IMPLEMENTATION OF AN ECO-DESIGN PROCESS TO MINIMIZE NEGATIVE ENVIRONMENTAL IMPACTS - CASE STUDY

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Abstract: As it is already known, the world is facing the problem of global warming. Therefore, environmental governance has become very important. For each category of the product life cycle (materials, product development, and design, production, distribution, usage, service, and end of life), an eco-design process is being developed to minimize carbon emissions, which are critical to global warming. In this study, a sample product was decomposed. The energy values and product carbon footprints for different scenarios were calculated. A new version was created by a life cycle assessment and the ECODESIGN+ tool software. According to the product-specific and EU requirements, the product was improved by a stakeholder analysis, and the sample product became more environmentally friendly.

Keywords: Eco-design, life cycle assessment, product carbon footprint, environmental impact, metrology

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1. Introduction

Contemporary design, manufacturing, and services with high-quality integrated standards, management systems, and high efficiency are some of the purposes of companies and industries at the production stage provided for consumers. Reducing the energy and material consumption of products throughout the product life cycle is directly proportional to the high quality of the products (Bodur et al., 2020).

Besides, an advanced measurement technique has to be contemplated as a pivotal need for manufacturing industrial products with controlled and improved quality as necessary for environmental efficiency. However, the collaboration of the technology designers with the rising generation of developers has been an ineluctable necessity for improving solutions to metrology trends in the environmental systems, too (Bauer et al., 2015). There are some memorable interactions between environmental management, sustainability, quality, industry, and measurement techniques. It can be said that quality and environmental management parameters are more substantial than the practical application of measurement techniques. However, it is not feasible to reach industrial products' upper quality and environmental suitability without convenient and intelligent measurements (Durakbasa et al., 2012). Intelligent measurements of environmental parameters such as carbon emission in each lifecycle steps improve the all-manufacturing process respecting quality, environmental conditions, and energy efficiency incessantly (Durakbasa et al., 2013). Life cycle stages should be developed with recyclability and re-usability in mind. For example, the waste material from cutting operations should be easy to recycle (Osanna et al., 2006).

One of the environmental management systems aims to prevent pollution, including eradication or diminution of needless sources, emissions, ejecting of any wastes, using resources efficiently, and replacing energy and material throughout life cycle stages (ISO 14005, 2019). Because of these pollutions, environmental management systems provide a prevention method of Eco-design to reduce the emissions in each category of a product life cycle: materials, manufacturing, usage stage, distribution, and recycling process. However, Eco-design is described as an efficient approach that takes cognizance of environmental aspects in design, research, and development to decrease unfavourable environmental effects throughout the lifetime of a product (ISO 14006, 2020). One method of reducing waste generated by a product is implementing what is known as an "End-Of-Life Management" strategy, where the product and its components are designed with recyclability, re-usability, and environmentally friendly disposal, which aims at providing lower disposal and use costs by the disassembly of non-usable components (Osanna et al., 2006). Furthermore, EU directives and standards, and customer requirements concerning environmental protection, energy efficiency, and costs must be considered when creating products (ISO 14001, 2015). Environmental energy efficiency as well as reducing carbon emissions can be sustainable improvements through Industry 4.0 in an Eco-Design Process. Application of Industry 4.0 technologies, distribution, and recycling stages of lifecycle by stakeholder analysis are directly linked to environmental sustainability (Majstorovic et al., 2019; Bonilla et al., 2018).

The integration of heuristic principles to product design and manufacturing through the product life cycle pays attention to time variation, determines the options, and operates from general to specific aspects necessary to its environment (Wimmer et al., 2004). Extensive environmental influences are shown in Fig. 1.

Fig. 1. Example of analysis for products environmental influence, separating influence factors into internal and external categories

2. Methodology and Theoretical Aspects

This article works on the desk lamp as a case study shown in Fig. 2. According to environmental parameters, product carbon footprint (PCF) is calculated in different scenarios with the following implementations.

Fig. 2. Desk Lamp – test product and the components of the desk lamp

After these implementations, the stakeholder analysis depends on environmental requirements and directives. With stakeholder analysis parameters, it is possible to create necessary improvement strategies. Thus, specific solutions are achieved in product improvement with those strategies.

General Information about the product. All the environmental information is presented below that is reachable. Before implementation and for the first step of the Eco-Design Process, the sample product is dismantled, as seen in Fig. 2. The environmental parameters are demonstrated for each part of the life cycle management. The product presented in this study, "White Desk lamp," has a weight of 1.38 kg without the packaging and a volume of 475x 275x 180 mm (23512500 mm³). The parts supplied with the product are the cable, bulb, and metal lampshade. The product's lifetime is ten years.

Functionality and flexibility are increased by implementing adjustable joints, which ensure accurate lighting for the work on the desk. The raw materials employed for the fabrication of the product are Steel, Aluminium (Al) Copper, Sand, Ceramic, PE or PP, and PVC. Of these materials, the most problematic ones are the PVC in cables and the PP or PE in the lampstand and housing. For the manufacturing of the product, different production technologies are employed. Injection molding of PP or PE for the Lampstand substructure and PE or PP without sand Lampstand housing, extrusion and cutting are employed for the Al bars, also cutting and bending for the Metal-Lampshade.

The Lampshade and Lampstand housing are painted using white paint by the spray-painting method. Cutting and gluing of cardboard are employed for the manufacturing of the packaging box. Power is supplied to the product by the use of stranded copper cables. The manufacturing of the components is followed by the technical assembly of the product. Production waste consists of small amounts of Al during the cutting process and some paint during the painting process. For distribution, the product is packaged in a Single-use cardboard box and transported 1500km by truck.

The product's usability is increased by its flexibility and portability. Although portable, the product presents higher stability when used on a table. The energy consumption of the product is in the A++ -E class, IP20, using an E27 60 Watt lightbulb. The waste generated by the product is in the form of broken bulbs. The product does not generate noise or vibrations, and the only emissions generated are in the form of visible light. Maintenance for the product is limited. The only repairability possible is changing of broken lightbulbs. Mechanical repairs are not possible due to a lack of spare parts available for the product. The product can be disassembled in 1 minute by removing fasteners and joint screws. The parts are not reusable, and the product presents a rate of recyclability of approximately 30% of the total weight. Alternate realistic scenarios include using the product with different lightbulbs, leading to a variation in energy consumption.

Life Cycle Assessment (LCA) is essential for a product's ecological rendering (Koroneos et al., 2013).

LCA is used for the product's environmental aspects assessment and is performed over the product's complete life cycle, starting with the "use of raw materials" stage and progressing to the "end-of-life" stage.

Life Cycle Assessment, as well as the inputs and outputs of the stages in the case study, are performed according to guidelines stipulated in DIN EN 50693 (DIN EN 50693, 2018) which provides a standardized method for quantitative life cycle assessment and environmental declaration according to EEE product category rules. Product category rules (PCR) apply to a specific class of which the product is a member, in this case, the category of electrical appliances. These rules are complemented by product-specific rules (PSR), which correspond to a family of products, in this case, "Desk Lamp." The main functions of the product, which are delivered to the user, defined as Functional Units (FU), as well as the level of performance to be achieved by the functions, is selected for performing Life Cycle Analysis.

MET-Matrix stands for Material Energy and Toxicity, and it provides an overview of the product's environmental impact throughout its lifecycle.

Life Cycle Thinking (LCT) aims at identifying the environmental weak point in a product life cycle using the energy values as a first approximation to estimate the product's environmental performance for the duration of its complete life cycle (V. An et al., 2011).

Stakeholder Analysis. Type of Stakeholders: it must first be clarified what kind of Stakeholders this product has as end-user; B2B-case product is a B2C product primarily but could also be a B2B application (25 Must-Have B2B eCommerce RFP Requirements Categories, 2020), Environmental directives, and regulations, Eco Labels, Standards, Competitors. Requirements of customers, these are requirements a regular customer would give: easy to use, long lifetime, energy saving, easy to maintain. Business requirements in B2B are requirements a regular customer would provide: durability, a product's long life, and being environmentally safe.

Product Improvement. Product development is divided into five main steps: product specifications, functional structures, creativity sessions, product concept, and embodiment design. An important step of the development process for every product which initiates the re-design process is listing the product specifications that need to be achieved. This method is known as "function synthesis" and can be used for product development using a "step-based" strategy. Another method is known as "function analysis" and involves performing systematic analysis using functions. The objective of function analysis is to determine the function fulfilled by every part of the product. The function can then be described in general without mentioning a particular solution.

3. Results and Discussion

Materials, Energy consumption, and Toxicity is created for that case product as seen in Table 1:

	Material	Energy	Toxicity
Use of Raw Material	Polypropylene PP, Polyvinyl chloride PVC Copper for cable Al (Aluminium) foil Al ((Aluminium) cast Steel Ceramic	Energy consumption for raw material extraction, transportation to the production site	PVC
Manufacture	Excipients -lubricant for machine-, -paint white colour- -glue for packaging	Energy consumption for production technology	
Distribution	Packaging Material, -Cardboard-, -Polystyrene-	Energy consumption for the production of packaging and transportation to the shops	
Product Use	Spare parts (Lamps)	Energy consumption in usage	
End of Life	Excipients for the recycling process	Energy consumption for recycling and transportation to the recycling factories	PVC

Tab. 1. MET Matrix of the test product

3.1 Calculation of PCF with Life Cycle Assessment and Life Cycle Thinking

Life Cycle Thinking (LCT) is separated into five categories: Use of raw material, Manufacture, Distribution, Product Use, End of Life. Energy usage is calculated in every step of the product's lifetime, and the energy values are used to perform these calculations in Table 2. The improvement strategy is to reduce the impact of usage. The main goal is to start the improvement in this category. Perhaps, that case product could be shipped with lamps of lower energy consumption instead of 60 Watts. Also, a reduction in the number of toxic plastics in the development would improve the environmental performance.

Energy Values (MJ)						
Scenarios	Raw Material	Manufacture	Distribution	Product Use	End of Life	Total Energy Values
Maximum	86,67	10,5272	21,2	2991,84	-120,762	2989,4752
Average	86,67	10,5272	21,2	1399,92	-120,762	1397,5552
Minimum	86,67	10,5272	21,2	829,68	-120,762	827,3152

Tab. 2. Comparison of the Energy Values of Scenarios

Also, the packaging of the case product can be improved because it has packaging material up to 25% of total weight, including 20% polystyrene, which could be reduced. Another parameter is aluminium; some of these parts can be replaced with components made of steel; this would hopefully also reduce the energy consumption of the case product in the category of raw material. There is a significant difference between the usage scenarios of the case product. It is hard to say how long an average person uses a lamp like this per day. These scenarios have a significant impact on energy consumption in the usage.

3.2 Calculation of PCF with Eco-design+ Tool

The total greenhouse gas emissions over its life cycle are known as the Product Carbon Footprint (PCF). For the calculation, the life cycle assessment (LCA) and the whole life cycle approach are used (ISO 14040, 2016; DIN EN 50693, 2018). ECODESIGN+ is the software for the product model (ECODESIGN+, 2019). The report provides the CO₂ equivalent results for the product's entire life cycle (Fig. 3).

Fig. 3. Three of the most significant impact in PCF for case product

Besides, it is a predictable parameter. That impact can be reduced by shipping it with another lamp that has maybe lower energy consumption than 60Watts without sacrificing visible light output (higher electrical to visible light energy conversion efficiency).

EQFD- Environmental Quality Function Deployment																				
Environmental Parameter	Stakeholder Requirements																			
	customer importance	weight	volume	supply parts env. perfor.	lifetime	functionality	materials used	problematic materials	production technology	production waste	packaging	transportation	usability	energy consumption	waste(generated)	noise and vibrations	emissions	maintenance	repairability	fasteners and joints
Unit		kg	m ³						kwh	kg	kg	km		kWh	kg	dB				
Easy to recycle	10						9	3		9										3
Easy to reuse	0			9	3															9
Easy to disassemble	5	3	3															9	9	9
Free of hazardous substances	10						9	9			9									9
Energy Saving	10					3						3		9						
Lifetime, durability	3	3		3	9		9											9	3	
Colour Rendering	0							3												
Easy to use	10	3	3			9							9			3				
Environmentally Safe	0							9	9						9		9			
Easy to maintain	3	3	3														9		3	3
Importance relative %		4	4	1	2	8	14	8	0	6	6	2	6	6	0	2	0	2	5	4
No Relationship - 0; Medium Relationship - 3; Strong Relationship - 9; Customer Wishes - 10																				

Tab. 3. EQFD – Environmental Quality Function Deployment (Masui et al., 2013)

Also, an alternative product design maybe leads to a lower PCF. One option would be to replace all the aluminium parts with steel. The impacts in distribution can also be decreased by transporting it on the railway instead of a truck. Furthermore, polystyrene use can also be reduced in the packaging.

EU Requirements has to be considered for the case product resulting from WEEE, ROHS, AND ERP (Directive 2009/125/EC), also product-specific requirements from Eco-Label like Blue Angel - Long-lived and Energy-Efficient Lamps (Blauer-Engel, 2020), Nordic Swan – Criteria of lighting sources in furniture and fitments (Nordic Swan, 2017), EU Eco-Label – Criteria for Light Sources (EU Eco-Label, 2020). After that, an Environmental Quality Function Deployment table is generated in line with the weighted environmental requirements of the stakeholder.

In Table 3, the relative importance of every single column in the yellow field at the lower end of the page can be observed. It mentions which one of the environmental parameters is essential. Every value in the main table (white) is multiplied by its weight. After that, the relative importance is calculated. The numbers in the white field show the relationships between the rows and columns by giving numbers. 3 is a medium relationship, nine is a strong one, and 0 is no relation at all in Table 3. It is possible to see that "materials used" (14%), "problematic materials" (8%), and "rate of recyclability" (12%) have the most substantial impact on the relative importance of the product. The identified environmental parameters are used to improve the product. Improvement strategies are formed for each environmental parameter.

3.3 Identification of the ECODESIGN improvement strategies.

ECODESIGN measures and ECODESIGN tasks	
ECODESIGN measures to implement	ECODESIGN tasks for improving the desk lamp
Realize simple principle of functioning	reduce the number of parts, less complex joints
Ensure high functional quality of product and minimize the influence of possible disturbances	joints made of metal instead of plastic
Make possible use of environmentally sound process materials	Lead or other toxic substances in Lightbulbs > use of LED lightbulbs
Make possible use of process materials from renewable raw materials	photovoltaic panels for the reduction of the consumption of the electric energy
Indicate consumption of product along use stage	Showing consumption on display to the user
Prevent environmentally harmful abuse of the product	automatic switch-off at leaving workspace, less use-intensive mode for not completely dark surrounding
Reduce or eliminate the usage of toxic components and materials	PVC can be reduced or replaced by other not toxic substances
Adopt renewable raw materials	Maybe some of the plastic parts can be done with renewable bio-polymers
Ensure simple extraction of harmful and valuable substances	easy take apart of the joints
Make possible extraction of process materials and unavoidable harmful substances	use Led bulbs instead of conventional ones and replace PVC
Ensure labelling of materials conforming to standards	Implement labelling for different materials

Tab. 4. Summarizing the ECODESIGN tasks

Improvement strategies are determined for each impact in the case product. It can be observed that the case product is usage-dominated in terms of energy consumption. This is shown in the PCF of the case product. Table 4 summarizes how a desk lamp can be improved with the help of Eco-design tasks.

The method for integrating new ideas into a new version of the product can be seen in Fig.4. The new functions that need to be fulfilled by the product are determined, and the technique to find new concepts is presented.

Different variations of the product can be developed before one version is evaluated, leading to the development of a prototype and ultimately of a marketable product. Morphological boxes can also be employed for documenting new ideas found for function fulfilment. Solutions and functions can be combined with each other, resulting in a large number of product versions.

Functions	Possible solutions for functions		
make it stable	lampstand	fixed at the table	
light source	incandescent Lamp	energy saving Lamp	LED lamp
supply with electricity	cable (grid)	battery	Photovoltaic panel
changing the position of the light source	rotatable arm with two metal bars	rotatable arm with a bar	Swan Neck made of steel
Auto switch off mode	no switch	Motion sensor	switch at the chair
Simplify product design	arm design with joints made of plastic	simplified arm design with joints made of steel	jointless arm design
Insulation the cable	PVC	rubber	
Easy to disassemble	bolts	thread	glued

V1.0 V2.0

Fig. 4. Case product's morphological box for the functions

The product implementation or the ECODESIGN improvements are carried out based on the product specifications:

- Replacing the PVC insulation of the cables with rubber
- Plastic joints, springs, and aluminium bars are replaced by a simple steel swan neck structure
- Implement auto-switch off-mode
- Using LED Lamp instead of light bulb (Consumer Energy Solutions, 2020).
- Replacing the polystyrene in packaging with cardboard

Fig. 5. Environmental design of the desk lamp

All these mentioned ideas are implemented and lead to a new product design presented in Fig 5. in the form of a drawing with the description of several parts. After all PCF data, the conclusion of PCF for V2 may be seen below in Fig. 6 and Fig. 7. For V2, the total product carbon footprint is 20,362 kg CO₂-eq, the total weight is 1.335 kg, and the estimated time of service is ten years.

As seen on the above chart, the highest improvement is in the usage stage. The CO₂-eq is reduced by 80,442%, as seen in Fig 7. It shows that the new product produces less CO₂ equivalent emissions in the whole product life cycle stage.

Fig. 6. Three of the most significant impact in PCF for V2

Fig 7. Comparison of the lifecycle of old and new product design

The Environmental Communication Type of this case product is a combination of type I and type II. The labels are shown on that case product according to ISO14024 (ISO 14024, 2018), as the EU-ecolabel, and some information is also given regarding the case product and the environment without any third-party certification. These self-declared environmental claims as: "extended life product," "designed for disassembly," and "reduced resource use" are shown on the packaging of the case product with a QR-code which links to the homepage of the product where further information about these claims is given.

4. Conclusions

The study starts by gathering information about the product, and the disassembly of the product brings us a better understanding of the components and materials the case product is made. A detailed analysis is performed to determine every piece of information about the product. The case product is then analyzed in terms of toxic substances, of which some are found in the insulation of the cables used. After that, the study is continued with LCT, which is separated into five categories: Use of raw material, Manufacture, Distribution, Product Use, and End of Life. These five categories are analyzed and calculated in terms of energy consumption. The results show that product usage is the life stage with the most significant impact. After this first calculation, the product is modeled with the Eco-design+ software tool. This gives us more detailed information about every single life stage. Likewise, information about the legal aspects of the case product is compiled.

The stakeholder requirements are researched and built up for the case product. In addition, the stakeholder requirements are evaluated by the EQFD-method. The most critical requirements of the stakeholders can be figured out by this method. "Materials used," "problematic materials," and "rate of recyclability" are identified as the most important ones.

Further, work is performed with the Eco-design-pilot tool to get structured improvement ideas. Every idea is evaluated, and then the best ideas get implemented in the new product. A new product design with all the ideas is created.

The resultant new product design is then modeled in Eco-design + to evaluate the improvements. The results indicate that the product is improved in environmental concerns and also in usability for the customer. The end product is more environmentally friendly, has lower consumption, and is more durable than the old model.

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6. References

- 25 Must-Have B2B eCommerce RFP Requirements Categories (2021). Available from: <https://b2xpartners.com/writing-your-b2b-ecommerce-rfp-requirements-25-must-have-requirements-categories> Accessed: 2021-05-12
- Bauer J.M., Durakbasa N.M., Bas G. (2015). Development Trends in Automation and Metrology. IFAC-PapersOnLine pp. 48-24 168–172
- Bodur, Osman; Stepanek, Vojtech; Walcher, Eva Maria; Durakbasa, Numan (2020). Precision in Additive Manufacturing, Optimization and Evaluation of the Accuracy of 3D Printer based on GPS System. In: Branko Katalinic und Branko Katalinic (Hg.): Proceedings of the 31st International DAAAM Symposium 2020, Bd. 1: DAAAM International Vienna (DAAAM Proceedings), S. 963–972
- C. Koroneos, E. Nanaki, D. Rovas, M. Krokida (2013). Life Cycle Assessment: A Strategic Tool for Sustainable Development Decisions, The 3rd World Sustainability Forum
- Consumer Energy Solutions (2020). Available from: <http://www.consumerenergysolutions.com/wp-content/uploads/2015/02/led-lighting-comparison-chart.png>, Accessed: 2020-03-12
- D. Majstorovic, N. Durakbasa, Y. Takaya, S. Stojadinovic (2019). Advanced Manufacturing Metrology in Context of Industry 4.0 Model, IMEKOTC14 2019, LNME, pp. 1–11

DIN EN 50693:2018. Method for quantitative eco design via life cycle assessment and environmental declarations through product category rules for EEE, Publication date: 2018-05

Directive 2009/125/EC of the European Parliament and of the Council (2009), Establishing a framework for the setting of ecodesign requirements for energy-related products, Available from:

<http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:285:0010:0035>

Accessed: 12.03.2020

Directive 2011/65/EU of the European Parliament and of the Council (2011), The Restriction of Hazardous Substances Directive 2011/65/EU, Available from: <https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX:32011L0065>, Accessed: 2020-03-12

Directive 2012/19/EU of the European Parliament and of the Council (2012). Waste Electrical and Electronic Equipment Directive 2012/19/EU, Available from: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32012L0019>

Accessed: 2020-03-12

Durakbasa M.N., Osanna P.H., Bauer J.M. (2012). Innovation in Production Metrology for Precision Engineering and To Support Sustainability and Improvement of Process and Product Quality in Modern Manufacturing Industry. MSD Journal, Volume 4, 1; S. 5 - 11.

Ecodesign+, Ecodesign company engineering and management consultancy GmbH, source: <http://www.ecodesignplus.com/en/ecodesign-plus-en/about-en>, Accessed: 2020-03-12

EU Eco-Label – Criteria for Light Sources, Available from: <http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32011D0331>, Accessed: 2020-03-12

ISO 14001:2015, Environmental management systems -- Requirements with guidance for use, publication date: 2015

ISO 14005:2019, Environmental management systems — Guidelines for a flexible approach to phased implementation, publication date: 2019-05

ISO 14006:2020, Environmental management systems — Guidelines for incorporating ecodesign, publication date: 2020-01

ISO 14024:2018, Environmental labels and declarations — Type I environmental labelling — Principles and procedures, Publication date: 2018-02

ISO 14040:2016, Environmental management -- Life cycle assessment -- Principles and framework, publication date: 2016

ISO 17450-1:2011, Geometrical product specifications (GPS) -- General concepts -- Part 1: Model for geometrical specification and verification, publication date: 2011

K. Masui (2013). Environmental Quality Function Deployment for Sustainable Products, Hand-book of Sustainable Engineering pp 285-300

Long-lived and Energy-Efficient Lamps, Available from: <https://www.blauer-engel.de/en/products/home-living/lamps-illuminants> Accessed: 2020-03-12

M.N. Durakbasa, G. Bas, J.M. Bauer, G. Poszvek (2013). "Intelligent design and advanced metrology as strategic approaches to efficiency and quality improvement in smart manufacturing", 7th International Working Conference TQM & AIA, 4th – 7th June, 2013, Belgrade.

Nordic Swan (2021), – Criteria of lighting sources in furniture and fitments, Version 4.17, 17 March 2011 – 31 December 2022

Osanna, P. H.; Durakbasa, M. N.; Bauer, J. M.; Tahirova, H. S.; Kraeuter, L. (2006). Intelligent flexible disassembly and recycling of used products to support sustainability and total quality management in modern manufacturing industry. In: C. A. Brebbia, E. Tiezzi und M. E. Conti (Hg.): Management of Natural Resources, Sustainable Development and Ecological Hazards. Ravage of the planet 2006. Bariloche, Argentina, 12.12.2006 - 14.12.2006. Southampton, UK: WIT Press, S. 209–215.

S. H. Bonilla, R. O. Silva, M. T. Silva, R. F. Gonçalves, J. B. Sacomano (2018). Industry 4.0 and Sustainability Implications: A Scenario-Based Analysis of the Impacts and Challenges, Sustainability, 10, 3740

V. An, D. Evelien, G. Theo (2011). Life Cycle Assessment of printed matter, Vision on Technology

W. Wimmer, R. Züst, K. M. Lee (2004). Ecodesign Implementation, Springer, ISBN: 978-1-4020-3071-0