling plant, the recycling plant is transported closer to the deposits.

Material and Methods

The study is based on a life cycle approach, in accordance with ISO 14040/44 standards (International Standard Organization 2006a, 2006b). The scope of the study used for the life cycle comparison include cradle to exit gate stages (Jolliet et al. 2010, Grisel and Osset 2008). The study only focuses on recycling steps of metals. The by-products are included in the environmental impact calculation, but the environmental and economic benefits of the by-products are not integrated into the study scope. The functional unit used is as follows: producing one ton of aluminum intended for end-user applications, with the purity higher than 97% using current industrial technologies located in Europe. The study scope boundaries are summed up on the Figure 26-1.

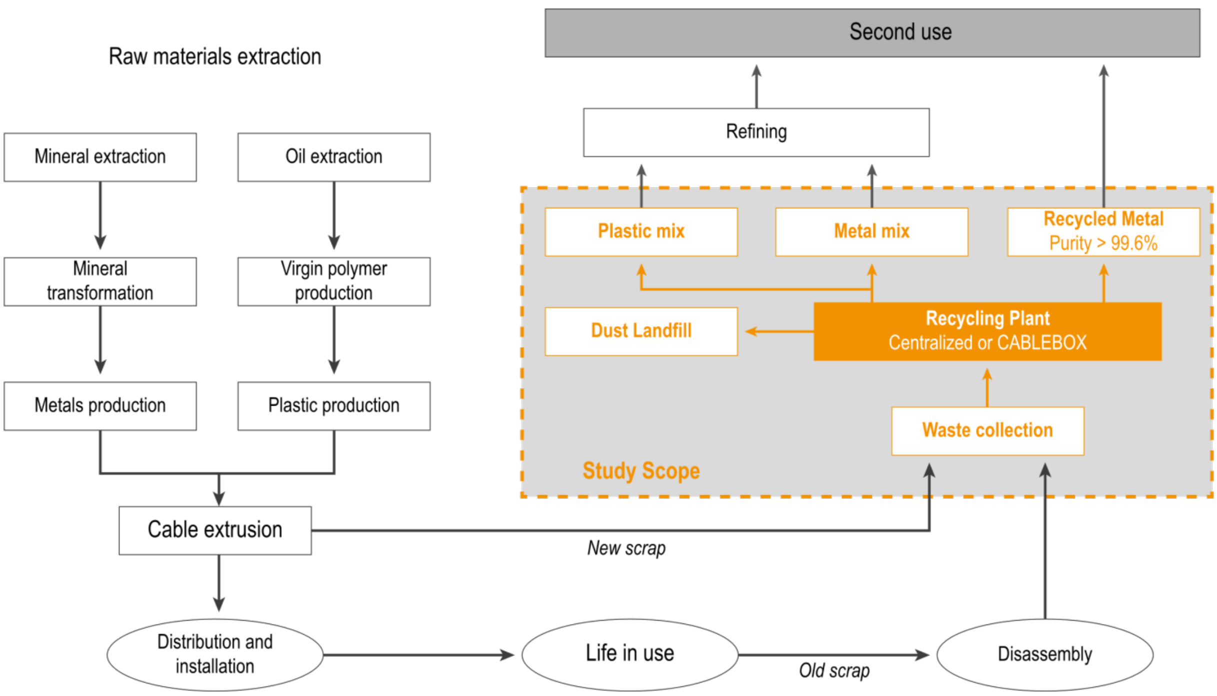

Figure 26-1: *Study scope for the cable recycling system boundaries.*

MTB Centralized Recycling Plant System

For the MTB centralized recycling plant systems, we use data from the MTB recycling treatment line located at Trept in Isère (France). This treatment line has been reviewed by a complete Life Cycle Analysis (LCA) (Grimaud et al. 2017). In this article, we propose only a simplified presentation of the results to compare them with the CABLEBOX system which was not assessed with the first complete LCA. The Table 26-1 presents the technical data of the MTB recycling plant based in Trept for aluminum and copper cables.

Specifications	**Value**	**Comments**
Output	4 t/h	Measured median value
Annual Tonnage	15,360 t	Measured Value
Electric power installed	1,479 kW	Technical Data
Electric charge rate	58%	Measured value
Annual working time	3,840 h	Calculated value

Table 26-1: *Main specifications of the MTB cables recycling plant at Trept (FR).*

The working time is fixed on a 250 working-day basis including ten days of complete shutdown for maintenance. The daily maintenance is carried out by night at regular intervals. The line automation makes it possible to limit the workforce to 2.5 operators. One half-time crane operator at the beginning of the recycling process and two operators for the handling at the end of the recycling process. Waste collection takes place at an average distance of 535 km by articulated truck. The truck average load is 23 tons. A total of nearly 700 trucks are required each year to supply the recycling plant. Supply is not exclusively done in France.

CABLEBOX Transportable Recycling System

The CABLEBOX CBR 2000 is a transportable recycling plant that takes place in two 40-foot containers, one 20-foot container and one 10-foot container. The visualization of the CABLEBOX is given on Figure 26-2. The flow rate reached with the CBR 2000 version is 2 t/h. Compared to the Trept plant, the flow is divided by two. A first CABLEBOX unit has been in operation since January 2017 in the USA. The use of the international container standard sizes ensures maximum transportability by all modes of transport (road, rail, maritime). In addition, the containers offer modularity with upstream and downstream processes that can be easily implemented. The CABLEBOX system is not autonomous, it requires an external power source. The energy mix used for the local supply of the system depends on the location. There are no direct local emissions but only indirect emissions.

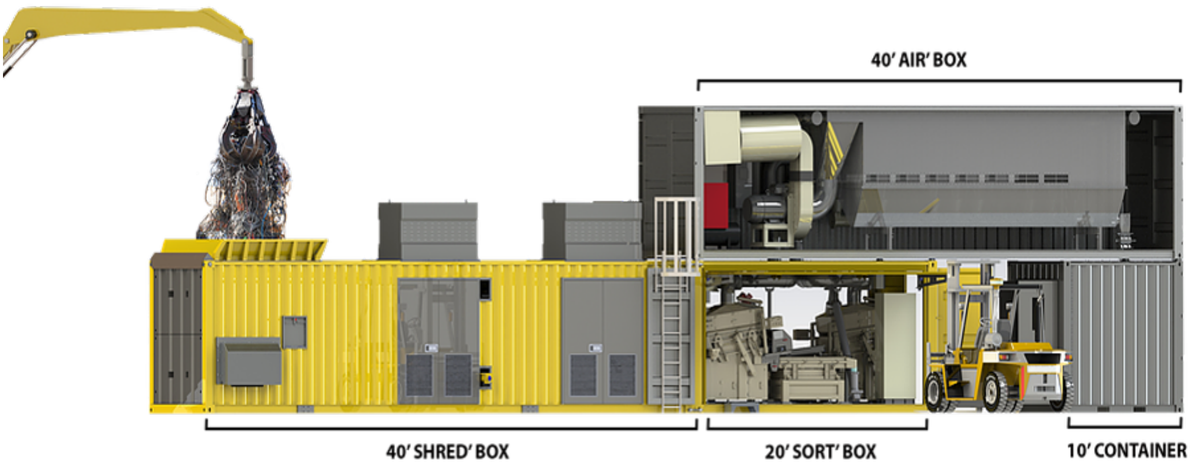

Figure 26-2: *3D visualization of the CABLEBOX CBR2000 system.*

The technologies introduced in the CABLEBOX system are similar to those used by the treatment line of the MTB centralized recycling plant systems. The machines are smaller and have been optimized from an energy and caloric point of view to operate in a container-type enclosure. These developments have made it possible to reduce the power installed capacity for a treatment flow that remains high compared to the size. The main specifications of the CABLEBOX CBR 2000 unit are summarized in Table 26-2. Over a year, we consider a 250 working-day basis including 20 transit days and 230 days of production. The operating scenario of the CABLEBOX system is organized in two teams working 8 hours per day. The total worked hours per year is 3,680 h.

Specifications	**Value**	**Comments**
Output	2 t/h	Measured median value
Annual tonnage	6,000 t	Calculated tonnage
Electric power installed	330 kW	Technical Data
Electric charge rate	65%	Measured value
Annual working time	3,744 h	Estimated Value

Table 26-2: *Main specifications of the CABLEBOX CBR 2000.*

Unlike the centralized system at Trept, the CABLEBOX system moves to get closer to the waste production sites. The four containers of the CABLEBOX are transported on three lorries. The time required for handling and installation of CABLEBOX is 1.5 days. The installation requires a crane for the duration of four hours. In our study, we have imagined a transit scenario composed of four displacements per year. The scenario is composed of four displacements made partly by truck (2,800 km) and by cargo ship (7,100 km). On average, transit by truck is carried out in two days, cargo trips result in a greater number of transit days (three to six days).

Shared Data for the Two Systems

For life cycle impact assessment, environmental, the inventory data come from the Ecoinvent 3.3 database. The modeling of road transport was carried out using two types of truck presented in the Table 26-3.

Truck type	Ecoinvent Data
Ampliroll truck	Transport, freight, truck 7.5-16 metric ton, EURO5
Articulated truck	Transport, freight, truck 16–32 metric ton, EURO5

Table 26-3: *Data selection for transport life cycle inventory.*

For the comparison of the systems, we use several electric mixes. The first electric mix used corresponds to the European electric mix without Switzerland: *market group for electricity, medium voltage | electricity, medium voltage | APOS, U – Europe without Switzerland.* This is the standard energy mix used for the isoperimetric comparison. Nevertheless, the centralized plant MTB located in Trept has chosen to be supplied exclusively with renewable energy. The corresponding electrical mix in the Ecoinvent data base is: *market for electricity, medium voltage, label-certified | electricity, medium voltage, label-certified | APOS, U – CH*. The electricity mix uses mostly hydroelectric sources from altitude dams. Further in the document the LCIA results using this specific electricity mix are marked green electricity. Modeling the tire shovel and the crane truck involve the following Ecoinvent data: *machine operation, diesel >= 74.57 kW, low load factor*.

For the two systems studied, we used the economic data in the Table 26-4 below.

Data	Value	Comments
Waste transport costs	2.85 €/km/truck	Average market value
Electricity price	0.085 €/kWh	French electricity data
Power Shovel (Diesel)	94 kW	Data from Manufacturer
Worker cost	50 €/h	Gross salary
Working days	250 days/year	Assumption

Table 26-4: *Shared economic values for the life cycle cost.*

Life Cycle Assessment Results

Life Cycle Cost and Environmental Impact Assessment Methodology

The life cycle modeling was done using OpenLCA V 1.5 software and Ecoinvent V3.3 database. The economic calculations were obtained from OpenLCA. Environmental impact assessment is done using ILCD Handbook recommendations (JRC - Institute for Environment and Sustainibility 2012). In OpenLCA ILCD 1.0.8 2016 Midpoint without long term was selected for the calculation. For environmental calculations, we only present results for the climate change indicator for this simplified environmental study. The impact factors selected from climate change is the 100-year IPCC baseline model (IPCC 2007). The environmental impact allocation is based on a mass allocation.

In our study, the LCC analysis only considering the costs of each system regardless the profit from recycled materials sales. The method used does not include the environmental costs of impacts (Office of Acquisition and Project Management 2014).

Recycling System Environmental Comparison

The results for the environmental LCA comparison are present on the Figure 26-3 using the climate change indicator (Global Warming Potential 100 years). The smelting recycling of aluminum is used as a reference for the characterization of the systems. The GWP of the primary aluminum (from mining) is added on Figure 26-3 to show the recycling environmental benefit.

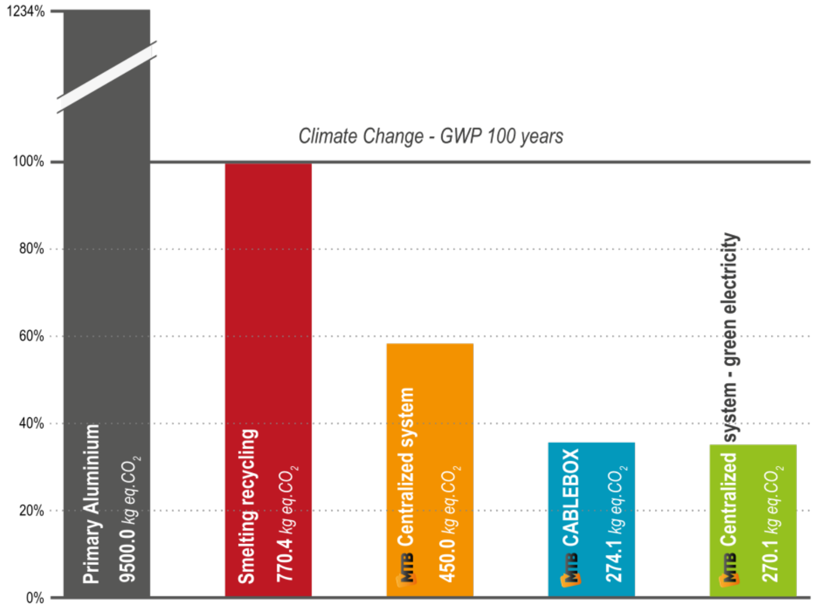

Figure 26-3: *Results of the environmental LCA system comparison on the climate change indicator (kg eq.CO_2).*

With the European electrical mix, the CABLEBOX system is far less impacted than the centralized system. The results for climate change are shown on the Figure 26-3. The environmental impact of the recycling system on climate change indicator is reduced by 60%. This hierarchy is similar on all the impact indicators of the ILCD methodology.

The process contribution was made for each system. In the case of the centralized system, using the European electricity power mix, the impacts of the recycling process is almost twice more impacting than the CABLEBOX system. However, the main difference is the contribution of transport, which is five times greater in centralized system. Nevertheless, the choice of a renewable electrical power mix makes it possible to compensate the upstream logistic impact. Thus, allows the centralized system to remain competitive from an environmental point of view.

The processes contribution for the CABLEBOX recycling system case shows that the electricity power required for the recycling process contributes to two thirds of the final climate change impact. Upstream logistics transport is the second-largest contributor. The CABLEBOX transit scenario represents 2% of the final climate change impact.

Life Cycle Costing Analysis Results

The Life Cycle Cost (LCC) calculation gives us the results present on Figure 26-4. In the column *CBR tonnage*, the values for centralized system of the waste collection, electricity consumption and working costs are given for the CABLEBOX annual tonnage (6,000 tonnes). This adaptation makes it possible to compare the results directly with the CABLEBOX system. Maintenance costs per tons are considered similar for both systems. We do not report operating costs for reasons of trade secrets.

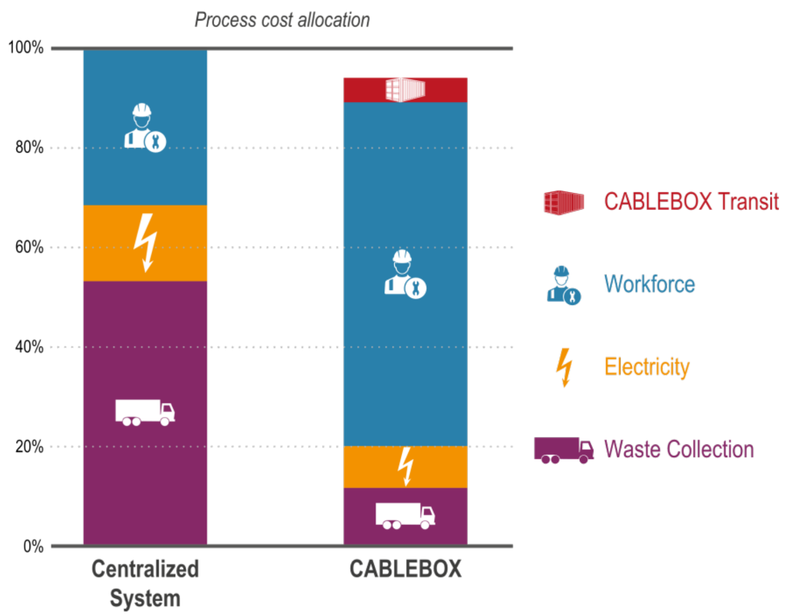

Figure 26-4: *Results of the life cycle costing systems comparison – relative values.*

Conclusion

CABLEBOX is the first integrated and transportable cable recycling solution. It is designed to be a system plug and run. This solution minimizes waste transport before recycling. Conversely, the flow rate is greatly reduced, and the process does not go as far in valorizations as a centralized system. While environmental gains are indisputable regardless of the electrical mix, the economic gains obtained remain low. We struggle with the difficulty of correlating environmental and economic benefits. Our approach reveals the difficulty of responding to the three pillars of sustainable development.

From an environmental perspective, the recycling by sector remains the most relevant. As already demonstrated for cables. Although product centric recycling solutions show good environmental performance results; they concern only specific products. We must work on the development of this approach in the coming years to ensure efficient and consistent resource use. On a case-by-case basis, solutions are possible, but the right technologies adapted to each product remain to be defined. Moreover, optimizing recycling pathway systems is long and demands powerful assessment tools such as Mass Flow Analysis (MFA), LCC and LCA (Peças et al. 2016). The first limit of this approach, results are obtained after entry into service of processes, the investment is already made. De facto, manufacturers are reluctant to improve efficiency (Hauschild 2015, Herrmann et al. 2015).

Therefore, it seems to be necessary to develop an effective methodology to evaluate and guide process design choices to ensure economic, environmental and social efficiency (Allwood 2014). Offer to designer an assessment tool will optimize the sustainable performance of pathways. Our team is focusing our research on this issue to offer recycling engineer tools to assess recycling pathways according to technical, economic and environmental performances.

Acknowledgments

The authors want to thank MTB Recycling and the French National Association for Technical Research (ANRT) for the funding of the PhD study (CIFRE Convention N° 2015/0226) of the first author.

27. Recycling Plastic and Marine Debris: What Can Be Done about Bottle Caps?

Richard Anthony ✉

Abstract

When will the weight of all fish in the ocean equal the weight of plastic discards in the ocean? These plastic discards in the water impacts birds and sea life around the world. Just as the canary in the coal mine forewarns of danger, the Laysan or Pacific Albatross provides a way to measure the impact of plastics in the ocean. Known as the sailor's companion, this once ubiquitous bird is threatened to extinction because of the unintended consequences of our discards that look like food but are not.

The cultural change needed to reverse this trend is to focus the public's attention to the unintended consequences of single use non-recyclable plastic packages, containers, and products. The plight of the Albatross due to the large amount of plastic debris washing up on Midway Atoll and the Northwest Hawaiian Islands is somewhat like an oil spill. The flow must be stopped, and the residual must be removed.

The Save the Albatross (albatrosscoalition.org) Campaign objective is to motivate identified producers to pay for plastic clean-up on Midway and other US Pacific Islands which are nesting areas for the Laysan and Black-footed Albatross. Bottle caps are one of the most frequent plastic items found in coastal clean ups. There is need to bring the producers these products and packages to the World table to draft Zero Waste responsibility plans for proper management of discarded plastic via redesign for recyclability, buy back purchasing opportunities (closed circle), and recovery campaigns for vagrant plastics on land and sea.

Keywords: Marine Debris, Plastic, Zero Waste, Albatross.

Introduction

The paper discusses the science and the campaign which includes legislative action to force the redesign to leash the lid, a law suit to fund the cleanup and a public education campaign that includes returning the caps found in costal clean-ups back to the producer. The Pacific Albatross roosts in the middle of the Pacific Ocean on islands of the Midway Atoll (Figure 27-1). This Bird is one of the largest and can fly around the artic circle without stopping. They dive for shrimp and krill.

Figure 27-1: *Albatross roosting at Midway Atoll (Photo by Jared Blumenfeld, World Traveler, albatrosscoaltion.org).*

Plastic in the Ocean

While marine debris data reports extensively on the quantity of plastic ending up in the ocean, there is No real data to characterize the quantity of specific plastic products that are ending up in the ocean. We don't know what are the most prevalent human made plastic products ending up in the ocean. What we do have is nearly 40 years' worth of International Coastal Cleanup Data (Table 27-1). Bottlecaps and lids are number five on the list of most often found items.

Top 10 items found	
Cigarettes/cigarette filters	2'117'931
Food wrappers/containers	1'140'222
Beverage bottles (plastic)	1'065'171
Bags (plastic)	1'019'902
Caps, lids	958'893
Cups, plates, forks, knives, spoons	692'767
Straws, stirrers	611'048
Beverage bottles (glass)	521'730
Beverage cans	339'875
Bags (paper)	298'332

Table 27-1: *Average composition of discards found at international coastal clean-ups (Gordon 2017).*

The Albatross sometime mistake plastic items in the ocean to be food. Figure 27-2 illustrates this phenomenon. A dead albatross is shown having the stomach filled with plastic items. Caps and lids meet the visual criteria from the air (Figure 27-3). As a result, the bird cannot pass these items and dies.

Figure 27-2: *Bottle caps in a dead Albatross (Photo by Jared Blumenfeld, World Traveler, albatrosscoaltion.org).*

Figure 27-3: *Bottle caps are found on most beach clean-up sorts (Captain Moore on a typical beach clean in California. Photo by Katie Allen Algalitia.org).*

Leash the Lid campaign is one small step in the list of strategies needed to fight the tsunami of plastics entering the ocean. Why is this important?

Because 70-80% of the trash in the oceans is plastic and most of it comes from land-based sources, like trash in urban runoff.

According to Worrell et al. (2017), solid waste resulting from the tsunami that washed ashore in Fukushima, Japan has been found on the west coast of the United States. E-waste has become a problem of global dimension as toxic waste are transported between different continents and an ecological treatment is not always guaranteed. Waste gyre's (vortex) exist in the ocean. A lot of plastic is entering the marine environment, conservative estimates range from 5- 8 million tons of plastic entering oceans each year. In 2010, 275 million metric tons of plastic waste were generated in 192 costal countries with 4.8 to 12.7 million tons entering the ocean. ''

As referenced in UNEP (2016), plastics enter the marine environment and subsequently degrade into smaller and smaller pieces. So the problem starts out as a macro-plastic issue, but as plastics accumulate and degrade from photo-degradation and wind and currents causing break-down, they become micro plastics. UNEP estimates there are nearly 51 trillion pieces of plastic debris in the world's oceans today.

Plastics are present throughout the water's surface, in the water column, and on the sea floor. They are present in all shapes and sizes (Figures 27-4 and 27-5). Therefore, they impact all kinds of marine life- 700 species documented. Including- the filter feeders, like jellyfish and mollusks and baleen whales, marine mammals fish and others that mistake them for food or become entangled in these Plastic discards.

On Jan. 31, 2017, researchers from the university begin dissecting a two-ton whale that was beached in shallow waters off Sotra, an island west of Bergen. The sperm whale found in Norway had plastic bags in its stomach (phys.org 2017).

Figure 27-4: *Plastic in the ocean (Gordon 2017*).

Figure 27-5: *Plastic bottle in the ocean (Gordon 2017*).

According to Wilcox and Hardesty (2015), seabirds are heavily impacted. 90% of all seabirds have ingested marine plastic. Figure 27-6 shows a seabird holding a plastic item. It gives an insight into the interaction between seabirds and plastics present in their environment.

Recent research provides a clue as to why seabirds are so heavily impacted. Turn out that petrels, shearwaters, and albatrosses who spend most of their lives gliding above the ocean, find their food by sniffing out a sulfur compound called dimethyl sulfide, or DMS. When krill and small fish munch on algae, DMS is released acting as a sort of scent alarm for the birds.

The smell triggers their instinct to forage on ocean animals near the surface. What the researchers found was that DMS-emitting algae grows on the bits of plastic debris, and through the course of natural wave movements, it is emitting and mimicking the scent birds seek out to identify food. Attracted by the smell, they eat the plastic.

While scientists are conservative and have a hard time proving how much plastic ingestion is contributing to seabird mortality, seabird populations declined by 67% from 1950 to 2010 (in 60 years). Plastic pollution is certainly a contributing factor.

Figure 27-6: *Impacts of plastic on seabirds: 90% of seabirds have ingested plastic; same foragers find their food by sniffing out dimethyl sulfide released by fish and krill munching on algae; when plastics accumulate algae, it acts as a food bell (Gordon 2017).*

Conclusions

The first step is to request the manufactures to leash the lid. The second step is to educate the public as to the problem. Proposed Assembly Bill (Stone) Leash the Lid requires the cap to be attached to the beverage or bottle (Figure 27-7). Legislation is part of the educational process.

Figure 27-7: *Components of proposed legislation, AB 319 (mark stone): requires caps attached to the bottle or beverage consumed without removing cap; goal: decrease the cap litter and increase recycling; bottle caps typically made from recyclable polypropylene (Gordon 2017).*

28. Smart Sensor Buoys - Scalable Solution for Continuous and Flexible Water Monitoring

Dennis Bakir ✉, Robin Bakir

Abstract

Within this paper an industry-driven insight to an environmental development project will be given. The approach offers the novel possibility to interconnect commercially available sensors to economic and high-performance floating platforms. Each platform of the meshed environmental monitoring system acts as weather- and animal-resistant housing and as logic connection regarding self-sufficient energy and data communication.

The buoys are uncommonly small in scale and emit a rather low level of electromagnetic emissions, to act widely unnoticeable once set up into the ecosystem. Furthermore, the buoys auto-negotiate among each other, store the acquired data and generated information autonomously internally and in a central database. Due to this, each user/operator may exchange the types of used sensors, the frequency of data acquisition or the operation mode of each participant of the wireless meshed network within regular operation.

Keywords: Industry-Driven Innovation, Smart Data, Ecology, Water Management, Industry 4.0.

Motivation

About 1.5% of the area of Germany is covered with fresh, inland water, which corresponds to a total surface of 5,182 km². Inland waters traditionally are classified into groundwater, spring water and surface water. These surface waters again are differentiated into running and stagnant waters, which include all rivers and lakes. As far as Germany is concerned there are about 2,292 single lakes, which will be focus of the ongoing industrial research project, described within this paper (European Environmental Agency 2016).
A considerable amount of fresh water is used for agricultural irrigation. As a direct result of this intensive usage, the quality of the used "excess" water decreases, because fertilizer and other types of eluviation of the agricultural area are transmitted into the groundwater. Much more dramatic than the natural/seasonal entry of additional biomass into inland waters (e.g. foliage) is the single-point entry of large quantities of waste, fertilizers, chemicals etc. by local occasions, such as accidents, leakages or illegal discharge. This local disposal of significant amounts of harmful substances and nutrients usually leads to a complete dying of the ecosystem in and around the directly contaminated waterbodies. However, to monitor for example just nitrate pollution of German groundwater (as a leading indicator to intensive agricultural use), more than 1.200 centre-gated sensor stations would be needed in Germany (European Environmental Agency 2016, European Commission 2016).
Measuring stations e.g. in the terms of sensor occupied buoys, are not widely used in the context of inland waters but as walk-on-able offshore solution. Especially regarding inconspicuous appearance and the level of interference of the ecosystem, previous mentioned solutions are not particularly suitable. Existing systems are based on voluminous platforms that record data via big sensor units at the point of data acquisition and store it in different systems. Although this may create a continuous data string, in a rather low frequency of data acquisition (measured as data point per hour), the created information is uncommonly available in real-time. So, reactions regarding local effects regarding specific concentrations or physical shifts can only be initiated with a quite huge offset of time. Furthermore, there exists no inexpensive and high-performance system that acquires and pre-processes measured data at various positions, in a high-frequency and energy-efficient ways, to output them to multivendor-capable clients through a server-based interface.

Scope of the project "Smart Sensor Buoy"

As the ideal carrier platform of the novel high-performance and high-compatibility logic board for data aggregation and communication, a rather unusual small buoy-type was elaborated, as shown in Figure 28-1. The functional main part of the installed technology is located below the water level, due to better stability, so only a small part is visible. With a height of about 300 mm and a maximum width of about 220 mm, the buoy is uncommonly compact. Energy cells are installed in the lower part, so the buoy can be operated autonomously for more than 6 months. For additional energy support there is a photovoltaic unit on the top. Different sensor interfaces offer the user-individual possibility to control up to 16 analogue and digital sensors simultaneously with each buoy.

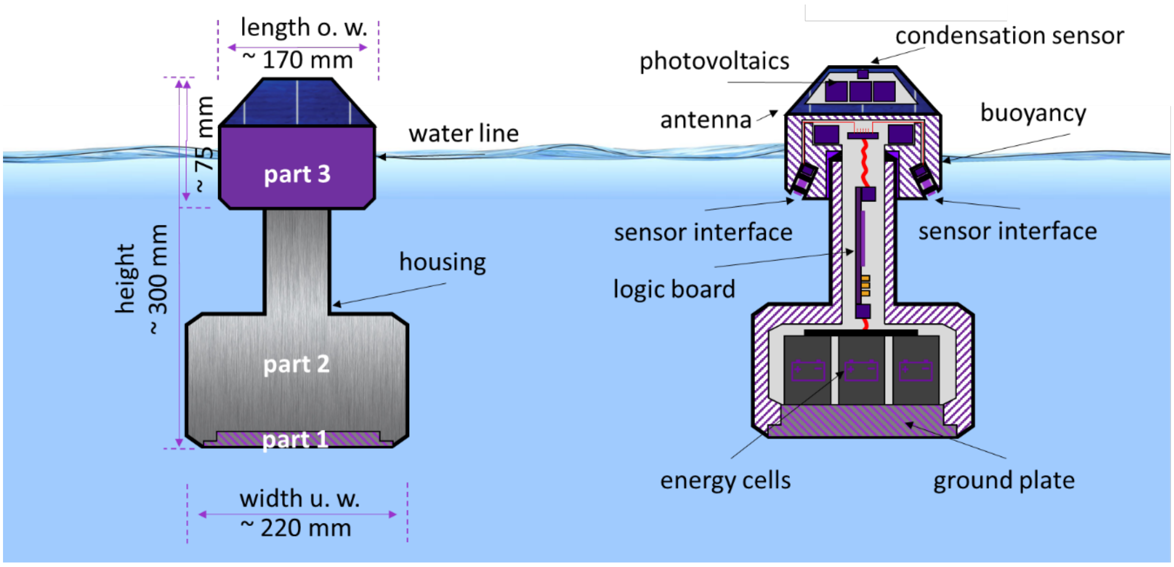

Figure 28-1: *Scheme of a smart sensor buoy.*

However, the core of the innovation is not just the development of a single floating sensor buoy, able to integrate commonly available sensors without additional hardware and software. More than this, the development based on a meshed network of very small-scaled smart buoys, which can implement various actions in a network and each agent operates in collaboration.

Every single floating platform is enabled by a specific radio transmitter to communicate with other platforms and to interact with them automatically. The function of data acquisition is mainly effectuated by usage of a unique time code, decentralized at the individual platforms and finally aggregated in a hub (buoy).

Smart sensor buoys are now able to be set up a decentralized and location-independent, as well as cost-effective monitoring-system and data collection network for the permanent recording of environmental parameters and to correlate a wide variety of sensor types (EIO 2016). As a result, effects in a low-maintenance and low-cost option for the unattended, qualitative and quantitative monitoring of inland waters.

Because of the directly pre-evaluation of influencing values within the measuring units, guidelines for action can also be generated, as well as water-polluting entry points can be identified immediately. The novel floating network of small buoys does not interfere visually or functional with the original usage of the waterbodies. Furthermore, emissions of the system are uniquely low, so the surrounding fauna will not get excessively interfered.

Development insights

Core of development was a scalable hardware-framework for the buoys themselves that may be used universally and adapted to different equipment types. Today there is a light-weight made of a functional >3-layer composite layout, that supports the inner structure of the buoy.

A size of 300 x 220 mm was realized and already confirms the possibility of further miniaturization.

Of course, there was the need to develop a buoyancy unit in order to set the buoy upright even in adverse conditions. Parallel to this it was decided to store the power-supply, as a rather heavy unit, in the bottom of the buoy. This causes a very low centre of gravity and supports the effectiveness of the buoyancy unit, necessitating additional buoyancy force.

On this base, beside the development of the logic-board itself, the second most important feature, the ultra-low-power mode of operation for each network participant, was developed. This secures a long-lasting time of operation of each buoy. The effective uptime within the applied scenario of validation excesses 6 months. To extend the time of operation, different operational modes were developed, considering various approaches. Due to the fact that each single buoy in the meshed network can be updated over-the-air, different scenarios of usage may be applied. This means that e.g. the acquisition of nitrate is much more energy demanding than the prevailing water temperature, air humidity or velocity of the current. In case of one/a few buoys slowly running out of energy they may measure last mentioned values and in a lower frequency, while other participants of the mesh negotiate among each other and take over the measuring duty of this buoys additionally. Remote located buoys then will be contacted via all buoys in reach, auxiliary act as repeater stations. Thus, the network can be enlarged almost without limits. In order to document the data each value will receive a unique time-stamp and be encrypted on a hard- and software level.

The development of the novel logic-board, responsible for all main functions and features, mentioned before was essential. As it hosts all I/O and components and accomplishes multifunctional operations and communications at the same time it was necessary to develop an own logic-board. Regarding the user individual attached sensors, a novel calculation and activation approach was needed to gather, save and analyse the data in an energy-efficient way and to transmit them into the mesh. Edge-Computing was another solution and has already been positively tested on the devices, with respect to the total power demand. When the controller is not in use it will be switched into a deep hibernation mode, requiring only a few nano-ampere of power. By this, the energy demand was minimized and at the same time the unit is available 24/7 and systems´ wake-up time is only at <10 µs.

In comparison with already available solutions of buoy-systems for environmental monitoring purposes the current undergoing will offer a small-in-size and economic solution even for online transmission and analyse the data on place. By that, the effect prediction is more accurate for a very low price, compared to the state-of-the-art technology (BMUB 2014).

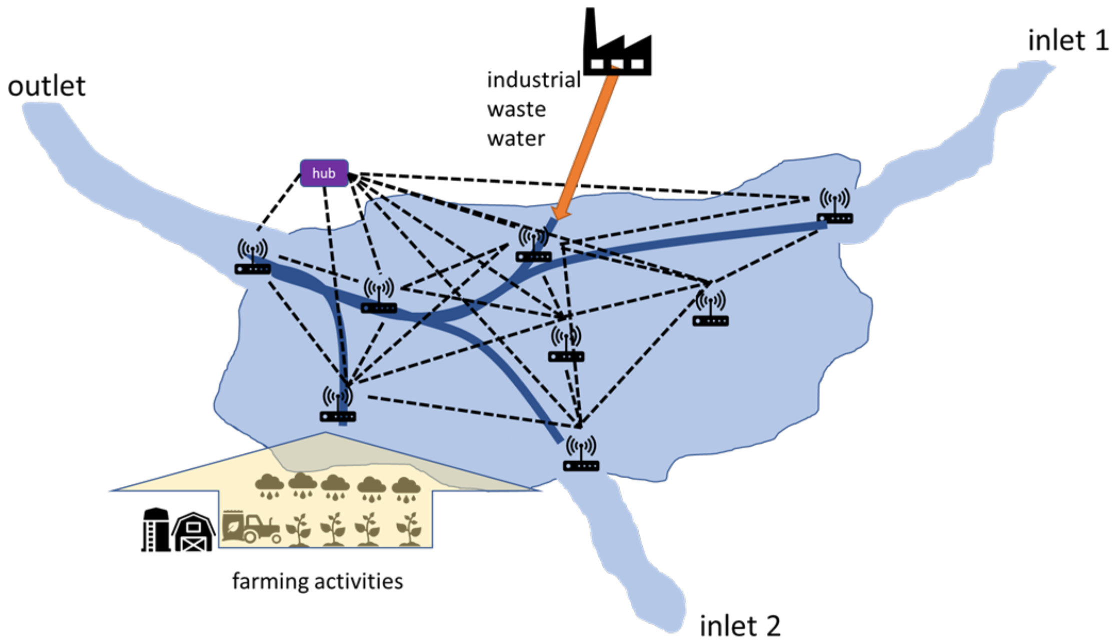

Figure 28-2: *Scheme of a meshed buoy network with nine participants.*

Conclusion and Outlook

Regarding latest development and information there is still the need for comprehensive systems to monitor especially public waterbodies on a regular and reliable basis. Different type of loads and seasonal occurrences have a strong impact on the water quality and cause long term effects, as recent studies reveal. Thus, a comprehensive predictive data-set shall be set up in order to adapt for example cleaning strategies in production and purification plants (Kreimeier 2013).

With the current state of development, an energy-efficient and small-sized hardware-prototype of the sensor buoy has been developed and validated. Further efforts need to be expended with respect to the data security and final transfer concept, as there is an additional strong demand regarding SME-allocable environmental interferences (DeStatis 2015).

Following this approach, the buoys will be roll-out to more waterbodies, used to gather a broader data base. In the following the data analysis and algorithms will be adapted as well as the communication concept to realise a location-sovereign connection of various sensors and buoys. Once fully tested in an aquatic surrounding the function of the buoys shall be fundamentally extended with an online pollutant tracing as well as agents, capturing air-pollution.

Acknowledgements

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29. Food Action: A Pilot Program for more Sustainable Food Habits

Carlos Oppe, Hans Van Thienen, Marilyn Mehlmann ✉

Abstract

Food is a critical global resource that impacts all 17 of the UN Sustainable Development Goals, and a huge contributor to both problems (climate, environment, health) and solutions. The Food Action project engaged 5 countries in developing and testing a program to enable consumers to contribute to solutions.

The project was deemed highly successful by the funders and could make a large and measureable contribution to sustainable development in affluent populations. It also revealed fruitful ground for further research and development, not least in the use of ICT to bring about lasting behaviour change.

Keywords: Food, Behaviour Change, Waste Reduction, SDGs, Climate.

Why food?

Food, the most basic of all natural resources, should nourish us (see Figure 29-1). Instead, it's killing us. No single action will reverse the picture; but the role of consumers is one critical factor (Garnett 2016).

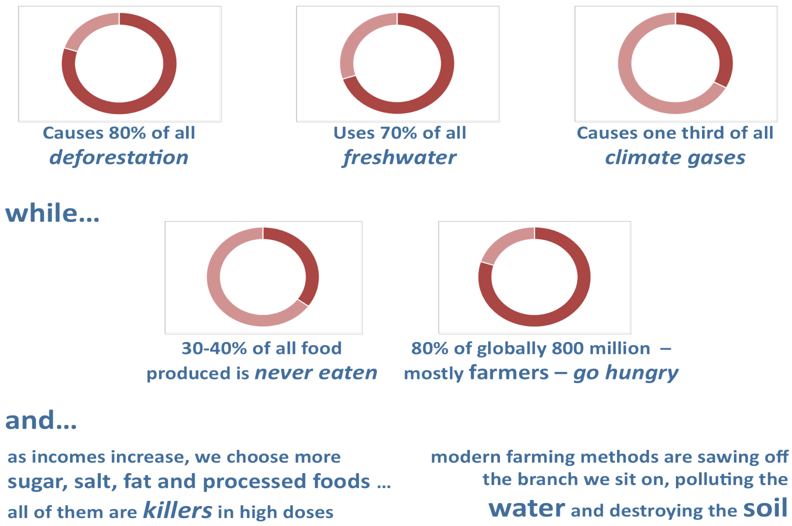

Figure 29-1: *The size of the global food production dilemma.*

Food also implicates all 17 of the UN's Sustainable Development Goals – the SDGs, already adopted by nearly 200 countries.

Objectives of the Food Action project

To enable consumers to contribute to a more sustainable food regime

- In a pilot project: 5 European countries, 6 languages, Erasmus+, 2 years 2015-2017
- Through a culturally-adapted action pack for adults/households
- Building on proven behaviour-change methods
- Incorporating and testing several innovations

Innovations

A. Include all 3 major aspects of sustainable food, i.e. waste, climate/environment, health.

B. Use proven methods, while experimenting to reduce the support needed for good results.

C. Test using IT solutions both to deliver the program and to market it.

A. Three topics presented in books/action packs

During the cultural adaptation process, all three topics were found to be relevant in all participating countries. There was some difference in the power of attraction of each topic, but the combination proved decisive. For instance, in Spain, 80% of participants joined the program because of their concern about environment or health - but the actions that they most favoured were those related to waste reduction.

For the developers, the challenge was to find meaningful actions, and indeed food recipes, that are beneficial or at least not detrimental to all three aspects of food sustainability; and to present them in a way that raises awareness of their interconnectedness.

Furthermore, the Food Action program is designed for long-term change of habitual behaviour. The criteria for action selection are thus different from those for a limited-term campaign. Emphasis is placed on low-threshold rather than high-impact actions, drawing participants into a process of self-examination that continues long past the end of program participation (Staats and Harland 1995).

B. Proven methods

A set of methods and models successfully used in previous programs for ‘sustainable lifestyle’ (Global Action Plan UK 2008) were brought together in the design of Food Action:

- Cultural/contextual adaptation of common materials
- Design of effective behaviour-change programs
- Empowering coaching
- Empowering writing
- Diffusion of innovations

The section ‘Methods’ below outlines how they were used in the Food Action program.

C. IT solution for delivery and marketing

Delivery via a web site has been demonstrated to work, AND can be much improved. In particular, it would be beneficial to develop an online support system that matches the personal ‘empowering coaching’ that is so effective in off-line delivery systems.

The experiment with social marketing was not successful. Despite high social media impact, actual sign-ups were very small in number. The importance of strategic alliances with international and national organizations has been demonstrated. In addition, more research is needed, combining the known principles of empowering behaviour change with, for instance, Social Presence principles.

Methods

Adaptation of common materials

The kick-off meeting for the project included a half-day workshop on the principles of cultural /contextual adaptation – a process that was subsequently used as the basis for planning.

The actual adaptation included research and experimentation, and took about one year. Finally, each program included around seven action suggestions for each of the three topics, reflected in the questionnaires to participants. Many were similar, but only a few identical.

Design of effective, sustainable behaviour-change programs

Action research over several decades has led to an effective set of principles for the design of empowering programs (Mehlmann and Pometun 2013). The principles build on a spiral (rather than linear) model of behaviour change that offers multiple intervention points for the program designer. The design principles are taught as part of the workshop on cultural adaptation.

Independent research shows that use of the methods, for instance in the Global Action Plan program ‘EcoTeam for sustainable lifestyle’, are both exceptionally strong and exceptionally long-lasting. Indeed, a year or more after the end of the EcoTeam program participants are found not only to have maintained their new, more sustainable lifestyle, but indeed to have continued to enhance it (Garnett 2016, Mehlmann and Klimchuk 2007).

Empowering coaching

The process of empowerment is in the first place the inner journey of an individual, a group or a community. Secondly, it can refer to externalities: factors or interventions that may facilitate, hinder, or indeed reverse the journey (Tengqvist 1996). Such interventions can be personal: a mentor, coach or other person or group can act in an empowering way. Principles for empowering coaching have been distilled from the same action research program as the principles for program design (above).

The principles are well understood when it comes to personal interventions. For instance, experiments in Sweden (in the 1990s) showed a dramatic increase in completion and in reporting when they were introduced, compared to methods normally used by experienced study-circle facilitators. Measured and estimated behaviour change also improved, including when verified by independent researchers. The Food Action project included on-line training for national coach trainers, which received a satisfactory evaluation (EU Erasmus+ fund 2017). What is less well understood is how similar results can be obtained through on-line support.

Empowering writing

Action research has also led to formulating principles for writing text in a style that is most likely to lead to action on the part of the reader. An on-line interactive course of 14 lessons on ‘empowering writing’ was delivered to the national program development teams.

Diffusion of innovations; early adopters

How new behaviour spreads through a population is much researched, and often referred to as ‘diffusion of innovations’ (AtKisson 2017). From this research has emerged, among other things, the concept of the ‘change agent’. By engaging with this process, a program can be designed to shift norms with a minimum of effort. At the heart of the design strategy is the concept of using change agents to engage so-called ‘early adopters’.

The Food Action pilot project therefore aimed to recruit a small number of early adopters as the basis for testing the program. The recruiting strategy was successful. For instance: in Hungary three-quarters of the participants were already part of a community- supported agriculture (CSA) group; the Italian responses to the pre-program postulates: “I know the meaning of the different date labels” and “I know the rules of composting in my community” both elicited a response rate of 73%. In the German survey, the response to the same postulates was over 90%.

Monitoring, evaluation, findings

The project included a strong component of monitoring and evaluation, embodied i.a. in

- The 'before and after' questionnaires /surveys that were a component in each language
- A few carefully-selected requests to participants to measure their changes (see Key Findings 1, below)
- Selective surveys, for instance of those attending national coach training
- Peer review of the emerging books/action packs

Systematic learning from experience through use of the *Learning for Change* methodology (Benaim and Mehlmann 2013).

Key findings 1

Adoption of new food habits

Including decreased meat eating -

- Hungary: "I make one day a week (at least) meat-free." 50% responded 'yes' before they participated in the program. Still, 32% of the remaining participants reported decreased meat eating after the program.
- Hungary: "I eat healthy sweets and snacks (nuts, seeds, dried fruit)." Nearly 40% of the respondents switched to healthier snacks after the program.
- Germany: "I drink tap water." Many already did so before the program, though 17% never did. After the program, all participants were drinking tap water half the time or more; 25% of the respondents changed their behaviour.

Reduction of food waste and food miles

The overall reduction was 10-15 %.

- Overall: participants using leftovers increased from 73% to 92%
- Overall: "I make a shopping list (& stick to it)." 23% showed an increase.
- Italy: "I grow at least one food item at home." Before the program 45% said yes; after, 83%
- Hungary: "I shop at a farmers' market or buy directly from the farmer." 40% of the participants bought locally produced food more frequently after the program.

Previous experience

These findings are in line with the outcomes of other 'sustainable lifestyle' programs delivered to several million people worldwide. The latter also show:

- New habits persist and are augmented over time
- Each participant influences 7-8 more people (Garnett 2016)

As recruiting progresses from 'early adopters' to 'early majority', gains increase; for instance, in several countries, average decreases in production of solid waste of 30% by volume or 50% by weight have been recorded, not least due to composting.

Key findings 2

Measuring

Measurements and surveys are integral to empowerment programs. In this program the measuring of food waste was significant - one participant referred to it as 'a revelation'.

Since the effects are long-lasting, it should be possible to convert the outcomes to CO_2e per annum, and to extrapolate the results: for example, to calculate how such lifestyle changes would impact the climate if 12% or 50% (early adopters and early majority) were engaged. In particular, reduced meat consumption, reduced food waste, and reduced 'food miles' are susceptible to such calculations.

Engagement and prospects

Nearly all engaged during the project, from participants to coaches to the national project teams, say they want to continue. Many say they would like to actively engage more people – to recruit friends and families. Others are interested in engaging young people.

The pilot project shows extremely promising results, and the level of engagement indicates big scope for continuing and expanding the program. Organizations from four other countries have already expressed interest in conducting their own adaptation process. It is not yet clear how scaling up will be organized or funded (see below).

Anticipated long-term effects

Behaviour change brought about using the empowerment models on which Food Action builds can be expected to persist and indeed intensify over time, as evidenced by independent research concerning other, similar programs; eg a longitudinal study by Leiden University. See Staats and Harland 1995 and *Design of effective, sustainable behaviour-change programs* above. The research also showed that each person engaged in the program influenced 7-8 other people to modify their behaviour in the same direction.

Conclusions and challenges

The project was highly successful as a pilot program, nominated by the major funder as an outstanding example. The challenges in scaling this initiative to a level that makes a substantial contribution to food sustainability are of several kinds: there is a need for more research and development; and there are organizational and financial questions to be answered.

- Develop /adapt leading-edge IT delivery platform
- Research, test and apply effective ways to recruit and support participants also on-line; connect to research on gamification, to develop and test additional design principles
- Develop 'marketable' behaviour-change packages; build long-term local, national and international alliances
- Explore potential for similar programs at community/multi-stakeholder level

IT delivery platform

There is scope for a new tool for the many organizations now aspiring to bring about long-term behaviour change, with the internet being a primary delivery mechanism. We envisage a platform that would enable a program developer without prior expertise in either computing or on-line program design to

- Define roles and rules that determine participants' learning journey
- Refine a list of desired behaviour changes, weighted for difficulty and scored
- Describe each desired change in language most likely to lead to action
- Create before-and-after surveys
- Define a small number of measurables, and create on-line reporting mechanisms
- Enable and support development of on-line 'change-maker communities'
- Garner regular statistics, including impact of the programs
- Launch programs and recruit participants

Recruit and support participants

Recruiting and supporting face-to-face programs, for instance evening classes, is a well-known process. A key element is the forming of strategic alliances to enable rapid dissemination.

For internet-based programs a platform such as that described above needs to bring together the latest research concerning not only program design principles but also conversion of interest into active participation, creation of on-line peer-to-peer communities, and on-line support either on demand or triggered by predetermined indicators. This research is still scattered. Some is to be found in social marketing, some in education, some in gamification/game design; and there are probably important gaps.

Develop market packages

The potential of a Food Action or similar 'sustainable lifestyle' program depends not least on how it can be transformed into a high-value service for which there are many potential clients: for instance, businesses and local authorities with a mission to influence employees, customers and residents to adopt more sustainable daily habits. This in turn depends partly upon the potential for internalizing costs that are currently externalized, and moving towards a circular food economy.

Once the packages are established, dissemination is likely to be faster if undertaken not by the initiating organization alone but through a network of alliances at all levels and in different sectors. It could be useful to have an archive of different contractual arrangements, for instance franchising.

Community/multi-stakeholder programs

The Food Action program started as one 'leg' of an envisaged community engagement initiative, the Food-Wise Community program. The design is based on principles of Collaborative Learning: a simple but effective stakeholder engagement process enabling a community to relatively quickly establish a vision, platform, and program for a more sustainable community food regime. We believe there is still scope for bringing the original idea to fruition. It is a question not of research but of development building on existing competence and skills.

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