Identifying sustainability increasing measures for an environmentally straining industry: a modeling framework proposed

Jay Jay Kleinendorst – 4218388

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Delft University of Technology. Jaffalaan 5, 2628 BX, Delft, the Netherlands.

Abstract:

Governmental regulations are pushing all industries to increase sustainability. For some industries, there are no known ways to increase this sustainability. These industries have a technology-pull and are seeking solutions for their End-of-Lifecycle product from the academic world. The carpet industry is one of these industries. This study advices on the usage of a statistical model to identify and assess the impact of sustainability increasing measures. This model is established to both prevent unnecessary implementation costs and to limit risks. A framework is presented to create such a model. This article discusses the framework using an example of the carpet industry. It discusses why a model should be established, how it should be established, and how the modeling results should be interpreted. The end product is a structured guide on how to establish a model that will aid any sustainability seeking industry. Further research is advised to refine the framework and to evaluate how it holds up to highly futuristic sustainability increasing measures.

I. Introduction

Global warming is an universal threat that is a high priority to the European Union (Wanders, 2017). Every member state is subject to policy measures that pushes towards reductions of greenhouse emissions. The Netherlands aims at a 95% reduction of greenhouse emissions by 2050, with the baseline being the 1990 levels (Wanders, 2017). Furthermore, Dutch government is increasingly striving towards the establishment of full circular industries (Looman, 2019). Many industries that currently operate sub-par in terms of sustainability are cornered and desperately seek ways of decreasing their environmental impact sustainably. The carpet industry is one of the many examples of industries that are failing and seeking sustainability. A carpet tile is one of the most environmentally straining products the textile industry produces (Choudhury, 2014). With high virgin (exhaustible) resource reliance and a waste product that is very hard to recycle, the carpet scores low on circularity and sustainability (Choudhury, 2014). Both the industry as well as the government are seeking ways to reduce the strain of this industry on the environment (Biehl, Prater & Realff, 2007; de Kok & van den Acker, 2019, march).

The industry has put some effort into collecting end-of-lifecycle carpets in aims of achieving full circularity (Deutsche Umwelthilfe, 2017, February). It was however quickly identified that these efforts are wasted, as there is no processing capability to turn EOL carpet into new carpet (Biehl et al., 2007). There is a technology pull by the carpet industry for increased sustainability that has gone unanswered. Instead, all carpets are landfilled as even incineration of carpets with energy regeneration is not an available alternative. Through academic research, solutions are sought that could lead to an increase of the sustainability of the carpet industry.

Identification of possible recycling or downcycling methods will not automatically lead to an implementation by the industry. This holds for the carpet industry, and for any other industry that seeks sustainability. The Technology Acceptance Model framework by Davis (1989) describes how the acceptance of any technology is, amongst other factors, dependent on the perceived usefulness. In other words, effectiveness of implementation is a major criteria to adaptation. As case experiments are expensive or not even possible at a scaled-down level, a model would be a perfect tool to compare different policies and their implications on reaching a more sustainable industry. This research set out to create a framework for establishing this model through the following research question:

How can a universal modeling approach benefit an industry, and how can this model best be designed?

This article describes the creation of a framework that dictates how a model for sustainability seeking industries should be established. This model should also be capable to simulate future policy adaptations. It does so by discussing the framework applied to the carpet industry as an example. This article will serve as a discussion and a handbook for those modelling the carpet industry, or any other industry.

The structure of this article is as follows. Chapter II discusses how the created model should have a justification. Chapter III discusses how the theoretical and conceptual model should be established. Chapter IV continues on this model through discussing the generation of the nil-alternative. Chapter V proposes how this conceptual model is quantified and validated. Chapter VI adds to this chapter by discussing how the sustainability increasing measures can be equally quantified. Chapter VII discusses how the modeling results are to be interpreted. Chapter VIII describes how these results can be used outside of the modelling environment. In the concluding chapters, chapter IX describes the framework in short, where chapter X presents a conclusion on the framework and advices on future studies.

II. JUSTIFICATION

Before setting out to model any industry, there should be a justification why that industry needs modeling and needs increased sustainability. This justification should address both the societal as well as the academic relevance.

For the carpet industry, no widely available, universal, calculation method for emissions was discovered. The need for such a model is high, as indicated by several failed policies by the industry aimed at increasing sustainability.

Both Interface and Tarkett/Desso, world leaders in carpet tile manufacturing, have been actively collecting EOL carpet tiles all across the world in aims of recycling them (Deutsche Umwelthilfe, 2017, February). However, when this recycling proved to be too costly and too difficult, their effort was halted (Deutsche Umwelthilfe, 2017, February). With promises to their clients to recycle the carpets, these carpets cannot be disposed either. So instead they await in storage, scattered all across Europe, the Middle East and Africa, for a recycling opportunity to present itself. In this process a lot of logistic value is gone to waste.

It is doubtful that with the availability of a model, the same mistake would have been made. A well established model is able to predict the effectiveness of such a policy, as it processes several input variables into a calculation of environmental costs. In this example, it would have resulted in higher transportation costs and no gains in terms of resource recycling, an indication of a failing policy measure. A model could help the industry identify what an efficient sustainability increasing policy should entail at a fraction of the time and costs of a case experiment.

III. ESTABLISHMENT OF THE MODEL

This study believes that any industry could greatly benefit from having a tool to study the effects of different sustainability increasing measures. But before these effects can be calculated, it is of vital importance that the basics are established well and that the model accurately describes any current production method. According to the "garbage in, garbage out" principle, a ill-established model will not accurately reflect the effects of policy alterations (Rose & Fischer, 2011). Thus, a priority is to look at the needs and requirements of the model by the industry and the literature. This can be achieved through several methodologies. This study used the MoSCoW method, describing the "must have", "should have", "could have" and "will not have" functionality of the model, detailing the input and output measures in a prioritization list (Haughey, 2011). Once these factors are established, the next step is to design a model. This model should first accurately describe the current situation, also known as the nil-scenario, before being used to calculate the effects of policy measures compared.

IV. CREATING A NIL-SCENARIO

For the establishment of a nil-scenario model run, a thorough analysis of the entire supply chain of the industry is necessary. This is best achieved through the framework of Cline, LeMay and Helms (2015). In order to get an understanding of the supply chain, the following questions have to be asked: "what", "how", "who", "why" and "where". These insights can be obtained through either a literature study or through cooperation with the industry.

With these factors known, it is advised to project these insights onto a map to create a graphical overview of the industry. This will become the foundation of the mathematical model. For the Dutch carpet tile industry, the following graphical display of the supply chain was generated.

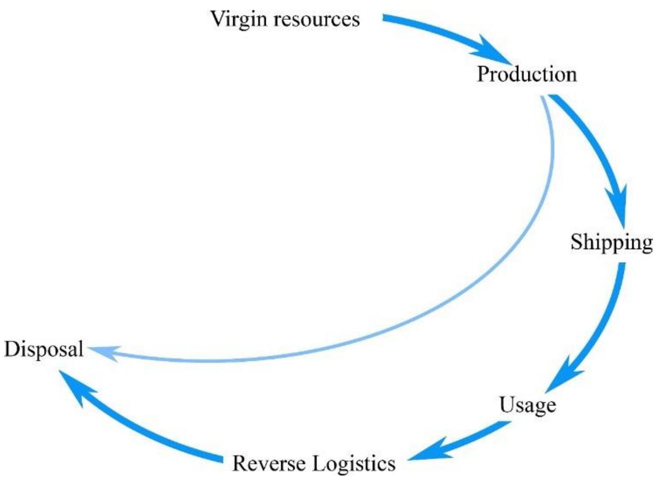

Figure 1. Nil-alternative conceptual model

In this example, there are clear indications that a closed supply loop, and thus full sustainability, is not achieved. The "why" question will have yielded some insights into why sustainability is not achieved. In the case of the Dutch carpet tile industry, it was discovered that three stages could be improved to increase the sustainability of the entire chain. These areas are the production stage, shipping/reverse logistics (RL) stage, and the disposal stage (Cline et al., 2015; Helms & Hervani, 2006; Realff, Ammons & Newton, 1999).

The next step is a literature study into these identified areas where sustainability could be increased. During this literature study, means are sought that have the potential to fix these resource leaks, given the constraints to the model. A table is created to reflect the solution space. For the Dutch carpet market, the following means were identified that could increase the industry's sustainability:

Table 1

Solution space

	Option 1	*Option 2*	*Option 3*	*Option 4*
Production	Zero-emission manufacturing	Zero Waste manufacturing	Zero-emission recycling	Zero-emission resources
Transportation	Industry relocation	Electric transport	Local collection	
Waste	Incineration	FRC	Insulation	Full circularity

This solution space is then added to the projection of the supply chain to create a full overview of the current situation and possible futures. This leads to the establishment of a conceptual model. For the Dutch carpet market, this resulted in the following conceptual model:

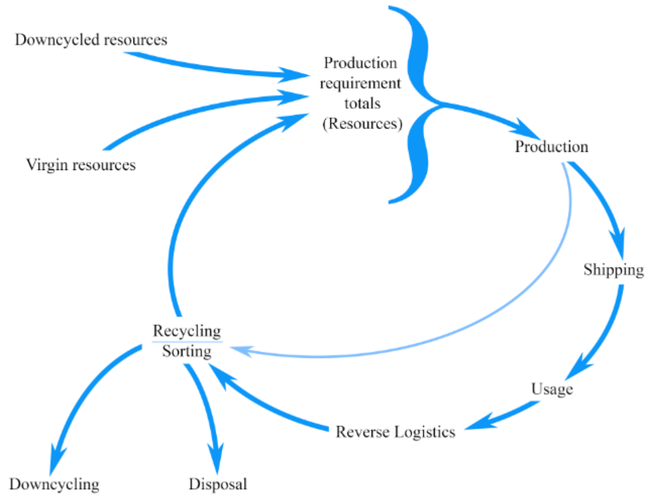

Figure 2. Full conceptual model with solution space

With the establishment of this conceptual model, the foundation for the quantified model is complete. This full conceptual model displays the primary behavior of the model, and through the process some sustainability increasing measures are discovered. A lower aggregated level of conceptual model is then created, to display modeled relationships between factors and interdependencies. These subsystems all relate back to the full conceptual model as described above.

V. Quantification of the Model

With the conceptual model(s) established, which serves as the foundation of the model, the model is ready to be quantified. For quantification, a modeling tool is to be chosen. This study used Excel, but any other system dynamics tool will suit the modeling needs equally well or even better. Excel was chosen for its low-threshold use, in order to stimulate industries adapting and using the model.

With a modeling tool selected, the model input and output should be specified and created. This framework is specifically designed to feature sustainability, so factors were identified that indicate sustainability for the Dutch carpet industry. These were found to be the usage of virgin resources, the energy requirement of the system, the emission of greenhouse gasses by the system and the emission of particulate matter by the system. The virgin resource usage is a input measure, something that can be directly altered by the industry. The latter three factors are products of the entire supply chain, and are thus identified as the primary output variables of the model. These factors are derived from the MoSCow list.

With a chosen modeling tool and known input- and output variables, the model is quantified through the adaptation of key figures. These figures are preferably directly from the industry. Other well-documented academic sources are acceptable as well, with a preference for national studies. The preference for national key figures is based on incompatible systems. Dutch waste incineration plants were i.e. found to have a vastly different tolerance for emissions than equal plants in the United States (Pirrone, Keeler & Nriagu, 1996). Using national key figures, the model will more accurately reflect the costs of emissions.

With the input, output and interdependencies mapped, and key figures identified, the model can be fully quantified. The first modelling effort should be a simulation of the current situation, the nil-scenario. The modeling results of this nil-scenario are to be validated before continued use of the model (Kleijnen, 1995). In this study, the nil-scenario, and general model, are validated through an extreme condition test, sensitivity test, an expert validation process and through a Environmental Product Declaration data comparison (EPD).

EPDs are readily available for carpet tiles. An EPD is an independent assessment of the environmental effects of a specific product, in this case carpet tile. This is a great tool to quickly compare the modeling results to known scientifically based emission factors. For this study, the global warming potential (GWP) of the modeled nil-alternative shows a 0.2% deviation from the GWP as stated by the EPD. Based on this slim error margin, and upon closer inspection of the error distribution across all factors of the model, it was found to be valid. If the EPD is used as a validation step, it is of importance that the EPD is not used as a source for the construction of the model in any way. This accounts for any validation tool, as validating based on the data used to generate the model with leads to an invalid validation (Kleijnen, 1995).

VI. Quantification of Means

If the model is deemed valid, it can be used to calculate the effects of the different sustainability increasing measures. Many of these measures require to be implemented into the model, through for instance a selection switch. These adaptations are just front-end, interface related, as it only changes already modeled effects. If a measure is identified that requires a revision of the model, it can be assumed that the conceptual model is incomplete. In this study, i.e. a zero-emission manufacturing process was found to relate to the already modeled production waste factor, zero emission transport related to vehicle specific emissions and an implementation of downcycling measures affected the energy/emission costs and gains of disposal.

The modeling outcomes of the proposed sustainability increasing measures are expressed in terms of costs/gains compared to the nil-alternative. This study produced the following results for the Dutch carpet tile industry:

Table 2

Means effects and modeling results

	GWP	*ENERGY*	*PM_{10}*
Zero emission manufacturing	-3.5%	0%	-53.9%
Zero Waste manufacturing	-1.0%	-1.0%	-0.7%
Zero emission recycling	0%*	0%*	0%*
Zero emission resources	-74.7%	0%	-53.9%
Industry relocation	-2.2%	-1.3%	-19.1%
Zero emission transport	-2.3%	-2.3%	-4.6%
Local collection	-2.2%	-1.3%	-19.1%
Waste incineration	-2.2%	-26.3%	+45.4%
FRC	-5.4%	-0.1%	+2.6%

Insulation	-24.4%	-6.6%	+2.6%
Full circularity	-81.3%	-81.4%	+14.9%

For zero emission recycling, no results were obtained from a stand-alone aspect, as the nil-scenario does not feature any recycling efforts. These factors present how the alternative behaves compared to the nil-alternative.

VII. Interpreting results

The outcomes of the model are a numerical expression of the modeled assumptions. A qualitative reflection on these measures is essential to fully understanding the results. Some measures can be implemented seamlessly side-by-side, while others are exclusive.

There are also scenarios in which (un)desirable effects occur that are not included in the model. An example of this is in the usage of nuclear energy or through the creation of fiber reinforced concrete (FRC). These produce unusable waste products, but these effects are deemed out of scope for the established model and are thus not included in the model. Likewise, this study included incineration of carpet tiles as a disposal method, but Dutch waste incineration plants proved to be uncapable of incinerating carpets. This measure was included for modeling purposes, as it is one of the features people will look for when modeling the emissions of the industry, but any policy advice will fail on implementation if this measure is selected. This indicates the need for a critical reflection of the modeling results by the researcher, given the model constraints and limitations.

VIII. Beyond the model

With a conceptual model established with the aid of the industry, valid nil-scenario modeling results and the calculation of the effects of certain (policy) measures, the model has served its purpose. Depending on the type of research, this could either mark the end of the analysis or be the starting point. This study suggests to conduct a multi-criteria analysis on these results, to identify which measures are the most likely to be adapted by the industry. As these results are categorized in different resource leak areas, measures can be combined as discussed earlier. This is achieved through a morphological chart design approach in the study.

IX. The framework

In conclusion, a framework is discussed which facilitates the establishment of a model. This model simulates the emissions and sustainability of any industry seeking sustainability. This framework proposes a design approach according to the following steps:

Step 1: Needs & requirements of the model

A list of the needs and requirements for the model is created, to get a basic understanding of the functionality of the model. This list is preferably created with the end-user of the model, either being the industry or the government. The MoSCoW methodology proved to be excellent for this purpose.

Step 2: Understanding the current process

A model cannot be established without proper insights into the entire supply chain. Through the questions “what”, “why”, “who”, “how” and “where”, the researcher is encouraged to fully explore the modeled industry and it’s logistic operations.

Step 3: Displaying the current supply chain

The current scenario will be one of the most difficult to establish modeling scenarios, as well as one of the most important. This will become the primary focus of validation. It will become the foundation of all modeling efforts. A visual presentation will help the researcher identifying modeling relations as well as be a tool for validation later on.

Step 4: Identification resource leaks and fixes
Through the establishment of the MoSCoW list and the identification of the current supply chain, some measures will already have been identified that will cause an increase of sustainability for the industry. In this step, the researcher is encouraged to look at the model and literature to discover more sustainability increasing measures or discover general areas where resource leaks occur.

Step 5: Full conceptual model & subsystems
With insights in ways how the industry can establish greater sustainability, these measures are to be presented as future scenarios. They have to be adapted into the model. Sub-systems are generated that describe in greater detail how the system operates. If a measure cannot be implemented into the model, it either indicates that this measure does not affect the system, or that the conceptual model is missing some aspects and would require an iteration/refinement.

Step 6: Quantification
With all sub-systems and overall system known, all relationships are quantified. A mathematical equation is generated that will process the, in step 1 identified, input variables into output variables. This quantification is area specific, and is thus advised to be primarily based on local data sources or national averages.

Step 7: Validation
When this mathematical model is completed, all input variables are set to reflect the current situation. This allows for several validation efforts. The primary focus of validation should be a manufacturers EPD, giving an accurate measure of the expected nil-alternative results. If the model is found to produce accurate results in the nil-alternative, all other methods of validation can be applied to the model

Step 8: Model usage
With a valid model, the model can be used to calculate the effects of different means on the system. Keep in mind that the model is a distilled representation of the actual system and with that, limitations apply to the modeling results. Some effects cannot be expressed in the model and are up to the researcher to consider and describe.

X. Conclusion and further research

This article proposes a framework to constructing a mathematical model of a failing supply chain. This framework is orientated at designing sustainability increasing measures for an industry, thus heavily relies on design principles. Within this article, the example is presented of the carpet tile industry, but any other industry can be examined using the same framework. The finished product that this framework describes is a model that is able to accurately calculate different environmental effects of any industry by identifying opportunities in resource leaks. The quantification of any policy advice is strongly encouraged as it is a great tool to assess the costs/benefits, limiting the chances of a misjudgment.

Further research is advised to improve upon this framework. Case experiments and other empirical researches should be conducted to see if this framework holds ground when applied to other industries than the carpet industry. A second analysis should be conducted on how well this framework behaves for measures in the distant future. The described example discusses the identification of currently available measures, with an implementation time of up to 10 years. Highly technologically advanced measures could be harder to identify and have greater uncertainty. This analysis could indicate the need of refinement for the framework to incorporate measures futuristic of nature.

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