Dynamic Business Modeling for Sustainability: Exploring a System Dynamics Perspective to Integrate Social Lifecycle Sustainability Assessment

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***Abstract*—In the last decade, both sustainability (Green & Blue Economies) and business models for sustainability (BMfS) have increased in importance. Social life cycle sustainability assessment has not fully achieved goal, mainly because sustainability-oriented business is very complex and dynamic. System Dynamics (SD) is a powerful methodology and computer simulation modeling technique for framing, understanding and discussing complex issues and problems. This paper responds to the urgent need for a new business model by presenting a concept for dynamic business modeling for sustainability using system dynamics. The paper illustrates the key operating principles through an application from the smartphone industry with help from STELLA® software for simulation. Simulations suggest that dynamic business modeling for sustainability may contribute to sustainable business model research and practice by introducing a systemic design tool that frames environmental, social, and economic drivers of value generation into a dynamic business model causal feedback structure, therefore overcoming shortcomings of current business models when applied to complex systems.**

Keywords— business models design; business models for sustainability; system dynamics modeling; sustainability; social lifecycle sustainability assessment .

I. INTRODUCTION

In the last decade, both sustainability (Green & Blue Economies) and business models for sustainability (BMfS) have gained increasing attraction worldwide. Research streams are multiplying (e.g., Business Model (BM) ontology, Business model design (BMD), BM innovation, circular BMs, etc.) as testified by the growing number of contributions appearing in scientific journal special issues, dedicated conferences, workshops, as well as international academic networks [1]. Researchers addressed topics such as how to make a supply chain sustainable and how to use system dynamics methods to analyze sustainability issues in the smartphone lifecycle.

A. Sustainability issues in the smartphone lifecycle

Figure 1 shows issues in the smartphone lifecycle, which are provided by J. Zufall et al. [2].

Life cycle	Resource extraction and manufacturing	Distribution and network operations	Usage	End-of-life
Sustainability issues	Hazardous or conflict minerals extracted for smartphones (Fitzpatrick et al., 2015; Wu, Chan, Middendorf, Gu, & Zhong, 2008); poor working conditions: harmful practices of mining, extraction and processing (Wilhelm, Hutchins, Mars, & Benoit-Norris, 2015); low living wages, long working hours (Wernink & Strahl, 2015); energy and resource intensive manufacturing processes (Li, Ortiz, Kuczenski, Franklin, & Chong, 2012)	Freight and transport emissions (Moberg et al., 2014); locked-in business models at the point of sales (Boons & Lüdeke-Freund, 2013)	Short use phase varies between 12 month to 3 years on average (Suckling & Lee, 2015); behavior acts as barrier for return, reuse and recycling (Welfens, Nordmann, & Seibt, 2016)	Informal recycling sector for valuable materials, environmental pollution and health problems caused by toxic materials in e-waste (Bridgens et al., 2017; Panambunan-Ferse & Breiter, 2013)

Figure 1. Sustainability issues in the smartphone lifecycle.

They also identified seven sustainable business model patterns to cover different life cycle phases [3]. This paper focuses on the first pattern, "Sustainable Resource Company," during the "Resource Extraction" and "End-of-Life" phases (see the red labeling in Figure 2. High resolution figure can be viewed in Appendix I). Social sustainability issues like child labor, poor working conditions, low living wages, pollution, and health problems caused by toxic materials in e-waste occur mainly in these two phases. Our study applied system dynamics methods with simulation software to determine how a solution applied to a complex system would impact environmental, social and economic aspects.

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Life cycle phases and sustainability issues ► / SBM patterns ▼	Resource extraction and processing: Illicit operations / conflict minerals	Resource extraction and processing: Poor working conditions	Resource extraction and processing: Environmental degradation	Design and manufacturing: Energy/resource intensive manufacturing	Design and manufacturing: Poor working conditions	Design and manufacturing: Exposure to toxic substances	Design and manufacturing: Poor product design choices	Distribution and network provision: Transport emissions	Distribution and network provision: Fast replacement business model	Usage: Short lifetime	Usage: Electricity consumption	Usage: Stockpiling of functional devices	End-of-life: Stockpiling of defect devices	End-of-life: Illicitly imported electronic waste	End-of-life: Informal recycling	End-of-life: Poor working conditions	End-of-life: Toxic substances / lost materials
Sustainable resource company	X	X	X												X		X
Sustainable manufacturer				X	X	X	X	X	X	X	X	X	X	X	X		X
Sufficiency-advocating network provider								X	X	X	X						
Usage-extending distributor								X		X	X	X	X	X	X		X
Refurbishing & repair gap-exploiter										X	X	X					
Refurbishing & WEEE service provider										X	X	X	X	X	X		X
WEEE service provider													X	X	X	X	X

SBM: sustainable Bussiness Model
X: Focus of my Research

Figure 2. Lifecycle sustainable issues along smartphone lifecycle and the research focus

B. System Boundaries

Life cycle sustainability assessment refers to the evaluation of all environmental, social, and economic impacts in a decision-making process according to the sustainability of products throughout their life cycles [4]. Although it involves several aspects including environmental and economic, our study focuses on social impacts. The system boundaries we used are presented in Figure 3. This research focuses on three categories: sustainability, environment and social. The environmental part is divided into two subcategories - upcycling and recycling. Upcycling focuses on the evaluation of smartphone function prolongation, and recycling focuses on reducing the environmental impact of smartphone disposal by recycling its parts. The social category focuses on social issues created by resource extraction and the manufacturing process [5].

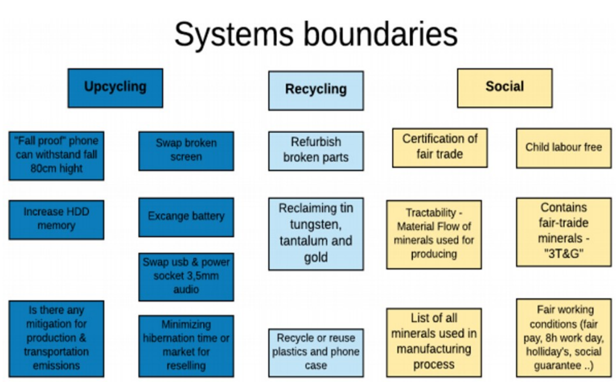

Figure 3. System boundaries of this research

C. Stakeholder -influence matrix

In August 2019, the Business Roundtable released its new stakeholder model of the revised purpose of the corporation, stating explicitly that businesses exist to serve multiple stakeholders—including shareholders, customers, employees, communities, the environment, and suppliers.

The stakeholder model represents an emerging model for the *strategic* vision of a company. Environmental, Social, and Governance (ESG) metrics can be used to measure company performance and its relative positioning on a range of topics relevant to the broader set of company stakeholders in the same way that financial metrics assess company performance for shareholders. This paper addresses at a "conceptual" level the key questions and guidelines for assessing a company's *readiness* for - and potential approach to - implementing ESG metrics and goals in executive incentive programs [6].

Figure 4 provides Pay Governance's generalized perspective on the alignment between ESG initiatives and stakeholders. The matrix below is illustrative and is not exhaustive of all ESG metrics and stakeholder impacts.

Class	Category	Example Subcategories	Employees	Community
Environment	Carbon and Climate	• Energy and fuel efficiency • GHG emissions • Technology and opportunity (investments)		✔
	Natural Resources	• Water (use and pollution) • Land, forests, biodiversity (use and pollution) • Sustainable sourcing		✔
	Waste and Toxicity	• Hazardous and non-hazardous waste • Emissions and spills • Electronic waste • Packaging material	✔	✔
	Management of Environmental Risk	• Disaster planning, response and resiliency • LEED design and certification	✔	✔
Social	Human Rights	• Ethical sourcing • Supply chain standards	✔	✔
	Labor, Health, and Safety	• Fair wages, benefits, training and development • Labor standards, job stability, and mobility • Employee engagement	✔	✔
	Diversity and Inclusion	• Equal opportunity and participation	✔	✔
	Product Safety, Quality, and Brand	• Customer satisfaction • Affordability and accessibility	✔	✔
	Community Engagement / Partnerships	• Volunteer hours • Workforce/community demographic parity • Alliances with key organizations, councils, and institutions • Corporate philanthropy	✔	✔
	Board Composition	• Minority representation • Gender equality	✔	✔
		• Anti-corruption • Cybersecurity and data privacy		

Figure 4. ESG metrics and stakeholder impacts

Figure 5 shows the Stakeholder Influence Matrix derived from a survey in 2021 and interviews with stakeholders from electronic companies including Siemens, Huawei, and Samsung.

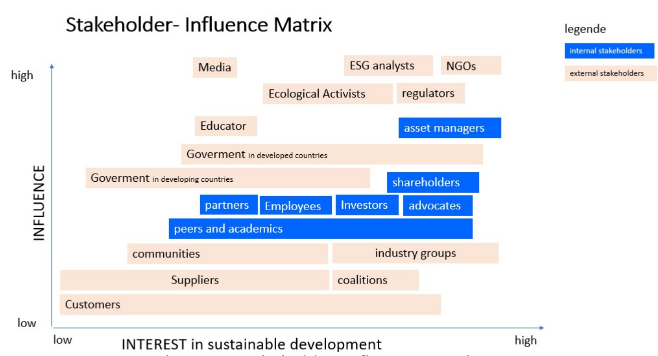

Figure 5. Stakeholder Influence Matrix

The remainder of this paper is organized as follows. Next, we describe the system dynamics method and software. Section III presents the dynamic business modeling framework. Section IV discusses the case study with the smartphone life cycle. The last section on modeling STELLA® simulation software concludes with

- Modeling with simulation software STELLA®

- Dynamic business modeling framework
- Case study with smartphone

II. SYSTEM DYNAMICS METHOD AND SOFTWARE

System Dynamics (SD) is a methodology for analyzing complex systems and problems over time with the aid of computer simulation software [7]. It handles complex systems in different domains. SD steps include making a loop diagram, connecting the variables, and documenting the relationships among them (direct or inverse). SD can improve communication and identify interactions among different related components in a system that enhances decision making policies in different scenarios. The modelled systems could be socio-economic, financial, climatic, or physical. System Dynamics models consist of only a few basic types of variables which are used to construct stock and flow diagrams with feedback loops and delays [8].

Table I lists software tools for simulation [9]. Dynamo was a breakthrough and foreshadowed several numerical modeling approaches and non-procedural programming languages [10]. It was a text-based system for representing model equations and continued to be used for multiple decades. Current software for System dynamics is diagram-based, but equations are still part of the model and retain forms quite similar to those of Dynamo.

Other modeling products include Anylogic, Goldsim, Berkely Madonna, Sysdea, and SimGua. Vensim, Insight Maker, and StatSim are free for education and personal use.

TABLE I. SYSTEM DYNAMICS MODELING SOFTWARE

DYNAMO	No longer distributed commercially.
iThink ® and STELLA®	Two names for one model development platform published by **iSEE™** systems. STELLA® (Systems Thinking, Experimental Learning Laboratory with Animation) is available in different configurations under commercial and academic licenses for Windows and Macintosh.
Powersim Studio	Available in a number of different configurations from Powersim Software. This Windows software is available under commercial and educational licenses and comes in a free version. It allows publishing standalone models.
VenSim®	Available in a number of different configurations from Ventana Systems, Inc. Licenses are available for commercial use, funded research, and academic use. It runs on Windows and the Macintosh.

Both STELLA® and Powersim Studio support system dynamics; build graphical diagrams using stocks and flow, including delays and feedback for non-linear models; support units, multi-dimensions running scenario simulations and Monte Carlo simulations. STELLA® also supports JavaScript and has discrete event modeling with some agent-based capabilities. The drag-and-drop user interface builder in the Architect version allows simulations to be published online. It handles multilevel hierarchical models, reusable modules, multidimensional arrays, optimization, and Monte Carlo analysis [11].

STELLA®, also marketed as iThink®, is a visual programming language for system dynamics modeling introduced by Barry Richmond in 1985. The program distributed by **iSEE™** systems allows users to run models created as graphical representations of a system using four fundamental building blocks. STELLA® has been used in academia as a teaching tool and has been utilized in a variety of research and business applications. The program has received positive reviews, particularly for its ease of use and low cost.

Our research used STELLA® Architect (Version 2.1.x).

III. DYNAMIC BUSINESS MODELING FRAMEWORK

Cosenz et al. proposed a dynamic business modeling for sustainability approach that combines an adapted sustainable business model canvas and system dynamics modeling. They also reviewed the state of the art in Design Business Modeling for Sustainability (DBMfS) design tools [1].

Building on this comprehensive literature review, the paper proposes and illustrates the DBMfS approach as a lean systemic method to model and explore sustainable value creation processes. Then, following a qualitative perspective, the approach is tested empirically. Figure 6 shows the research approach.

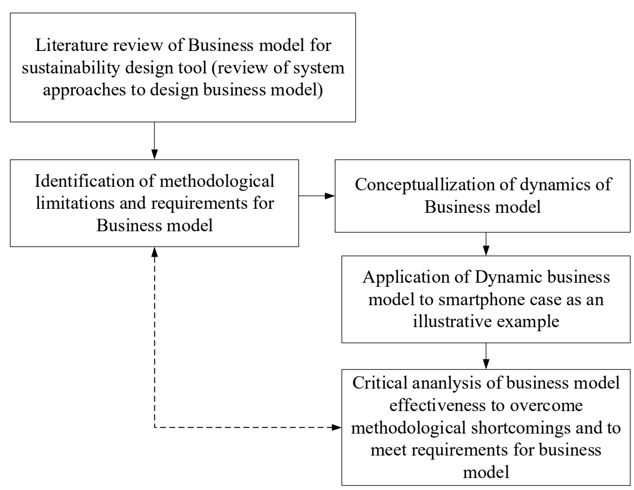

Figure 6. Research Approach Using Design Business Modeling for Sustainability

A case study may help evaluate a modeling approach. In our research, it could help determine how to frame BMfS elements within a systemic structure [1]. Figure 7 (high resolution figure can be viewed in Appendix II) displays an application of DBMfS to cobalt usage in a smartphone lifecycle.

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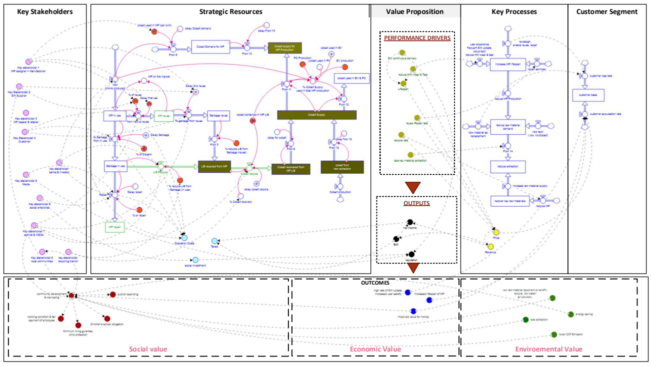

Figure 7. Dynamic business modeling for sustainability applied to Cobalt usage in a Smartphone lifecycle
EBIT, earning before interest and taxes; NGO, nongovernmental organization.

DBMfS elements outline how an organization operates in achieving both sustainability and viability goals. They are (a) Key Stakeholders, (b) strategic resources, (c) value proposition, (d) key processes, (e) customer segments, (e) cost structure, and (f) revenue streams [1].

IV. CASE STUDY WITH SMARTPHONE

A. *Selecting a case study*

Smartphone has been chosen as case study for this research because of its ubiquity and the global cooperation involved in many types of products.

A huge part of the world population uses smartphones.

- 7.9 billion people by 2020
- 6 billion smartphones end of 2020
- In average 1.5 billion new smartphones produced per year
- 36 smartphones are produced per second, which exceeds the human birth rate

A typical smartphone lifecycle includes the following:

- Mine/Mine Traders#, Smelters/Refinery in DRC#
- Design, development, marketing, and creation of software in USA.
- Mixed-signal chips (such as NFC): NXP from Netherlands; accelerometer from Bosch in Germany, Gyroscope from Italy/France
- Smelters/Refinery in China and
- Batteries** & Flash memory from Korea
- Display/Camera and eCompass from Japan
- Touch ID Sensor and DRAM mostly from Taiwan
- Plastic Construction in Singapore
- Assembly in China#
- Disposal/Dismantle/*Recycle*## done mostly in Africa and China

Figure 8 presents the globalization of a typical smartphone (high resolution figure can be viewed in Appendix III).

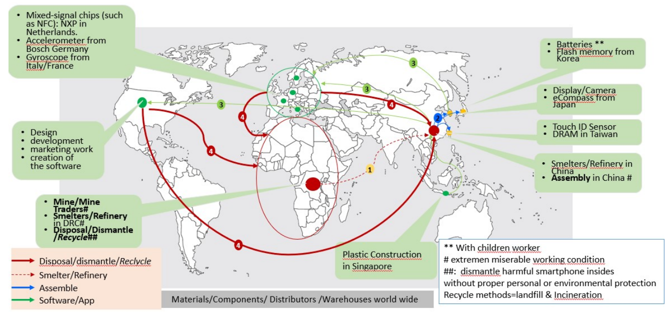

Figure 8. Material Life Cycle of smart Phone

Child labor might be hidden in the smartphone's supply chain [12], e.g., in Resource extraction and process, or End-of-Life phase.

Recently, many have expressed concerns about smartphone issues such as adverse impact on the environment from pollution in manufacturing and failure to recycle. The industry pays workers poorly, provides unhealthy working conditions, and employs children.

Figure 9 shows that smartphone manufacturers use deadly chemicals and up to 46 precious materials, like tin, tantalum, tungsten, Gold (3TG) and cobalt [13].

Figure 9. Application of Tantalum, Molybdenum and other metals in Mobile Phones

In 2020, smartphones averaged 8 grams of cobalt vs. 28 grams in a laptop, and 6803 grams in an Electric Vehicle (EV). **Statista**, the global Business Data Platform, reported 1.38 smartphones sold to end users worldwide in 2020 and projected 1.53 billion by 2021. 222.5 million laptops were shipped in 2020, and 276.8 million are expected in 2021. EVs numbered 6.0 million at the end of 2020. The total amount of cobalt used in smartphone is about 11250 tons vs. 62967 tons in laptops and 40800 tons in EVs. Table II summaries the total cobalt usage by the end of 2020 in different electric devices.

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TABLE II. COBALT USAGE IN ELECTRONICS BY END OF 2020

Smartphone	Laptop	electric vehicle
7.5 gramms of cobalt per unit	1 ounce (28.3 grams) of cobalt per unit	15 lbs (6.8 kg) of cobalt per unit
1.5 billion sold	222.5 million sold	6.0 million sold
11250 tonnes total cobalt used	6296.8 tonnes total cobalt used	40800 tonnes total cobalt used

Cobalt is a metal that occurs naturally in rocks, water, plants, and animals. Cobalt is less toxic than many other metals. At low levels, it is beneficial to human health and is a component of vitamin B12. But it is dangerous in high doses. Health risks depend on the amount and duration of exposure. The Centers for Disease Control and Prevention in the US warns that chronic exposure can cause “hard metal disease” and even skin contact with cobalt salts or hard metals can result in rashes. They say the safe workweek limit is 0.1 milligrams per cubic meters.

Cobalt is used in alloys, semiconductors, fertilizer, as a drying agent for varnish and enamel coating for steel. In the form of cobalt sulphate, it is particularly important in lithium batteries, where it acts as a cathode stabilizer. Lithium-ion batteries are increasingly in demand for electric cars, laptops and mobile phones, which means cobalt – once deemed a worthless chemical – is now the object of rivalry between the world’s biggest economies. A study from Kosiorek and Wyszkowski [14], shows that global production had increased more than sevenfold between 2008 and 2015 with an increasingly evident impact. “The appearance of cobalt levels exceeding environmental threshold levels has led to disturbances in the proper functioning of living organisms,” the paper concluded.

Amnesty International says human rights abuses, including the use of child labor, in the extraction of minerals, like cobalt, used to make the batteries that power electric vehicles, are undermining ethical claims about the cars.

The environmental impact extends through the lifecycle of the product from refineries, battery plants, consumers goods manufacturers, electronic recycling facilities and waste dumps. Among the most affected are workers at poorly regulated mines [15]. This has allegedly reached alarming levels in the Congo, As it is the largest cobalt mining country globally, this country is also by far the largest producer of cobalt intermediates. They produced 87.7kt Cobalt contained in intermediates in 2020, accounting for 68% of the global supply [1].

V. MODELING WITH SIMULATION SOFTWARE STELLA®

A. *Identify paramters*

Cobalt issues are paramount. e.g., reduce cobalt extraction while satisfying the increasing demand for cobalt in Lithium-ion batteries.

1) Reduce cobalt extraction from mines

2) Increase cobalt recovery from spent cemented carbide

3) Increase cobalt recovery from spent Lithium-Ion smartphone batteries using liquid–liquid extraction

a) Increasing recovery of cobalt from smartphone Lithium-Ion Batteries is one way to reduce cobalt extraction from mines.

4) Extend cobalt usage cycle by extending smartphone lifespan

b) Increasing the 25% smartphone recycle rate or extending the 2.5-year smartphone lifespan can also reduce the demand on new cobalt, especially cobalt extracted from mines.

c) The lifespan may be extended by (i) repairing smartphones instead of discarding them (e.g., change the battery or screen) (ii) increasing usage of second-hand phones. (iii) more frequently updating software to improve smartphone performance, thereby reducing demand for new phones.

5) Low-cobalt or cobalt-free battery design

Figure 10 shows a simplified STELLA® model with the above parameters that simulates cobalt usage in a smartphone (high resolution figure can be viewed in Appendix IV).

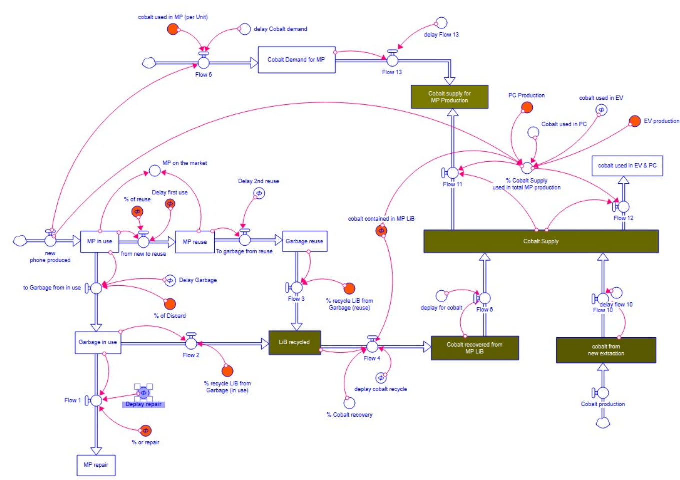

Figure 10. STELLA® Model for simulation of cobalt usage in smartphone.

EV: electric Vehicle
MP: Mobile Phone
Li.B.: Lithium Battery
PC: Personal Computer

B. *Calibration of model*

The model was calibrated step by step, parameter by parameter using real data.

Parameter 1: Reuse (smartphone)
Parameter 2: Delay of Reuse (smartphone)
Parameter 3: Discard (smartphone)
Parameter 4: Recovery Li.B. from discarded phone

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Parameter 5: Recovery cobalt from Li.B.
Parameter 6: Cobalt-free battery
Parameter 7: Production of e-Vehicles
Parameter 8: Production of PC (including Desktop, Notebook, Ultra-Portable personal computers)
…

Since it is almost impossible to get real data without company support, we used statistical data.

The goal of this model is to show the possible measures, which can be taken to reduce the raw material extraction in certain period, then indirectly solve the related social issues like child labor, unfair Payment, worse working condition, etc.

- Cobalt it taken as one example of relevant raw material because it comes from mines in areas with severe social problems.
- The typical and reasonable time span for long-term projects is 10 ~20 years.
- The measurements are those parameters for the model defined above.

The lowest target is to keep the current cobalt extraction amount (considering of the increasing demand on e-Vehicles and smartphones).

Figures 11-13 show the calibration result of the model. For example, Figure 11 illustrates graphically the Model calibration concerning mobile phone reuse/repair & discard. By calibrating Parameter 1 (Reuse), Parameter 2 (Delay of Reuse.) and Parameter 3 (Discard), increasing the rate of Reuse/Repair for Mobile Phone, extending the lifespan of Mobile Phone (increase the delay of reuse), reducing the rate of discard (see the line for "MP in use") will reduce first then stay steady. More mobile phones are reused phone (see the line for "MP Reuse"). The total number of phones on the market stays steady too, assuming the population is unchanged. The more phones are reused, the part of garbage caused by reused phone increase too.

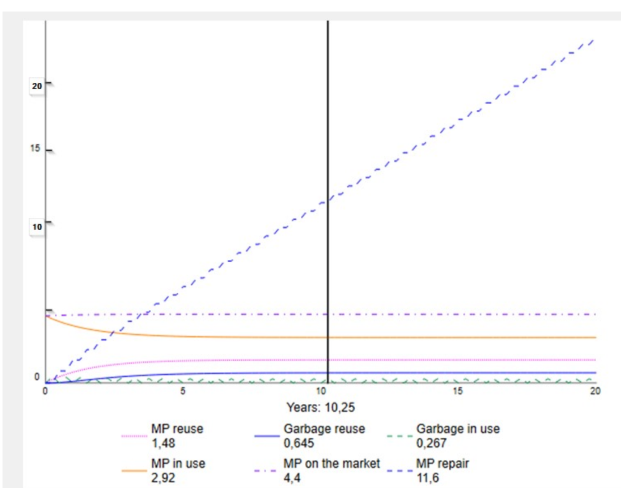

Figure 11. Model Calibration for Mobile Phone Reuse, Repair, Discard

Figure 12 illustrates the Model Calibration concerning Cobalt Supply and Demand. The X (horizontal) axis is the time axis, the Y (the vertical) axis is the unit axis, with measurement unit in Tons. By calibrating Parameter 4 (Recovery Li.B. from discarded phone) & Parameter 5 (Recovery cobalt from Li.B.), increasing the rate of recovery Lithium battery from Mobile Phone, and rate of cobalt recovery from lithium battery, the cobalt supply for Mobile Phone production increases too. Assume the demand on Cobalt keeps steady, then less cobalt would be extracted from mines. (see the vertical black line, shown in Figure 12, to the year of 8).

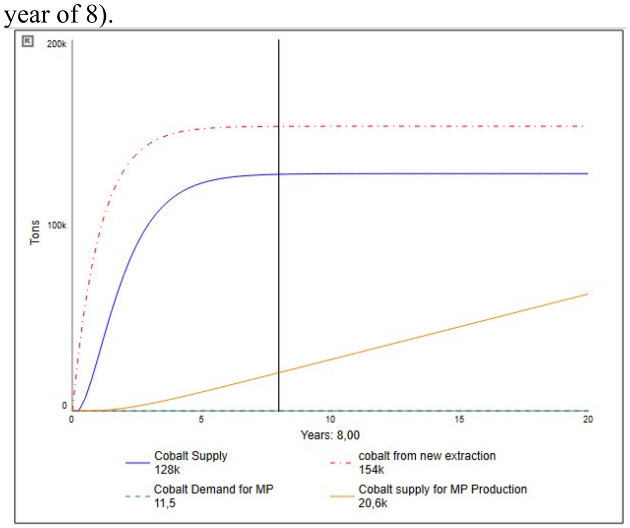

Figure 12. Graphic illustration of Model Calibration concerning Cobalt supply and demand

Figure 13 shows the same change trend and synchronously change of lithium battery recycled from Mobile phone; cobalt recovered from Mobile Phone Li.B.

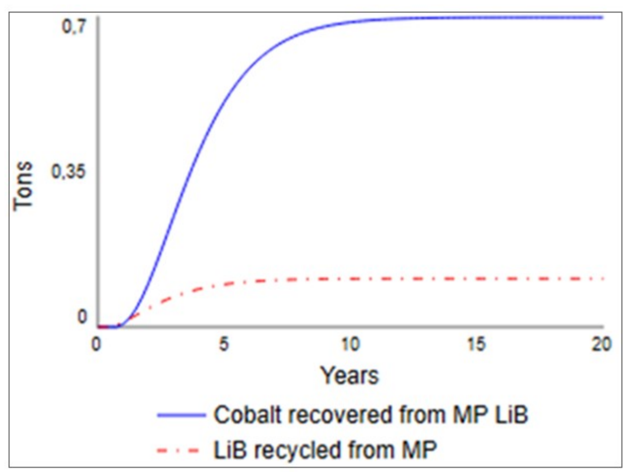

Figure 13. Timing of Model Calibration of Li.B. Recycling and Cobalt Recycling for a Mobile Phone (MP)

C. Visualization and Simulation of Model

With the help of STELLA®, a user can explore different assumptions and see the outcomes over time; add objects for interacting with the model such as action run buttons for simulating, and for viewing results such as graphs, tables, and gauges.

Figure 14 is one example, shows the immediately visualization how variables affect each other during a simulation. Here "Garbage Reuse" is taken as output, the relevant variables are "% of reuse rate", "delay of 1st. Reuse", "delay of 2nd. Reuse", "the rate of discard", "the amount of cobalt usage in each Mobile Phone unit".

Table III list the value setting for each variable in each run. Table IV is the simulation result of "Garbage Reuse" for each run over time frame of 20 years.

TABLE III. VALUE SETTING FOR EACH VARIABLE

variable / run	% of reuse	Delay first use	Delay 2nd reuse	% of Discard	Cobalt contained in MP LiB
Run 1	0	2	0,5	100	10
Run 2	25	2,5	0,5	75	7,6
Run 3	50	5	2	50	5
Run 4	75	5	2	25	3
Run 5	90	10	5	10	0

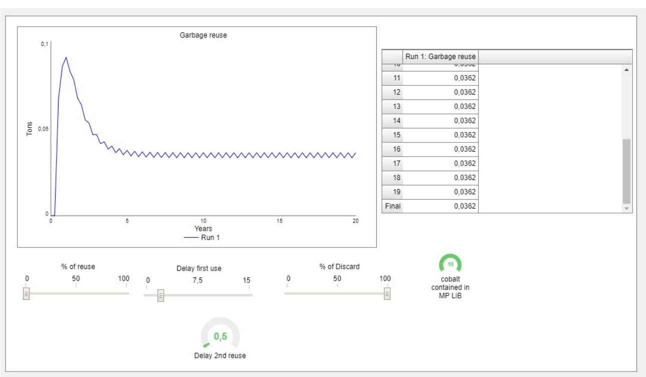

Figure 14 (A). Simulation result after 1. Run

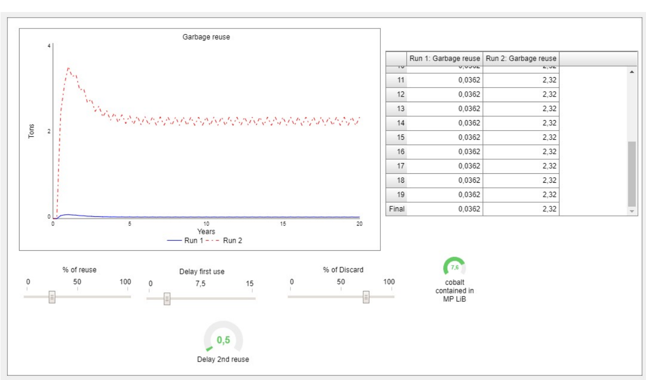

Figure 14 (B). Simulation result after 2. Run

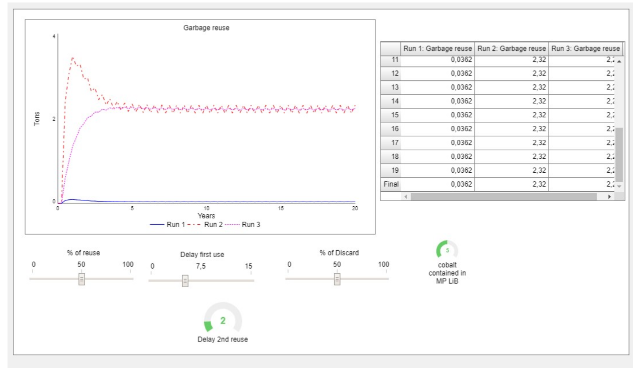

Figure 14 (C). Simulation result after 3. run

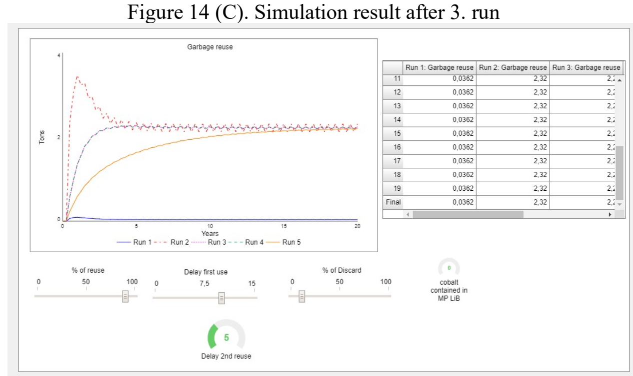

Figure 14 (D). Simulation result after 5. run

TABLE IV. SIMULATED "GARBAGE REUSE" UNDER DIFFERENT CONDITIONS

Run / Year	Run 1	Run 2	Run 3	Run 4	Run 5
0	0	0	0	0	0
1	0,091	3,47	1,35	1,35	0,587
2	0,0637	2,97	2,02	2,02	1,03
3	0,0466	2,57	2,22	2,22	1,3
4	0,04	2,41	2,27	2,27	1,49
5	0,0376	2,35	2,27	2,27	1,64
6	0,0367	2,33	2,26	2,26	1,75
7	0,0364	2,32	2,26	2,26	1,84
8	0,0363	2,32	2,25	2,25	1,91
9	0,0362	2,32	2,25	2,25	1,97
10	0,0362	2,32	2,24	2,24	2,02
11	0,0362	2,32	2,24	2,24	2,06
12	0,0362	2,32	2,24	2,24	2,09
13	0,0362	2,32	2,24	2,24	2,12
14	0,0362	2,32	2,24	2,24	2,14
15	0,0362	2,32	2,24	2,24	2,15
16	0,0362	2,32	2,24	2,24	2,17
17	0,0362	2,32	2,24	2,24	2,18
18	0,0362	2,32	2,24	2,24	2,19

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19	0,0362	2,32	2,24	2,24	2,2
Final	0,0362	2,32	2,24	2,24	2,2

Figure 15 shows an extension of the model in Figure 10 that covers financial aspects. Take repair as example. Assume the repair cost per year per unit of a phone is about 30 Euro annually and a new phone costs about 200 Euro per year for a 2-year life span. Figures 16(A) & 16(B) show the simulation results of the total costs over time. To this time point, this simulation is simplified by assuming the repair also happens in the first two years of usage. Repairing a phone is worthwhile after about 3 years of usage if the average repair cost is about 30€.

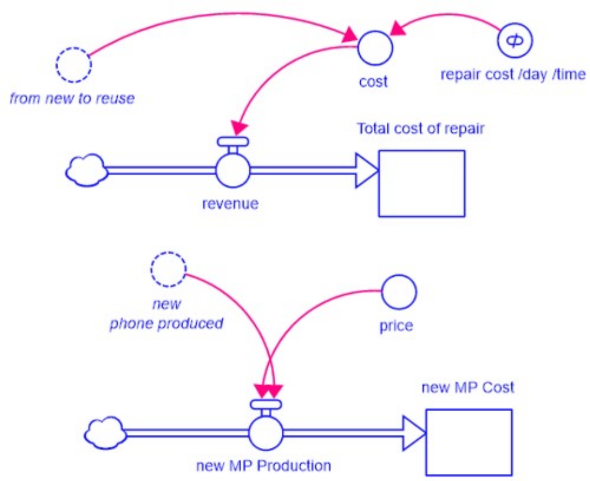

Figure 15. Financial sector of the model

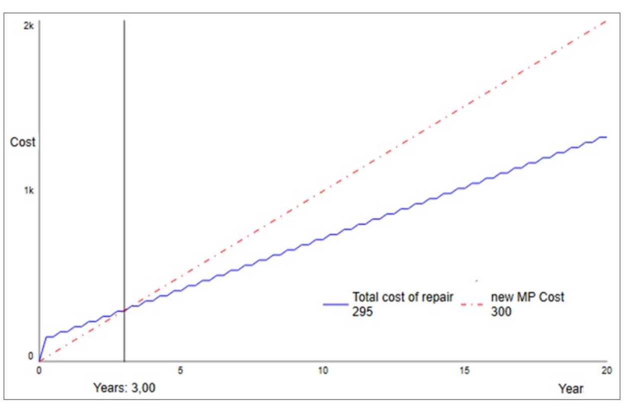

Figure 16(A). Comparison of new mobile phone cost and repair cost by reusing phone over time (Repair cost =30€ /a, new cost=400€)

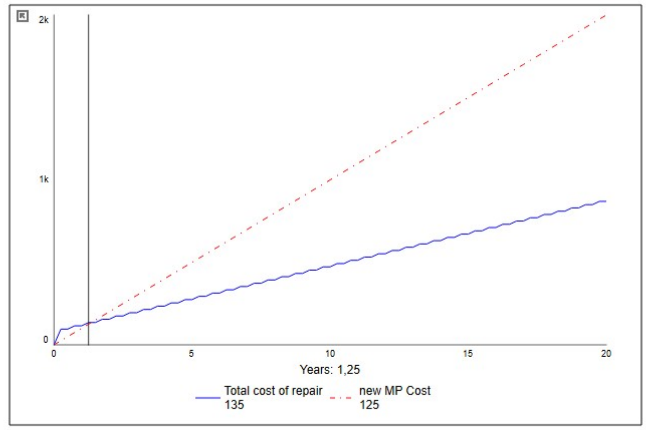

Figure16(B). Comparison of new mobile phone cost and repair cost by reusing phone over time (Repair cost =20€ /a, new cost=400€)

VI. Conclusion and Future Work

Model-building and calibration will continue, until a satisfactory number of parameters are accounted for. Parameters from economic and financial aspects will be added to the model. However, the more parameters added, the more complex the system will be. Statistical analysis of empirical data can help estimate some structural parameters of the model. This study contributed to the state of the art by applying system dynamic modeling and simulation to sustainability.

We provided researchers a new perspective for investigations into employing novel design tools and simulation to analyze complex systems. Practitioners could benefit from a better understanding of issues of a product or industry branch. The proposed DBMfS approach might aid policymakers in the development of sustainability-related regulations.

Applicability of our findings is limited by our use of statistics rather than real data from a company. Gathering both structural and non-structural data would strengthen findings in this research area. In the future, real data from a smart phone company will be very valuable to validate the model built and the solutions or parameters applied to the model.

Acknowledgment

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Appendix I: Lifecycle sustainable issues along smartphone lifecycle and the research focus

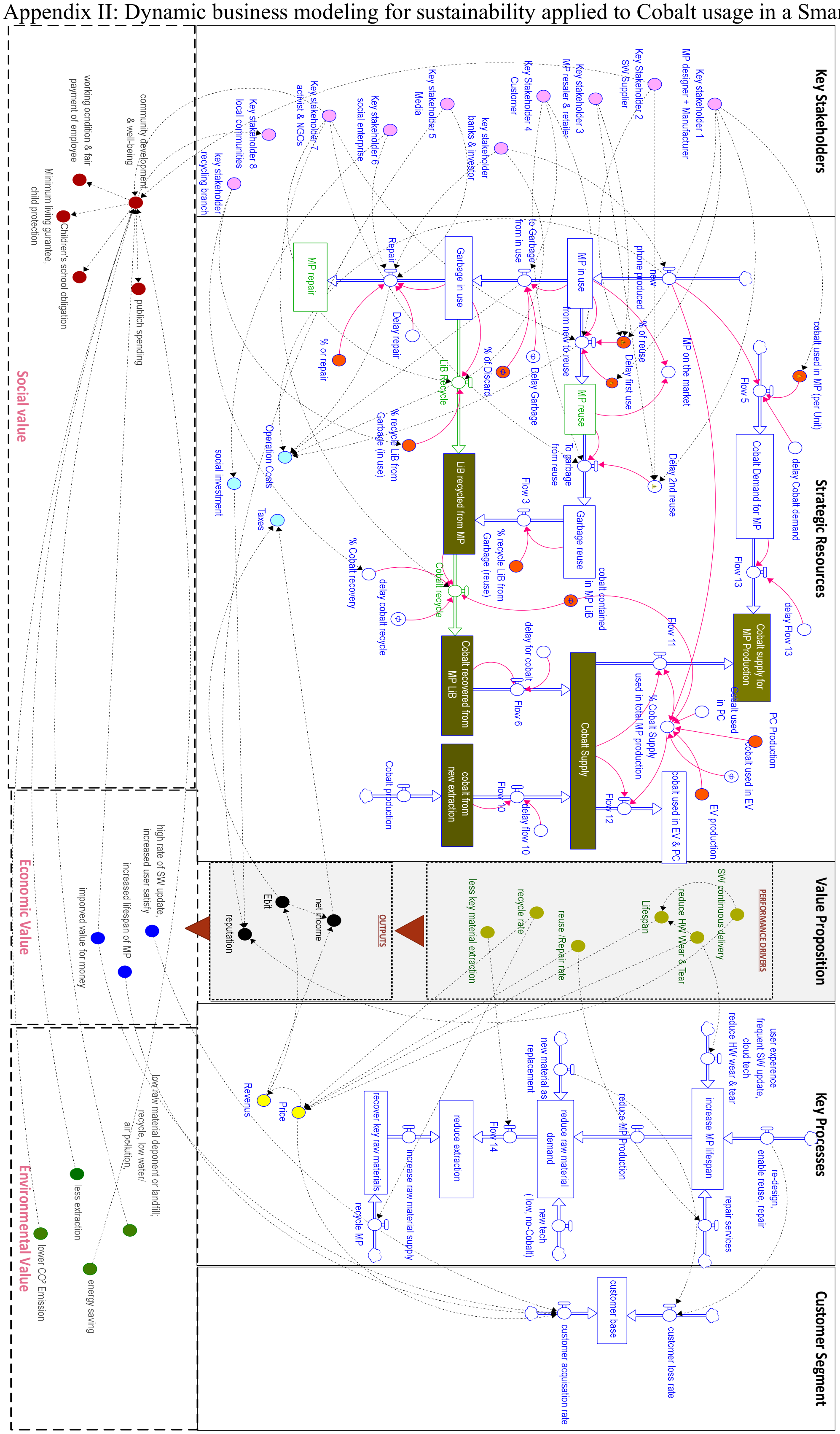
LifeCycle Sustainable Issues along Smartphone Lifecycle

Life cycle phases and sustainability issues ►	Resource extraction and processing			Design and manufacturing				Distribution and network provision		Usage			End-of-life				
SBM patterns ▼	Illicit operations / conflict minerals	Poor working conditions	Environmental degradation	Energy/resource intensive manufacturing	Poor working conditions	Exposure to toxic substances	Poor product design choices	Transport emissions	Fast replacement business model	Short lifetime	Electricity consumption	Stockpiling of functional devices	Stockpiling of defect devices	Illicitly imported electronic waste	Informal recycling	Poor working conditions	Toxic substances / lost materials
SUSTAINABLE RESOURCE COMPANY	X	X	X												X	X	
SUSTAINABLE MANUFACTURER				X	X	X	X	X	X	X	X	X	X	X	X		X
SUFFICIENCY-ADVOCATING NETWORK PROVIDER								X	X	X	X						
USAGE-EXTENDING DISTRIBUTOR								X		X	X	X	X	X	X		X
REFURBISHING & REPAIR GAP-EXPLOITER										X	X	X					
REFURBISHING & WEEE SERVICE PROVIDER										X	X	X	X	X	X		X
WEEE SERVICE PROVIDER													X	X	X	X	X

SBM: Sustainable Bussiness Model

$\boxed{X}$: Focus of my Research

Appendix II: Dynamic business modeling for sustainability applied to Cobalt usage in a Smartphone lifecycle



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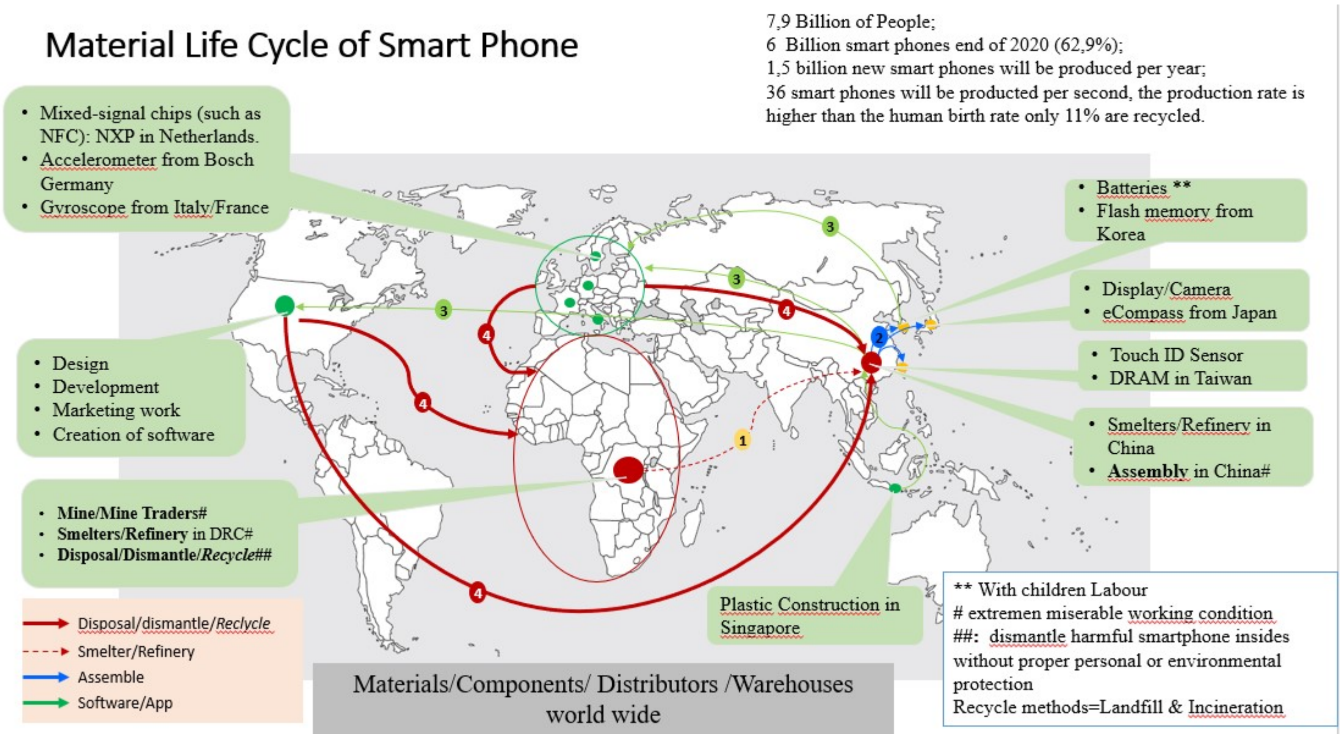
Appendix III: Material Life Cycle of Smart Phone



Appendix IV: STELLA® Model for simulation of cobalt usage in smartphone