GALATASARAY UNIVERSITY
GRADUATE SCHOOL OF SOCIAL SCIENCES
BUSINESS ADMINISTRATION

# PROPOSITION OF A NEW SUSTAINABILITY PERFORMANCE EVALUATION MODEL AND ITS APPLICATION ON ENERGY PROJECTS

**DOCTORAL DISSERTATION**

**Hüsnü Yağmur KARABULUT**

**Thesis Supervisor: Prof. Dr. Gülçin BÜYÜKÖZKAN FEYZİOĞLU**

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# ÖNSÖZ

Öncelikle tez çalışmamda bana yol gösteren, başından beri destek olan ve yönlendiren tez danışmanım sayın Prof. Dr. Gülçin Büyüközkan Feyzioğlu'na yürekten teşekkür ediyorum. Farklı bir programdan olmama rağmen beni doktora öğrencisi olarak kabul etti, daima büyük bir anlayışla zaman ayırdı, fikirler verdi, yepyeni ve farklı bakış açıları kazandırdı. Benim için çok özel ve değerli bir deneyim oldu.

Daha sonra tez izleme komitesi üyeleri sayın Prof. Dr. Yaman Öztek ve sayın Prof. Dr. Orhan Feyzioğlu hocalarıma tüm destekleri için teşekkürü borç bilirim. Ayrıca aldığım derslerde emeği geçen tüm öğretim üyelerine en içten sevgi ve saygılarımı iletiyorum. Tezimde sektörel tecrübelerini paylaşarak ve zaman ayırarak destek veren uzmanlara da çok teşekkürler. Galatasaray Üniversitesi, benim için her zaman birçok güzel anıyla dolu bir tecrübe olarak kalacak.

Yüksek lisansımı takiben on yıllık bir özel sektör tecrübesinden sonra akademik dünyaya geri dönmek kolay bir karar değildi. Diğer taraftan iş hayatımda edindiğim tecrübe ve bilgi birikimini kullanmak istiyordum. Bu aşamada beni cesaretlendiren sevgili Dr. Gürdal Ertek'e özellikle teşekkür etmek isterim. Tüm bu süreçte hem bana kolaylık sağlayan firmama, hem tüm bu süre boyunca destek olan eşime ve aileme içten teşekkürlerimi sunuyorum.

Mayıs 2017

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# ABBREVIATIONS

| | |
|---|---|
| AHP | Analytic Hierarchy Process |
| ANP | Analytic Network Process |
| DEMATEL | Decision Making Trial and Evaluation Laboratory |
| DM | Decision Maker |
| ELECTRE | ELimination Et Choix Traduisant la REalité |
| GDM | Group Decision Making |
| GRI | Global Reporting Initiative |
| LCA | Life Cycle Analysis |
| MCDM | Multi-Criteria Decision Making |
| MOORA | Multi-Objective Optimization on the Basis of Ratio Analysis |
| PROMETHEE | Preference Ranking Organization Method for Enrichment Evaluation |
| SPE | Sustainability Performance Evaluation |
| TOPSIS | Technique for the Order of Prioritisation by Similarity to Ideal Solution |
| VIKOR | VIseKriterijumska Optimizacija I Kompromisno Resenje |
| WtE | Waste-to-Energy |

# LIST of SYMBOLS

| | |
|---|---|
| **$C_j$** | Evaluation criterion |
| **$A_i$** | Decision alternative |
| **$\lambda_k$** | $k^{th}$ Decision Maker's weight |
| **CI** | Consistency index |
| **CR** | Consistency ratio |
| **RI** | Random index |

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# RÉSUMÉ

La durabilité est une préoccupation majeure pour les décideurs, les institutions non gouvernementales, les milieux universitaires, les acteurs commerciaux et les particuliers. Les activités durables ne sont plus une fonctionnalité « bon à avoir » ; ils sont devenus la manière naturelle de faire des affaires. Avec l'augmentation des opinions critiques, les changements sociaux et les sensibilités environnementales, l'une des principales barrières pour un monde plus durable est le manque des méthodes communes de mesure. Il y a beaucoup de débats sur la façon de prévoir, de surveiller et de faire rapport sur le rendement global de la durabilité des entreprises, des projets, des produits, etc. Cette étude suggère que de nombreux problèmes en cours résulteraient du manque de méthodologies largement reconnues pour capter les impacts de la durabilité, dans un équilibre et faisable, qui permet pratiquement de comparer, d'évaluer et de déclarer. Ainsi, il y a une nécessité pour disposer de cadres d'évaluation de la performance de durabilité suffisamment souples pour s'adapter à diverses fins.

Ce travail tente de fournir une solution à ce défi en proposant un cadre d'évaluation de performance durable, adaptable et intégré qui repose sur un modèle conceptuel solide et flexible combiné aux méthodes de prise de décision multi-critères (PDMC). Une vaste revue de la littérature se déroule tout d'abord pour prendre un aperçu de l'état de l'art de la recherche connexe et pour identifier les déficits et les besoins. Par la suite, un modèle conceptuel est développé avec un grand nombre de critères hiérarchiquement structurés pour couvrir autant d'aspects durables que possible. L'objectif est de proposer tous les facteurs pratiquement applicables à évaluer pour la capture intégrale des impacts globaux de la durabilité. Ces facteurs peuvent être étendus avec des indicateurs supplémentaires et des indicateurs spécifiques à l'industrie, ou éliminés pour se concentrer sur certains aspects des opérations commerciales. Ce modèle est adaptable pour des industries différentes, produits, projets et chaînes d'approvisionnement, entre autres. Une fois que les critères sont identifiés, leurs poids dans le problème global de la prise de décision sont d'abord évalués, puis les alternatives disponibles sont comparées et sélectionnées par des experts. Ces procédures sont méthodologiquement soutenues par des méthodes PDMC, transformant ainsi le modèle conceptuel en un cadre étendu.

Le développement de ce cadre commence par une revue de la littérature très détaillée pour analyser les publications liées à l'évaluation de la performance de la durabilité en mettant l'accent sur les entreprises. Cette revue documente d'abord l'état actuel, classe les publications, analyse les tendances et associe les concepts principaux, ainsi qu'une analyse des déficits, sur laquelle d'autres activités de recherche sont prévues. Les résultats de cette section d'évaluation suggèrent que l'évaluation de la performance de la durabilité reste un thème populaire, tant en termes de cadres conceptuels que de techniques analytiques. Les entreprises ont besoin d'outils adaptables, pratiques et objectifs qui sont utilisables pour l'analyse comparative et le reporting de leurs performances de durabilité, ce qui peut être réalisé en combinant des modèles conceptuels robustes mais flexibles avec des méthodes analytiques. Une fois que les besoins sont mieux compris, l'armature du cadre proposé est conçue. Cette base

est un modèle de critères en couches avec 4 niveaux, l'objectif placé au niveau supérieur (c'est-à-dire l'évaluation de la performance de la durabilité), les critères d'évaluation aux niveaux inférieurs et les alternatives disponibles au niveau le plus bas. Cette hiérarchie basique de type arbre avec les dimensions principales économiques, environnementales et sociales est choisie pour sa facilité de compréhension, sa large reconnaissance dans l'industrie et son adaptation pratique à des fins diverses, étant donné que la force du cadre proposé réside dans son applicabilité réelle dans l'industrie, en Turquie et à l'échelle mondiale.

Il existe différents cadres pour évaluer et rendre compte de la performance de la durabilité dans le monde des affaires et dans la littérature. Néanmoins, beaucoup de ces cadres ont une portée et une profondeur limitées, fréquemment sur certains aspects de la durabilité. En outre, bon nombre des cadres largement utilisés ne sont pas conçus pour des entrées numériques. Cette étude suggère que les parties prenantes, les entreprises inclues, ont besoin d'outils facilement applicables qui peuvent recueillir des opinions d'experts pour différentes catégories de durabilité, puis combiner ces opinions en messages de base (par exemple, un seul score de durabilité) afin de surveiller les progrès au fil du temps et de comparer avec les concurrents ou d'autres options. Ainsi, ces cadres doivent être basés sur des méthodes numériques. Le cadre proposé repose sur cette idée. Il permet une évaluation qualitative et quantitative plus structurée, standardisée, simple et connue. Ces techniques PDMC qui sont intégrées dans ce modèle de critères permettent une analyse approfondie de la durabilité scientifiquement robuste, innovante et techniquement réalisable.

Le cadre comprend un modèle conceptuel qui est un arbre de critères générique, utile et adaptable à 4 niveaux qui présente à ses utilisateurs l'option de l'ajuster spécialement aux outils de recherche d'opérations analytiques. Le modèle est développé avec une revue de littérature très détaillée, soutenue par des avis d'experts. Pour confirmer sa plausibilité, l'ensemble du modèle est testé et commenté par des experts industriels, après quoi des ajustements mineurs et des améliorations sont entreprises. Le modèle final se compose de 3 dimensions principales, 12 critères de 2ème niveau, 37 critères de 3ème niveau et 107 critères de 4ème niveau. Ensuite, à l'étape suivante, ce modèle est combiné avec des techniques analytiques pour le mettre en service. À cette fin, les méthodes PDMC sont préférées en raison de leur adéquation à la prise de décision sous différents objectifs généralement contradictoires. La méthode utilisée dans le cadre proposé repose sur l'application consécutive de deux techniques de décision multicritères (TDMC); Processus de hiérarchie analytique (PHA) pour déterminer les poids d'importance des critères d'évaluation et VIKOR (VIseKriterijumska Optimizacija I Kompromisno Resenje) pour les classements des alternatives (par exemple, entreprises, projets, produits, chaînes d'approvisionnement, etc.). Pour réduire le biais qui peut être introduit par un seul expert, les évaluations sont recueillies dans un environnement de prise de décision en groupe (PDG) à partir de plusieurs experts. En d'autres termes, le cadre se compose d'un modèle de critères d'évaluation de performance de durabilité avec des étapes PHA-VIKOR clairement définies sous PDG pour guider les gestionnaires d'entreprise afin de mieux prédire ou faire rapport l’impact de leur choix sur la durabilité.

Le cadre proposé est ensuite appliqué dans un domaine choisi pour illustrer comment cela fonctionne. En tant que zone d'application, le cadre proposé est pondéré pour l'industrie de l'énergie. Pour démontrer son efficacité, le cadre est appliqué sur deux études de cas réelles pour évaluer la durabilité de différentes alternatives de projets énergétiques. Dans la première étude de cas réelle, 4 centrales à énergie renouvelable et thermique de taille similaire de Turquie sont évaluées avec les 3 premiers niveaux de l'arbre des critères. Les résultats suggèrent que la « centrale éolienne » et la « busine de biogaz » sélectionnées sont présentées comme une solution définie comme étant les projets les plus durables. VIKOR peut proposer de telles solutions de compromis. Parmi les projets d'énergie sélectionnés, la « centrale hydroélectrique » se classe 3ème et la « centrale à gaz naturel » se classe au dernier rang. Dans la 2ème étude de cas réelle, une branche complète du critère-arbre, des aspects environnementaux, est appliquée pour illustrer comment le modèle peut être appliqué de manière flexible. Cette deuxième démonstration est réalisée avec tous les 4 niveaux de critères, sur 4 projets Waste-to-Energie de Turquie. Ces projets peuvent traiter les déchets solides urbains et, en même temps, produire de l'énergie en tant que solution multiple pour les municipalités. Les résultats montrent que l'installation de « digestion anaérobie » (biogaz) est le projet le plus respectueux de l'environnement, alors que l'option « décharge » est la plus performante. Les deux études de cas vérifient que le cadre est solide en tant que groupe de critères souples soutenu par les méthodes PDMC-PDG avec des résultats réalisables pour la sélection des projets de production d'énergie. Des études de cas montrent que le cadre fournit des résultats supérieurs avec des scores de performance clairs. Bien que les impacts économiques, environnementaux et sociaux soient mesurés pour des projets énergétiques, le cadre est applicable également pour des autres secteurs et des autres intentions.

Le travail se différencie en mettant l'accent sur l'analyse de projets concrets au lieu des technologies énergétiques génériques, la prise en compte d'échelles de projets similaires et l'introduction d'une structure de critères forte avec des priorités réglables. Le cadre repose sur un vaste ensemble de critères d'évaluation, qui couvrent non seulement presque tous les aspects de la durabilité des opérations commerciales, mais sont également définis au niveau par niveau, de sorte que d'autres méthodes PDMC peuvent également être appliquées, si désiré. Les catégorisations de critères et les nouvelles définitions de critères ajoutent également de la valeur à cette étude. En outre, cette structure en couches décompose l'exercice d'évaluation et facilite la collecte d'avis d'experts. Il permet aux décideurs d'utiliser partiellement le modèle, selon les besoins spécifiques, pour des applications plus faciles. Ces critères permettent également aux experts de comprendre ce qu'il faut considérer exactement selon chaque critère en examinant leurs sous-critères. Dans la littérature, il n'existe pas de modèle de développement équilibré conceptuel (connu) avec 4 couches avec une couverture thématique. Ces critères sont formulés sans aucune opinion intégrée et permettent la notation, au lieu des descriptions qualitatives. Un autre avantage principal est la structure équilibrée de l'arbre de décision ; non seulement les critères économiques, environnementaux et sociaux sont presque également représentés, leur nombre convient également aux méthodes PDMC. Une autre innovation de recherche est l'intégration de ce modèle avec PHA et VIKOR sous PDG, qui étend le modèle conceptuel à un cadre soutenu par des méthodes analytiques. Dans la littérature, les méthodes PHA-VIKOR supportées par PDG sont disponibles, mais aucune d'entre elles ne se concentre sur l'évaluation de la performance de la durabilité avec des modèles validés par des experts dans cette profondeur. Les études de cas reflètent également cette innovation ; ces méthodes PDMC n'ont pas encore été utilisées jusqu'à présent dans la littérature pour sélectionner des solutions de projets énergétiques concrètement définies, de taille similaire ou mises à l'échelle, y compris les énergies renouvelables, les centrales thermiques et les installations résiduaires à l'énergie.

Distinguer les technologies et les projets énergétiques est une nouvelle perspective pour ce domaine de recherche.

Pour les recherches futures, la dépendance des critères d'évaluation et de leurs interactions peut être analysée pour étendre cette analyse. Les méthodes PDMC sont fréquemment utilisées pour traiter les entrées incertaines et imprécises des experts. La logique floue peut être une solution appropriée pour prendre en compte l'imprécision naturelle des préférences humaines lors des processus décisionnels. En tant que point de vue de la recherche, les résultats du cadre proposé dans cette étude peuvent être comparés à la combinaison PHA-VIKOR floue.

**Mots clés** : durabilité, évaluation de performance de la durabilité, secteur d'énergie, prise de décision multi-critères, processus de hiérarchie analytique, VIKOR.

# ABSTRACT

Sustainability is a key concern for policy makers, non-governmental institutions, academia, business actors and individuals. Sustainable activities are not a ‘nice to have’ feature anymore; they have become the natural way to do business. With growing criticism, social change and environmental sensitivities one of the main barriers for a sustainable world is common measurement methods. There is much debate about how to predict, monitor and report on the overall sustainability performance of companies, projects, products etc. This study suggests that many such ongoing problems are a result of the lack of widely-recognized methodologies for capturing sustainability impacts in a balanced and feasible manner that practically allows comparison, benchmarking and reporting. Thus, there is a need for sustainability performance evaluation frameworks that are flexible enough for adapting to various purposes.

This work attempts to provide a solution to this challenge by proposing a standalone, adaptable and integrated sustainability performance evaluation framework, which is based on a strong and flexible conceptual criteria-tree combined with Multi-Criteria Decision Making (MCDM) approaches. An extensive review of the literature is conducted first to take a snapshot of the state-of-the-art of related research and to understand the gaps and needs. Thereafter, evaluation criteria are defined to setup a conceptual model that is hierarchically structured to cover as much sustainability aspects as possible. The aim is to come up with all practically applicable factors to be evaluated for capturing the overall sustainability impacts in an inclusive way. These factors can be extended with additional metrics and industry-specific indicators, or eliminated to focus on selected aspects of business operations. This model is adaptable to various industries, products, projects and supply chains, among others. Once the criteria are identified, their weights in the overall decision-making problem are evaluated first, and then available options to be compared and selected are assessed by experts. These procedures are methodologically supported with MCDM methods, thus transforming the conceptual model into an extensive framework.

The development of this framework starts with a very detailed literature review to analyze sustainability performance evaluation related publications with a focus on businesses. This review first documents the current status, categorizes publications, analyzes the trends and links main concepts, as well as provides a gap analysis, on which other research activities are planned. The results of this review chapter suggest that the evaluation of sustainability performance remains a popular theme, both in terms of conceptual frameworks and analytical techniques. Businesses need adaptable, practical and objective tools that are usable for benchmarking and reporting their sustainability performance, which can be achieved by combining robust but flexible conceptual models with analytical methodologies. Once the needs are better understood, the backbone of the proposed framework is designed. This basis is a layered criteria-model with 4 levels, the objective placed at the top level (i.e. sustainability performance evaluation), evaluation parameters stationed at the lower levels, and the available alternatives located at the lowest level. This basic tree-type

hierarchy with economic, environmental and social main dimensions is selected for its ease of understanding, wide recognition in the industry and practical adaptation for various purposes, considering that the proposed framework's strength lies in its actual applicability in the industry, in Turkey and globally.

There are various frameworks for evaluating and reporting sustainability performance in the business world and in literature. Nevertheless, many of these frameworks have limited scope and depth, frequently overlooking certain aspects of sustainability. Furthermore, many of the widely-used frameworks are not designed for numerical inputs. This study suggests that stakeholders, businesses included, need easily applicable tools that can collect opinions of experts for different sustainability categories and then combine these opinions into basic messages (e.g. a single sustainability score) in order to monitor the progress over time and compare with competitors or alternative options. Thus, such frameworks shall be based on numerical methods. The proposed framework is based on this idea. It allows a more structured, standardized, straightforward and well-known qualitative and quantitative evaluation. Those MCDM techniques that are integrated into this criteria model allow a thorough sustainability analysis that is scientifically robust, innovative and technically feasible.

The framework includes a conceptual model that is a generic, useful and adaptable 4-level criteria-tree which presents its users the option to adjust it especially to analytical operations research tools. The model is developed with a very detailed literature review, supported by expert opinion. To confirm its plausibility, the whole model is tested and commented on by industrial experts, after which minor adjustments and improvements are undertaken. The eventual model consists of 3 main dimensions, 12 $2^{nd}$ level, 37 $3^{rd}$ level and 107 $4^{th}$ level criteria. Then, in the next step, this model is combined with analytical techniques to bring it into operation. For this purpose, MCDM methods are preferred due to their suitability for decision-making support under various usually conflicting objectives. The method used in the proposed framework is based on the consecutive application of two MCDM methods; Analytic Hierarchy Process (AHP) for determining the level of importance of evaluation criteria on the outcome and VIKOR (*VIseKriterijumska Optimizacija I Kompromisno Resenje*) for ranking alternatives (e.g. companies, projects, products, supply chains etc.). To reduce the bias that can be introduced by one single expert, evaluations are gathered in a Group Decision Making (GDM) environment from multiple experts. In other words, the framework consists of a sustainability performance evaluation criteria model with clearly-defined AHP-VIKOR steps under GDM for guiding business managers to better predict or report on the sustainability impacts of their own choosing.

This framework is then used in a selected topic to illustrate how it works. As an application area, the proposed framework is weighted for the 'energy' industry. To demonstrate its effectiveness, the framework is applied on two real case studies for assessing how sustainable different energy project alternatives are. In the first real case study, 4 similarly sized renewable and thermal power plants from Turkey are evaluated with the first 3 levels of the criteria tree. The calculations suggest that both the selected 'wind power plant' and 'biogas plant' are presented as a solution set as the most sustainable projects. VIKOR can propose such compromise solutions. Among selected energy projects, 'hydropower plant' ranks $3^{rd}$ and 'natural gas plant' ranks last. In the $2^{nd}$ real case study, one complete branch of the criteria-tree, environmental aspects, is applied to illustrate how the model can be flexibly applied. This second demonstration is carried out with all 4 criteria levels, on 4 Waste-to-Energy projects from Turkey.

These projects can treat urban solid waste, and at the same time produce energy as a multi-solution for municipalities. Results show that the 'anaerobic digestion' (biogas) facility is the most environmentally friendly project, while the 'landfill' option performs the worst. Both case studies verify that the framework is strong as a flexible criteria pool supported by MCDM-GDM methods with feasible results for selecting energy generation projects. Case studies show that the framework provides superior results with clear performance scores. Although the economic, environmental and social impacts are measured for energy projects, the framework is applicable in other industries and purposes as well.

The work differentiates itself in its emphasis to analyze actual projects instead of generic energy technologies, its consideration of similar project scales, and the introduction of a strong criteria structure with adjustable priorities. The framework is built upon an extensive set of evaluation criteria, which not only cover almost all sustainability aspects of business operations, but are also laid out level-by-level so that other MCDM methods can also be applied, if desired. Criteria categorizations and new criteria definitions also add value to this study. Moreover, this layered structure breaks down the evaluation exercise and facilitates the collection of expert opinions. It allows decision makers to partially use the model, depending on specific needs, for easier applications. These criteria also help experts in understanding what to consider exactly under each criterion by looking at their sub-criteria. In literature, there is no (known) conceptual balanced sustainability model with 4 layers with such thematic coverage. These criteria are formulated without any embedded opinions and allow scoring, instead of qualitative descriptions. Another main advantage is the balanced structure of the decision tree; not only are the economic, environmental and social criteria almost equally represented, their numbers are also suitable for MCDM methods. Another research innovation is the integration of this model with AHP and VIKOR under GDM, which extends the conceptual model into a framework supported with analytical methods. In literature, GDM-supported AHP-VIKOR methods are available, but none of them focus on sustainability performance evaluation with expert-validated models in this depth. The case studies also reflect this innovation; these MCDM methods have not been put into use in literature for selecting concretely defined, similarly sized or scaled energy project alternatives, including renewable energy, thermal power plants and Waste-to-Energy facilities. Distinguishing energy technologies and energy projects is a new perspective for this field of research.

For future research, the dependence of evaluation criteria and their interactions can be analyzed to extend this analysis. MCDM methods are frequently used for processing uncertain and imprecise inputs from experts. Fuzzy logic can be a suitable solution for taking the natural vagueness of human preferences into account during decision making processes. As a research perspective, the results of the proposed framework can be compared with a fuzzy AHP-VIKOR method.

**Key words**: Sustainability, sustainability performance evaluation, energy, Multi Criteria Decision Making, AHP, VIKOR.

# ÖZET

Sürdürülebilirlik konusu; günümüzde karar vericiler, sivil toplum örgütleri, bilim insanları, iş dünyası ve bireyler için temel bir sorun haline gelmiş bulunmaktadır. Artık sürdürülebilir faaliyetler 'olsa da olur' anlayışının ötesine taşınmakta, iş yapmanın doğal bir yolu haline gelmektedir. Eleştirel görüşler, toplumsal değişimler ve çevresel hassasiyetler artarken daha sürdürülebilir bir dünya için en önemli engellerden biri olarak ortak ölçüm metodlarının eksikliği göze çarpmaktadır. Firmaların, projelerin, ürünlerin vb. sürdürülebilirlik performanslarının nasıl daha iyi öngörülebileceği, izlenebileceği ve raporlanabileceğine yönelik tartışmalar sürmektedir. Bu çalışma; süregelen bu gibi problemlerin temel sebeplerinden biri olarak sürdürülebilirlik etkilerinin pratik olarak kıyaslanması, benzerleriyle karşılaştırılması ve raporlanması için dengeli, uygulanabilir ve geniş kabul görmüş metodolojilerin eksikliğine işaret etmektedir. Bu açıdan farklı kullanım amaçlarına uyarlanabilecek esnekliğe sahip sürdürülebilirlik performans değerlendirmesi çerçevelerine ihtiyaç duyulmaktadır.

Bu çalışmada yukarıda sözü edilen sorunun çözümüne yönelik olarak, güçlü ve esnek bir kavramsal kriter ağacına dayanan, Çok Ölçütlü Karar Verme (ÇÖKV) metodlarıyla desteklenen, tek başına kullanılabilen bütünleşik bir sürdürülebilirlik performansı değerlendirme çerçevesi ortaya konmaktadır. Öncelikle çok detaylı bir literatür taraması ile bilimsel yazının mevcut durumu araştırılmış, böylece eksikler ve ihtiyaçlar derinlemesine belirlenmiştir. Ardından hiyerarşik şekilde konumlandırılmış çok sayıda kriterden oluşan ve sürdürülebilirlik etkilerini mümkün olduğunca geniş anlamda yakalayacak bir kavramsal bir model geliştirilmiştir. Bu yaklaşımdaki temel amaç, toplam sürdürülebilirlik performansını kapyasıcı bir bakış açısıyla algılamak için gerekebilecek faktörleri tüm yönleriyle belirlemek olmuştur. Bu faktörler ek metrikler ve sektöre özel göstergelerle genişletilebilecek veya operasyonların seçilen alanlarına daha iyi odaklanabilmek amacıyla modelden çıkarılabilecek şekilde tanımlanmıştır. Bu nedenle önerilen model birçok farklı sektöre, ürüne, projeye, tedarik zincirine ve benzeri yapılara uyarlanabilir niteliktedir. Değerlendirme kriterler seçildikten sonra tüm karar verme problemindeki ağırlıkları belirlenmekte, ardından seçilebilecek alternatifler bu kriterler ışığında sektörel uzmanlarca değerlendirilmekte ve seçilmektedir. Bu süreçlerin metodolojik bir bakış açısıyla ÇÖKV teknikleriyle desteklenerek yürütüldüğünden hareketle, önerilen kavramsal modeli de kapsayan bir çerçeve yapıdan söz etmek mümkündür.

Önerilen çerçeve yapının geliştirilmesine derinlemesine bir yazın taramasıyla başlanmaktadır. Burada özellikle iş uygulamalarına yönelik sürdürülebilirlik performansı değerlendirmesine yoğunlaşılmıştır. Bu taramada öncelikle yayınların güncel durumu incelenmiş, yayınlar kategorilere ayrılmış, yazındaki eğilimler ve gelişmeler analiz edilmiş, temel kavramlar arasındaki ilişkiler tanımlanmış ve bu bilgiler temelinde yazındaki eksiklikler ortaya konarak çalışmanın geri kalanı için yol gösterecek temel tespitler yapılmıştır. Yazın taramasının sonuçları; sürdürülebilirlik performansının değerlendirmesinin hem kavramsal modeller hem de analitik teknikler açılarından akademik ve iş çevrelerinde oldukça popüler bir konu olduğunu

göstermektedir. Bu analize göre iş dünyası, kendi sürdürülebilirlik performansını sağlıklı şekilde ölçmek, kıyaslamak ve raporlamak için uyarlanabilir özellikte, pratik ve objektif değerlendirme yöntemlerine ihtiyaç duymaktadır. Bu amaca yönelik olarak sağlam ancak esnek kavramsal modelleri, analitik metodolojilerle uygun şekilde kombine edilebilir. Temel ihtiyaçlar belirlendikten sonra önerilen çerçeve yapının iskeleti ortaya çıkarılmıştır. Bu çerçevenin temelinde 4 seviyeden oluşan katmanlı bir kriter yapısı yatmaktadır. En üst seviyede karar probleminin amacı (sürdürülebilirlik performansı) yer almakta, daha alt seviyelerde karar kriterleri bulunmakta, en alt seviyede ise seçilebilecek karar alternatifleri konumlandırılmaktadır. Sürdürülebilirliği ekonomik, çevresel ve sosyal boyutlarıyla hiyerarşik olarak değerlendiren bu yapının seçilmesinin temel sebebi, anlaşılmasının kolay olması, iş dünyasında kabul görmesi ve Türkiye ve dünyada endüstriyel uygulanabilirliği amaçlandığından kolay uyarlanabilmesidir.

İş pratiklerine ve yazına bakıldığında sürdürülebilirlik performansı ölçümü için çeşitli çerçeveler mevcuttur. Ne var ki bu çerçevelerin büyük çoğunluğu sınırlı kapsama ve derinliğe sahip olup, sürdürülebilirliğin geniş etkilerinin birçoğunu sıklıkla gözden kaçırmaktadır. Bunun ötesinde iş dünyasında kullanılmakta olan bir takım çerçeveler sayısal girdi almaya müsait değildir. İş dünyası da dahil olmak üzere paydaşların temel ihtiyacı, uzmanların görüşlerini farklı sürdürülebilirlik kategorilerinde toplayarak bu değerlendirmeleri birleştirecek ve nihai mesajlara (örn. sürdürülebilirlik endeksleri) dönüştürebilecek araçlardır. Böylece sürdürülebilirlik performansının zaman içindeki değişimi gözlenebileceği gibi, rakiplerle kıyaslama ve mevcut en sürdürülebilir alternatifi seçme de mümkün olacaktır. Bu fonksiyonları sağlayacak bir çerçevenin sayısal metodlara dayanması gerekir. Önerilen çerçeve bu temelde hem kalitatif hem kantitatif anlamda standart, adım adım ve anlaşılır bir değerlendirme imkanı tanımaktadır. Geliştirilen kriter modeline entegre edilen ÇÖKV teknikleri bilimsel olarak sağlam, yenilikçi ve uygulanabilir bir sürdürülebilirlik analizini mümkün kılmaktadır.

Geliştirilen çerçeve; jenerik, faydalı ve uyarlanabilir bir kavramsal 4 seviyeli kriter ağacı modeli içermekte ve kullanıcılarına özellikle yöneylem araştırması tekniklerini entegre etme alternatifi sunmaktadır. Model son derece detaylı bir yazın taraması ve uzman görüşleriyle oluşturulmuştur. Modelin ne ölçüde makul ve kullanılabilir olduğunu test etmek için endüstriden uzmanlarla çalışılmış ve alınan yorumlar ışığında gerekli düzeltme ve değişiklikler ele alınmıştır. Modelin nihai hali; sürdürülebilirliğin 3 temel boyutunda toplam 12 adet 2. seviye, 37 adet 3. seviye ve 107 adet 4. seviye kriterden oluşmaktadır. Bir sonraki adımda model analitik tekniklerle entegre edilerek performans ölçümünde kullanılabilir bir yapıya dönüştürülmüştür. Bu amaçla ÇÖKV metodlarının tercih edilmesinin temel sebebi, çok sayıda ve birbiriyle çelişebilen kriterin bulunduğu karar verme problemlerine olan yatkınlığıdır. Önerilen çerçevede arka arkaya kullanılmak üzere iki ÇÖKV tekniğinden yararlanılmıştır. Kriter ağırlıklarını hesaplamak için önce Analitik Hiyerarşi Prosesi (AHP) kullanılmakta, ardından firma, proje, ürün, tedarik zinciri ve benzeri yapılar için mevcut alternatifleri bu kriterler ışığında değerlendirerek sıralamak için VIKOR (*VIseKriterijumska Optimizacija I Kompromisno Resenje*) tekniğinden faydalanılmaktadır. Tek bir uzmanın görüşlerinin getirebileceği taraflılığı azaltmak için uzman değerlendirmeleri Grup Karar Verme (GKV) yaklaşımıyla birden fazla karar vericiden toplanmaktadır. Bir başKa deyişle önerilen sürdürülebilirlik performansı değerlendirme çerçevesi; bir kriter modeliyle bütünleşik ve GKV ortamında somut adımlarla uygulanan AHP-VIKOR tekniklerine dayanmakta ve bu şekilde iş dünyasının kendi sürdürülebilirlik etkilerini daha iyi öngörebilmesi ve raporlaması için kılavuzluk etmektedir.

Geliştirilen çerçeve, daha sonra nasıl ve ne ölçüde çalıştığını anlamak için seçilen bir alanda uygulanmıştır. Uygulama alanı olarak 'enerji' sektörü seçilmiş ve söz konusu kriterler bu sektör için ağırlıklandırılarak belirlenen enerji projelerinin sürdürülebilirlik performanslarının değerlendirilmesinde kullanılmıştır. Çerçevenin etkinliğini kanıtlamak için iki farklı vaka analizi için sayısal uygulama yapılmış ve bu şekilde önceden tanımlı enerji projelerinin ne ölçüde sürdürülebilir olduğu ayrıntılı olarak ortaya konmuştur. Birinci vaka analizinde Türkiye'de kurulu ve benzer kurulu güce sahip 4 farklı termik ve yenilenebilir enerji santrali, önerilen modelin ilk 3 seviyesi kullanılarak bir sürdürülebilirlik değerlendirmesine tabi tutulmuştur. Analizin sonuçları, önceden belirlenmiş olan rüzgar ve biyogaz enerji santrallerinin ikisinin birden en yüksek sürdürülebilirliğe sahip olduğunu göstermiştir. VIKOR tekniğinin böyle bir uzlaşı kümesi önerme özelliği bulunmaktadır. Diğer projelerden hidroelektrik santrali 3. sırada, doğalgaz çevrim santrali ise son sırada yer almıştır. İkinci vaka analizinde ise, önerilen modelin nasıl tek bir dalının kullanılabileceğini göstermek amacıyla yine enerji projeleri tek bir boyutta değerlendirilmiştir. Bu vaka analizinde modelin yalnızca çevresel kriterleri, bu sefer modelin tüm 4 seviyesi de kullanılarak yine Türkiye'den 4 farklı atıktan enerji üretimi projesinin değerlendirilmesi için uygulanmıştır. Atıktan enerji üretimi projeleri, belediyeler için kentsel katı atığı bertaraf ederken aynı zamanda enerji üretme imkanı tanıyarak çok amaçlı görevler üstlenebilmektedir. Uygulamanın sonucunda biyogaz tesisi en çevreci proje olarak belirlenmiştir. En düşük çevresel performansı ise düzenli katı atık depolama tesisi göstermektedir. Her iki vaka analizi de, ÇÖKV-GKV yöntemlerinin esnek bir kriter havuzuna entegrasyonuna dayanan bu çerçevenin enerji projelerinin seçiminde etkin rol üstlenebileceğine işaret etmektedir. Çerçeve, başarılı sonuçlar üretmekte ve karar vericilere somut sayısal performans ölçümü verileri sağlamaktadır. Her ne kadar bu analizlerde seçilen enerji projelerinin ekonomik, çevresel ve sosyal etkilerinin toplamı ölçülmüş olsa da çerçeve diğer seçilebilecek endüstrilerde farklı amaçlar için de kullanılabilir.

Bu çalışma, yazından belirli açılardan önemli derecede ayrışmaktadır. Özellikle jenerik teknolojilerden ziyade net ve somut olarak belirlenmiş olan spesifik projeleri karşılaştırması, projelerin karşılaştırılabilir büyüklükte olması gerektiğini vurgulaması ve son derece güçlü kriter hiyearşisi temel farklılıklar olarak öne çıkmaktadır. Ayrıca kriterlerin ihtiyaca göre yeniden ağırlıklandırılıyor olması, uyarlanabilir bir yapı sunmaktadır. Önerilen yapı, yalnızca sürdürülebilirliğin çok geniş bir alanını kapsayan çok sayıda kriterden oluşmamaktadır. Bu kriterler seviyeler halinde yapılandırılmış ve böylece arzu edilirse diğer ÇÖKV tekniklerinin aynı modele uyarlanmasını kolaylaştırmaktadır. Kriterlerin nasıl kategorilere ayrıldığı ve her bir kriter için verilen yeni tanımlar da yazına katkı olarak değerlendirilebilir. Katmanlı kriter yapısı, aynı zamanda böylesine karmaşık bir problemi daha basit parçalara ayırarak endüstriyel uzmanlardan görüş toplanmasına da yardımcı olmaktadır. Karar vericiler, modelin bütününü kullanabilecekleri gibi ihtiyaçları doğrultusunda modelin yalnızca daha üst seviye katmanlarını veya belirli bir dalını da uygulayabilmektedir. Yapının bir başka avantajı, uzmanlara kritelerin hangi alt kriterlerden oluştuğunu söylemesi ve böylece kriterin tanımının ve kapsamının daha iyi anlaşılmasını sağlayarak etkin değerlendirme yapılmasını desteklemesidir. Bilindiği kadarıyla yazında bu tip bir 4 seviyeli, sürdürülebilirliğin üç boyutuna dengeli dağıtılmış, böylesine kapsamlı bir tematik yayılıma sahip başka benzer bir model bulunmamaktadır. Kriterlerin gömülü yargılar içermesinden kaçınılmış, yalnızca sözel değerlendirmeye müsait tanımlardan kaçınılarak tüm kriterlerin skorlanacak yapıda olmasına özen gösterilmiştir. Dengeli bir hiyerarşi gözetilerek ekonomik, çevresel ve sosyal boyutlara benzer sayıda kriter tanımlanmış, aynı zamanda her bir kriterin altında tanımlanan alt-kriterlerin sayısı ÇÖKV tekniklerinin uygulamasına destek olacak şekilde belirlenmiştir. Çalışmanın bir başka yenilikçi yönü, modelin AHP-VIKOR teknikleriyle GKV temelinde entegre edilmesidir. Böylece ilk önerilen kavramsal model, analitik metodların desteğiyle kendi başına kullanılabilecek bir çerçeve haline getirilmiştir. Yazında GKV ile uygulanan AHP-VIKOR yaklaşımları bulunmaktadır. Ancak bunların hiçbiri, uzman doğrulamasına tutulmuş ve bu ölçüde derinlemesine bir sürdürülebilirlik performansı değerlendirmesi yapacak özellikte değildir. Vaka analizleri de öne çıkan bu avantajları desteklemektedir. Yenilenebilir enerji, termik enerji santralleri veya atıktan enerji için olsun, yazında teknolojiler yerine karşılaştırılabilir boyuttaki somut projeler özelinde, bu detayda sürdürülebilirlik odaklı ve bu ÇÖKV metodlarıyla desteklenen bütünleşik bir çerçeve mevcut değildir. Teknoloji ve proje ayrımına gidilmesi, bu konudaki araştırmalara kılavuzluk edebilir.

Gelecekte yürütülebilecek bilimsel araştırmalar için bu çalışmanın devamına yönelik bir perspektif olarak değerlendirmede kullanılan kriterlerin kendi aralarındaki bağımlılıkları ve karşılıklı etkileşimleri analiz edilebilir. ÇÖKV yöntemleri, sıklıkla belirsiz ve kesinlik içermeyen değerlendirme girdilerinin işlenmesinde kullanılmaktadır. Bulanık mantık yaklaşımı, kişilerin şahsi seçimlerinde doğal olarak bulunan muğlaklığı karar verme problemlerinde hesaba katmak için uygun bir çözüm olabilmektedir. Bu çalışmada önerilen yöntemin sonuçları, AHP-VIKOR kombinasyonunun bulanık mantık uygulamasıyla karşılaştırılabilir.

**Anahtar kelimeler**: Sürdürülebilirlik, sürdürülebilirlik performans değerlendirmesi, enerji sektörü, Çok Ölçütlü Karar Verme, AHP, VIKOR.

# 1 INTRODUCTION

Sustainable development can be defined as the "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). Another definition is the "development that meets the needs of the present while safeguarding Earth's life-support system, on which the welfare of current and future generations depends" (Griggs et al., 2013). Building upon this fundament, sustainable businesses implement policies that address the expectations of companies' stakeholders while not only defending and sustaining, but also enhancing society's and ecologic resources which will be indispensable by future generations (Deloitte and Touche and BCSD, 1992).

Despite many voluntary initiatives, business efforts and intergovernmental actions, the sustainability of economic activities of today's world is frequently questioned. A sustainable business addresses the expectations of its stakeholders and at the same time preserves, protects and enhances internal and external human and natural resources for future generations (Deloitte and Touche and BCSD, 1992). In current settings, however, economic benefits are reaped locally, while environmental and social externalities are borne regionally and globally. Finding solutions to these problems and successfully managing sustainability remains a challenge, partly because there are no commonly agreed methods about how to evaluate the extent of different sustainability criteria and how to combine them to give policy- and decision-signals. Assessing the achievement level of sustainability is a need for countries, industries, supply chains and individual firms. The question of how to assess it still remains open. The multidimensional and intertwined nature of the sustainability context in terms of ecologic resources, societal sensitivities and economic realities complicates this challenge. The conventional understanding of the sustainable development concept shall not only be seen as economic growth in the light of the alarming pressure on ecosystems, such as overfishing, deforestation, greenhouse gas emissions, overuse of freshwater etc., but also with regard to societal changes that demand fair employment, work-private life balance, safe workplace and integration with local communities, among many other aspects.

In today's world, businesses thrive to attain the highest financial results while preserving and improving their corporate reputation, competitiveness and innovation and balancing their environmental and social footprints. These activities are based on the assumption of an infinite-resources and perpetual-growth economy, which nowadays meets the limits of a finite planet. This infinite-planet understanding dates back to John Locke and Adam Smith, when the world was scarcely populated and available resources seemed more than sufficient for supporting continuous expansion of human activities (Zencey, 2014). The world has changed since then – today the planet is home to more than 7 billion people, who want to raise their living standards by consuming more resources than their ancestors did in the past. The so-called 'new economy' shall be based on a notion that there exist ecological and societal limits to economic activities. It is acknowledged that anthropogenic activities have an unavoidable level of environmental footprint with externalities going beyond geographic boundaries. Therefore, economic activities will have inevitable impacts anywhere between the two states of an unpopulated pristine world and the uncontrolled overutilization of scarce resources. Societal responses to these impacts include the continuation of status-quo, industrial ecology, deep ecology (low-tech where possible) or even radical ecology (return to low-tech) (Allenby, 1999), some of which have little prospect for the future. Obviously, this is a tremendously complicated problem with many stakeholders, conflicting interests, political dynamics, human expectations, generational and geographic justice, resource availability, technology and innovation, to name a few, with no easy solution.

In the last three decades, advancing economic growth and environmental quality together has been a major focus of literature. Many papers discussed the relationship between income growth and pollution, also known as environmental Kuznets curve, suggesting that growing incomes will first increase and then decrease emissions and ambient concentrations (Grossman and Krueger, 1995; Chimeli and Braden, 2009). Accordingly, at earlier stages of industrial development, environmental protection expenditures are negligible to prioritize capital accumulation for economic growth. Over time, these expenditures show a significant increase (Phillis and

Andriantiatsaholiniaina, 2001). However, environmental protection is a public good that shall not be downscaled to industrial pollution only. Its optimal provision includes costs related to the restoration of ecosystems, species re-introduction, reforestation and similar items as remedy options. These external costs are mostly unwillingly and unknowingly overtaken by the society. Global warming, for instance, is a consequence of mostly industrial greenhouse gas emissions that are being emitted to the atmosphere with almost no limitation, the burden of which is carried by the whole world in various ways, instead of the polluters themselves. This economic structure is obviously flawed, resulting in ecologic deterioration and social inequalities. Having said that, linking economic activities with environmental problems in a straightforward way would also be incorrect. The interactions are more complex than simple cause-effect relationships.

Sustainable practices are expected to comply with related legislation, take a precautionary environmental approach and contribute to corporate competitiveness at the same time (Stakeholder Engagement Standard (exposure draft), 2005; O'Connell et al., 2013). Under these circumstances, economic, environmental and social aspects of business operations shall be considered as a whole. These aspects can be perceived together with a 'sustainability performance' view point. As mentioned, improving sustainability performance of a company, project, product or supply chain necessitates its evaluation and comparison over time or with competitors in a holistic manner. Understanding the potential and actual impacts of business operations can guide companies to take better decisions. This study therefore deals with the concept of Sustainability Performance Evaluation (SPE) to propose a novel SPE framework as a decision-making support tool for businesses.

SPE can be described as quantifying a firm's total performance according to corporate performance indicators, which can include decisions, policies and actions of a company creating social, environmental and/or economic outcomes, in different time periods or to compare different firms' performance within a single time frame. Businesses expect suitable SPE frameworks that are not only able to evaluate their sustainability performance relatively easily and objectively, but also allow benchmarking with their competitors. Conceptual models constitute the basis of such frameworks and do provide different criteria structures to better understand the constituents of the overall sustainability performance. Some of these conceptual models are also extended into numerical analyses to quantify the level of the achievements. These high expectations make SPE a rather complicated process, where businesses struggle to find the most appropriate framework and apply them in a consistent, easily understandable, standardized way for their monitoring and reporting purposes. This study suggests that widely-recognized and simple SPE structures, such as illustrated in ***Figure 1.1***, can help organizations to adopt and apply such SPE frameworks easier.

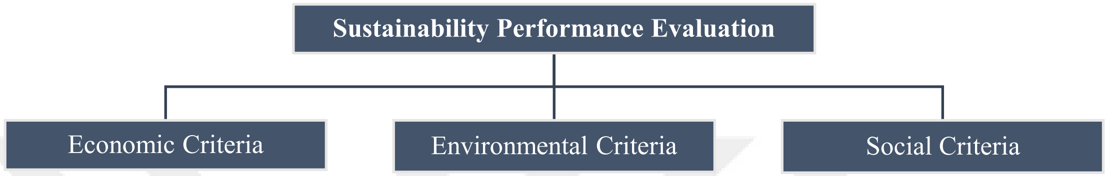


Figure 1.1. Basic Structure of Conceptual SPE Models

When it comes to the topic of sustainability performance, there are different routes researchers and industry specialists have taken. One route of sustainability performance regards sustainability as a pass/fail concept, categorizing activities either as sufficiently sustainable, or not. For such approaches, lower thresholds or similar limitations shall be defined. This prevents very significant incompliant issues with small weights not to get lost in the aggregation process, while it leaves less reasons to improve beyond the pre-defined sustainability threshold. Another route is based on the progress of sustainability performance, where positive improvement matters the most instead of the absolute baseline. Some methods also combine these two notions. In the proposed SPE framework, no such minimum sustainability thresholds are defined.

Numerical methods are needed to guide stakeholders about sustainability performance, considering that quantitative figures are helpful in capturing the progress, achievement of targets and comparison with competitors. For this purpose, analytical methods can be combined with conceptual criteria structures to bring such models into operation. In this work, a criteria tree is developed, which is then integrated with Multi-Criteria Decision Making (MCDM) techniques for understanding how much each parameter affects the overall decision (i.e. their priority, or weight) and determining how well each solution alternative performs with regard to these weighed criteria. For weighing the criteria, Analytic Hierarchy Process (AHP) method is applied. For evaluating the alternatives, VIKOR (VIseKriterijumska Optimizacija I Kompromisno Resenje) is used. These two methods are employed in a Group Decision Making (GDM) environment. These techniques will be described in detail in section 4.2. Once this framework is presented in detail, it will be applied on a selected field. For this purpose, the area of energy is chosen. Therefore, the framework will be employed in two real case studies in energy project selection.

The study starts with a very detailed literature review in chapter 2, which will be followed by the SPE model development in chapter 3. Then, in chapter 4 this model will be brought into operation by integrating it with MCDM methods. Chapters 5 and 6 will demonstrate the application of the proposed framework in the area of energy; more specifically on the selection of energy projects and waste-to-energy projects, respectively. Managerial and theoretical implications of this framework will be described in chapter 7, followed by the conclusions and perspectives in chapter 8.

This thesis aims to answer the following research questions, one after another. First of all, the answer to the question of “Which ‘sustainability performance’ shall be evaluated?” is sought. Then, two research questions are discussed; “What needs to be measured to capture the performance?” and “How shall the criteria be determined?”, respectively. Then, the answer to “How shall the criteria be assessed?” and “How shall the criteria assessments be aggregated to reach a result?” is explored. The goal is to come up with an applicable, innovative and generic model that can actually be used in literature and industry as a basis for assessing the level of sustainability impacts of projects, firms or products, beside others. Once all these questions are answered, the proposed combined solution, the SPE framework, is applied on two separate real case studies in the field of energy project selection from Turkey to demonstrate the capabilities of the proposed answers to these research questions.

# 2 LITERATURE REVIEW

This chapter examines the question of which sustainability performance shall be evaluated, or in other words, what one understands under ‘sustainability performance’ by looking at the literature. The concept of sustainability has various perspectives, such as environmental protection, ecosystem services, economic considerations, social acceptance, license to operate, externalities and stakeholder theory, beside many other aspects (Keijzers, 2002; Figge and Hahn, 2004; Bartelmus, 2010). Recent literature suggests that research is starting to extend beyond the terms of green and basic competitiveness towards a more holistic and methodological understanding of sustainability.

In this chapter, the underlying concepts will be introduced and particular issues will be raised to capture the current state of SPE literature. This way, research gaps will be identified and recommendations will be formulated to guide this research. This review’s scope will be limited to SPE on business level, where geographical or product related approaches, for instance, will not be discussed. The work onwards is structured as the following; section 2.1 will explain how the reviewed literature is selected. Section 2.2 will present a list of reviewed publications, along with their categorization and offer a meticulous appraisal of the literature for conceptual and analytical papers. In section 2.3, observations derived from the sections 2.1 and 2.2 will be presented and the findings will be analyzed in a structured way. Section 2.4 will discuss the research gaps, results and present recommendations.

## 2.1 Research Methodology

The review basically includes publications in the last 10 years that have appeared in the Web of Science (i.e. the core collection, Social Sciences Citation Index and the Science Citation Index Expanded). Conference papers and articles on journals other than SCI have been excluded from the analysis. Only international journals in the domains of engineering, finance and management in English language are included. Journals are searched in their titles, key words and abstracts with the following key words: *sustainability, sustainability performance, performance assessment, performance evaluation, performance measurement, sustainable*. Each article is examined thoroughly to check if they are suitable. Those papers that only concentrate on one single dimension of sustainability's triple bottom line approach (e.g. green themed articles) are left out. To further ensure that no other relevant publications are omitted, some of the references used in the reviewed papers are also checked in general for potential relevancy. Other than these, the above-mentioned key words have been queried in internet search engines to identify major publications that are not strictly academic.

Eventually, a total of 131 publications are identified. It is observed that SPE is a hot topic in literature and related articles abound. Many analytical and conceptual papers approach sustainability from different perspectives, where sustainability is discussed in various contexts. Literature reviews on SPE, however, are mostly found to simply exhibit the state of the art, rather than reviewing and analyzing related literature in depth.

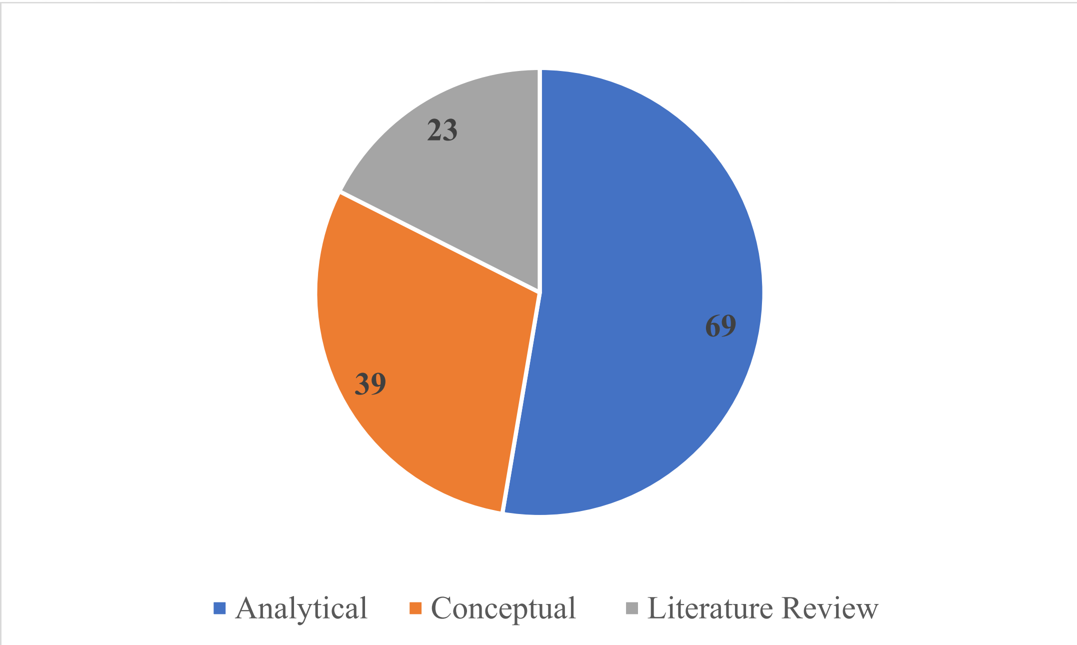


Figure 2.1. Numerical Distribution of Reviewed Publications Based on Type

There are many articles on the subject, which are listed in ***Table 2.1 - Table 2.3*** under different categories to provide a better insight and perspective. SPE-related literature can in general be grouped as product-related techniques, composite indices and integrated assessment techniques (Ness et al., 2007). However, this SPE analysis is focused on corporate level and excludes product-related literature. Therefore, in this study the identified papers are categorized into three groups according to their goals; i) literature reviews, ii) conceptual models that suggest new ways of '*what'* information to collect, and iii) analytical (i.e. numerical) applications that suggest '*how'* to collect and process data.

Conceptual papers are those that propose a qualitative model or framework (e.g. a new composite sustainability index structure) to better understand, categorize or approach the concept of SPE. Conceptual papers that are limited to discussions without proposing a new model have been left out. These papers are also categorized according to their field of focus or application, as illustrated in ***Figure 2.2***, which indicates that publications discuss a wide range of subjects and industries. There is no one single category that dominates the literature.

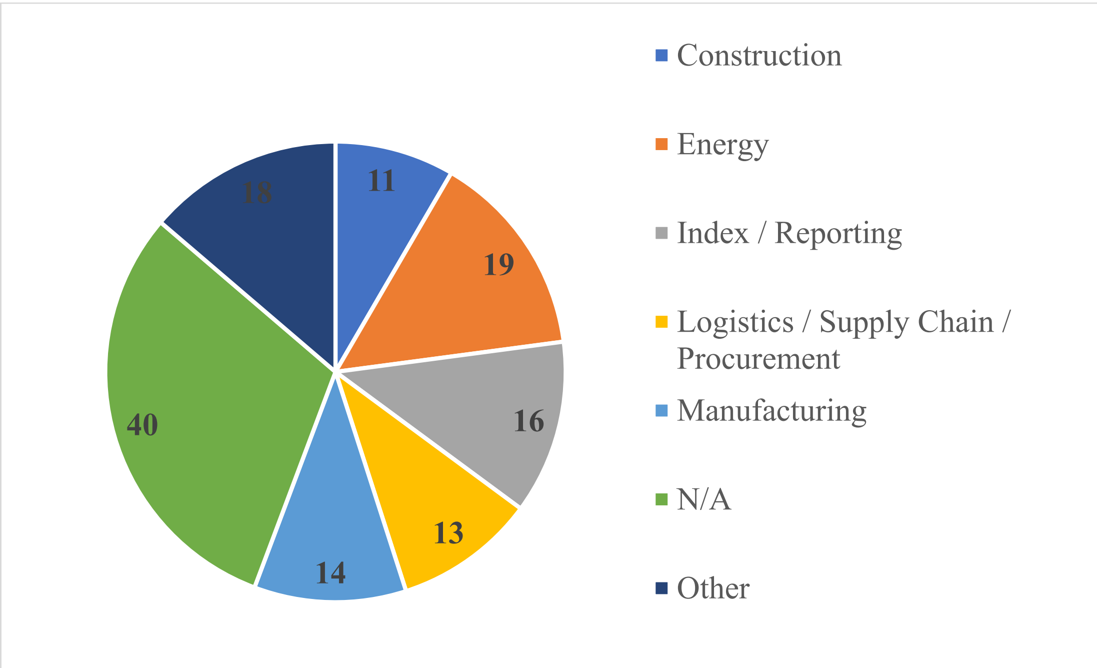


Figure 2.2. Categories of Publications by Subject or Industry

Analytical papers basically include quantitative methods, such as descriptive statistics, MCDM, optimization or similar methodologies to numerically attack the SPE problem. Analytical papers are further broken down into two sub-categories; i) papers that do propose their own model, such as their own set of indicators and then apply it numerically, and ii) papers that do use an existing framework, such as the Dow Jones Sustainability Index (DJSI), Global Reporting Initiative (GRI) or another research as it is as the basis. Furthermore, for each paper the specific technique is also indicated, which is particularly relevant for analytical papers.

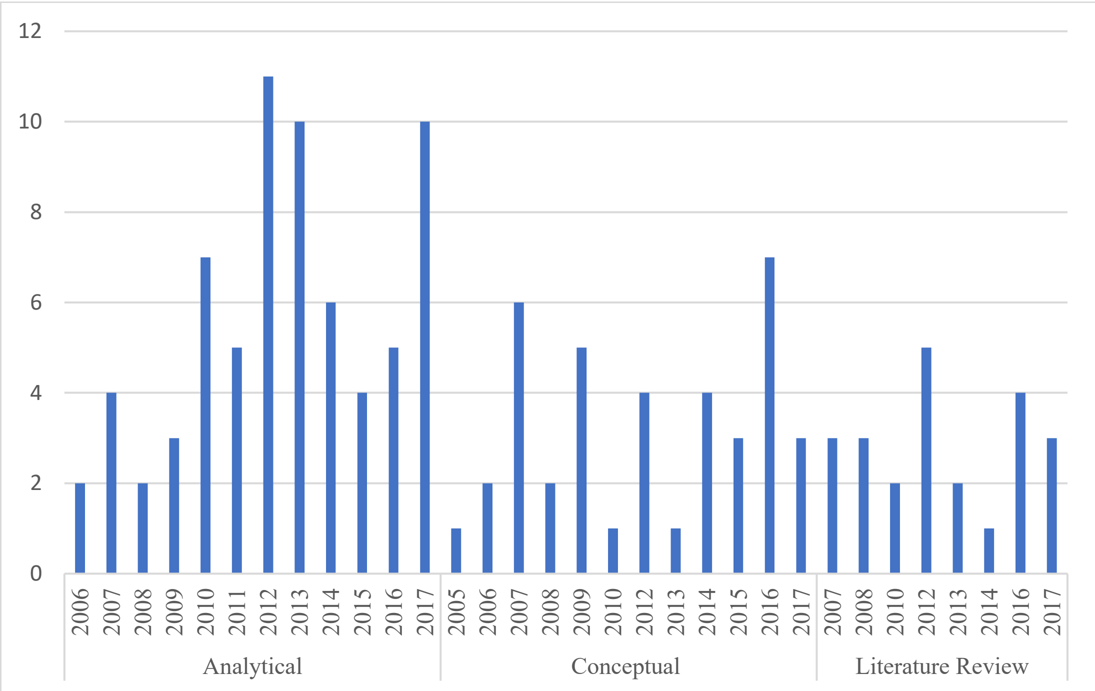


Figure 2.3. Evolution of Publications Over the Last Decade

As shown in ***Figure 2.3***, the distribution of reviewed publications indicates that; i) Total number of publications is increasing; ii) Conceptual articles and literature reviews/case studies show a varying trend; iii) Analytical papers are becoming more popular. Next, these articles will be discussed in detail.

## 2.2 Review of the Literature

Organizations can carry out SPE for various reasons. These can be voluntary disclosure, inclusion in a stock market sustainability index (e.g. Borsa Istanbul Sustainability Index), legal compliance, operational excellence, competitiveness, credibility etc. With such a variety of underlying reasons for companies to evaluate their sustainability performance, SPE attracts a lot of interest from management and engineering fields. Finance and business management related journals approach SPE with regards to financial/stock performance, competitiveness and corporate strategy, whereas operations research related articles are mainly interested in ranking, policy guidance and decision-making. This study contemplates with the latter.

### 2.2.1 Evaluating Sustainability Performance

SPE systems can be established within companies for management, planning or controlling tasks, as well as for measuring performance about the economic, environmental and social actions of that company (Searcy, 2014) to support businesses to effectively and regularly evaluate their sustainability performance. Development and use of SPE models and tools date back to the late 1990s. In mid-2000s, composite sustainability indices became popular. Such aggregated parameters are based on a series of metrics, which are defined as qualitative or quantitative measures that can be linked to clearly defined goals which are able to reveal relative achievement rates (Spangenberg et al., 2002; Nardo et al., 2005). Each of these indicators can be used to obtain one composite index by aggregating (i.e. weighing) these indicators using a specific model (Goldberg, 2002; Nardo et al., 2005). Such an index can be employed for various purposes (e.g. products, operations, cities, countries etc.) and enable researchers to apply quantitative techniques to make better use of available data. For these reasons, composite sustainability indices still remain popular for their simplicity.

The categorized listing of the reviewed papers is provided below. In the next section 2.2.2, those papers that propose conceptual models and analytical frameworks will be discussed in detail.

Table 2.1. SPE Literature Implementing an Analytical Approach

| Author | Year | Basic Approach | Technique(s) | Subject/Case Study |
|---|---|---|---|---|
| Acquaye et al. | 2017 | Input-output analysis | MRIO | Energy; Chemical processes |
| Akadiri et al. | 2013 | MCDM | FAHP | Construction |
| Artiach et al. | 2010 | Descriptive Statistics | Univariate and multivariate tests, sensitivity analysis | Stock market |
| Awasthi et al. | 2010 | MCDM | Affinity Diagram, AHP, Fuzzy TOPSIS | Logistics |

Table 2.1. SPE Literature Implementing an Analytical Approach (Cont'd)

| | | | | |
|---|---|---|---|---|
| Babcicky | 2013 | Descriptive Statistics | PSR, Regression | Index; Case Study |
| Barata et al. | 2014 | MCDM | ELECTRE | Energy |
| Begić and Afgan | 2007 | MCDM | ASPID | Energy |
| Bilbao-Terol et al. | 2012 | MCDM | Fuzzy Goal Programming | Finance |
| Bottani et al. | 2017 | MCDM | Fuzzy | Food |
| Büyüközkan and Berkol | 2011 | MCDM | ANP, QFD, ZOGP | Supply Chain |
| Büyüközkan and Çifçi | 2011 | MCDM | Fuzzy ANP | Supply Chain |
| Büyüközkan and Çifçi | 2013 | MCDM | QFD, GDM | Supply Chain |
| Castellani and Sala | 2010 | Composite Index | Arithmetic Weighing | Tourism |
| Chardine-Baumann and Botta-Genoulaz | 2014 | Composite Index | Arithmetic Weighing | N/A |
| Costa and Menichini | 2013 | MCDM | Fuzzy, 2-tuple | Sustainability Reporting |
| Dai and Blackhurst | 2012 | MCDM | AHP, QFD | Purchasing |
| Dinh et al. | 2009 | MCDM | AHP | Biofuels |
| Doukas et al. | 2010 | MCDM | TOPSIS | Energy |
| Erol et al. | 2009 | MCDM | AHP, Arithmetic Weighing | Retailing |
| Erol et al. | 2011 | MCDM | Fuzzy Entropy, Fuzzy MAUT | Retail Supply Chain |
| Escrig-Olmedo et al. | 2015 | MCDM | Fuzzy TOPSIS | Manufacturing |
| Frangopoulos and Keramioti | 2010 | MCDM | Arithmetic Weighing | Energy |
| Fuente et al. | 2017 | MCDM | MIVES | Energy |
| García-Melón et al. | 2012 | MCDM | ANP, Delphi | Tourism |
| Ghadimi et al. | 2012 | MCDM | Fuzzy AHP, Weighted Fuzzy Assessment | Automotive |
| Ghadimi et al. | 2017 | MCDM | Fuzzy | Automotive |
| Govindan et al. | 2013 | MCDM | Fuzzy TOPSIS | Supply Chain |
| Hsu et al. | 2013 | MCDM | ANP | Sustainability Reporting; Case study |
| Hu et al. | 2011 | MCDM | Fuzzy AHP | Sustainability Reporting |
| Kahraman and Kaya | 2010 | MCDM | Fuzzy AHP | Energy |
| Kamali and Hewage | 2017 | MCDM | Fuzzy | Construction |
| Karger and Hennings | 2009 | MCDM | Expanded AHP, Geometric Mean | Energy |
| Kolak and Feyzioglu | 2016 | MCDM | TOPSIS, Choquet integral | Transportation |
| Lee and Farzipoor Saen | 2012 | DEA | | Electronics |
| Li et al. | 2012 | Composite Index | PCA | N/A |
| Liu | 2014 | MCDM, Composite Index | Fuzzy AHP, Arithmetic Weighing | Energy |
| Maltz et al. | 2016 | Descriptive Statistics | Statistical charts | Energy |
| Medel-González et al. | 2016 | MCDM | ANP; BSC | Energy |

Table 2.1. SPE Literature Implementing an Analytical Approach (Cont'd)

| | | | | |
|---|---|---|---|---|
| Nikolaou et al. | 2013 | Composite Index | Arithmetic Weighing | Logistics |
| Onat et al. | 2016 | MCDM | TOPSIS; Intuitionistic fuzzy | Transportation |
| Parra-López et al. | 2008 | MCDM | AHP | Agriculture |
| Pask et al. | 2017 | MCDM | Fuzzy, Monte Carlo | Automotive |
| Pons and de la Fuente | 2013 | MCDM | Value Function | Construction |
| Rajak and Vinodh | 2015 | MCDM | Fuzzy | Automotive |
| Raut et al. | 2017 | MCDM | Fuzzy, AHP, TOPSIS, BSc | Finance |
| Ren et al. | 2013 | MCDM | DEMATEL | Supply Chain |
| Rivera et al. | 2017 | Numerical Analysis | Fuzzy | Stock market |
| Rodger and George | 2017 | MCDM | Fuzzy | Energy |
| Schmidt | 2006 | LCA | Sensitivity and Monte Carlo Analysis | Automotive; Case Study |
| Sikdar et al. | 2017 | Descriptive Statistics | Euclidean distance | N/A |
| Tan et al. | 2015 | Descriptive Statistics | Correlation and regression | Construction |
| Traverso et al. | 2012 | | LCA | Photovoltaics |
| Ugwu and Haupt | 2007 | Framework, MCDM | Arithmetic Weighing, Additive Utility Model, AHP | Construction |
| Ugwu et al. | 2006 | Composite Index | AHP, Arithmetic Weighing | N/A |
| Van de Kerk and Manuel | 2008 | Composite Index | Arithmetic Weighing | N/A |
| van der Voet et al. | 2014 | Framework, MCDM | N/A | N/A |
| Vinodh and Girubha | 2012 | MCDM | ELECTRE II | Manufacturing |
| Vinodh and Girubha | 2012 | MCDM | PROMETHEE | Manufacturing |
| Vinodh et al. | 2013 | MCDM | VIKOR | Manufacturing |
| Weber et al. | 2010 | Descriptive Statistics | Regression, discriminant and covariate analysis | Banking |
| Wibowo and Grandhi | 2016 | MCDM | Intuitionistic hesitant fuzzy Choquet integral | Energy |
| Wolfslehner et al. | 2012 | MCDM | PROMETHEE | Forestry; Case Study |
| Yakovleva | 2007 | Numerical Analysis | N/A | Food; Case Study |
| Yao et al. | 2011 | Scenario Analysis | N/A | Construction |
| Zhao and Li | 2016 | MCDM | fuzzy TOPSIS, stochastic AHP | Energy |
| Zhou et al. | 2012 | Composite Index | Various Normalization, Weighing and Aggregation Methods | Construction |
| Ziegler et al. | 2007 | Descriptive Statistics | Multifactor model | Stock market |
| Ziolkowska | 2014 | MCDM | PROMETHEE | Biofuels |
| Zolfani and Saparauskas | 2014 | MCDM | SWARA | N/A |

Table 2.2. SPE Literature Implementing a Conceptual Approach

| **Author** | **Year** | **Concept** | **Subject/Case Study** |
|---|---|---|---|
| Adams and McNicholas | 2007 | Action Research | Sustainability Reporting; Case study |
| Barnett et al. | 2008 | N/A | |
| Berardi | 2012 | Framework | Construction Sustainability Rating |
| Boiral and Henri | 2015 | Discussion | N/A |
| Brown et al. | 2009 | N/A | Sustainability Reporting; Case study |
| CDP | 2014 | Framework | N/A |
| Chee Tahir and Darton | 2010 | Framework | Palm Oil |
| de Almeida Guimarães and Leal Junior | 2017 | Framework | Transportation |
| Ferreira and Silva | 2016 | Balanced Scorecard | Supply Chain |
| Garcia et al. | 2016 | Framework | Energy |
| Gjølberg | 2009 | Composite Index | N/A |
| Global Reporting Initiative | 2013 | Framework | N/A |
| GS Foundation | 2012 | Framework | N/A |
| Hubbard | 2009 | Composite Index | N/A |
| Hutchins and Sutherland | 2008 | Framework | N/A |
| Ingwersen et al. | 2014 | Framework | N/A |
| Kim et al. | 2015 | Framework | N/A |
| Kühnen and Hahn | 2015 | Framework | N/A |
| Marshall and Toffel | 2005 | N/A | N/A |
| Miller et al. | 2016 | Composite Index | Transportation |
| Ness et al. | 2007 | Framework | N/A |
| Nunes et al. | 2016 | Framework | N/A |
| Pan and Kao | 2009 | Composite Index | N/A |
| Perrini and Tencati | 2006 | Framework | N/A |
| Poveda and Elbarkouky | 2016 | Framework | N/A |
| Rodrigues et al. | 2016 | Framework | Product development |
| Schneider and Meins | 2012 | Framework | N/A |
| Schöggl et al. | 2016 | Composite Index | Supply Chain |
| Schöggl et al. | 2017 | Framework | Automotive |
| Searcy | 2014 | Framework | N/A |
| Shen et al. | 2007 | Framework | Construction |
| Singh and Vinodh | 2017 | Framework | N/A |
| Singh et al. | 2007 | Composite Index | Steel |
| Tokos et al. | 2012 | Framework | Brewing |
| Waheed et al. | 2009 | Framework | N/A |
| Wang and Lin | 2007 | Framework | N/A |
| Wilson et al. | 2007 | Framework | N/A |
| Zhou et al. | 2006 | Framework | N/A |

Table 2.3. Literature Reviews on SPE

| Author | Year | Types of Reviewed Papers | Subject/Case Study |
|---|---|---|---|
| Amui et al. | 2017 | Conceptual | N/A |
| Bebbington et al. | 2007 | Conceptual | Sustainability Accounting |
| Böhringer and Jochem | 2007 | Analytical | Index |
| Čuček et al. | 2012 | Conceptual | Index |
| Dahl | 2012 | Conceptual | Index |
| Ding | 2008 | Conceptual | Construction |
| Fowler and Hope | 2007 | Conceptual | Finance |
| Gasparatos et al. | 2008 | Conceptual | Index |
| Goyal et al. | 2013 | Conceptual | N/A |
| Gunasekaran et al. | 2014 | Conceptual | Supply Chain |
| Hansen and Schaltegger | 2016 | Conceptual | N/A |
| Herva and Roca | 2013 | Analytical | N/A |
| Kumar et al. | 2017 | Analytical | Energy |
| Kylili et al. | 2016 | Conceptual | Construction |
| Maas et al. | 2016 | Conceptual | Sustainability reporting |
| Mayer | 2008 | Conceptual | Index |
| Moldan et al. | 2012 | Conceptual | N/A |
| Morhardt | 2010 | Conceptual | Sustainability Reporting |
| Morioka and de Carvalho | 2016 | Conceptual | N/A |
| Phillis et al. | 2010 | Conceptual | Index |
| Searcy | 2012 | Conceptual | N/A |
| Sikdar et al. | 2017 | Conceptual | N/A |
| Singh et al. | 2012 | Conceptual | Index |

### 2.2.2 Conceptual Models and Literature Review Articles

Conceptual SPE models are being actively developed since 1990s; however real progress was achieved in the last decade, in particular with the introduction of newly defined sustainability indicators and composite sustainability indices and their adaptations and applications for countries, companies, regions, industries etc. These models may differ in focus, coverage, methodology and objective. Some examples include, inter alia, Sustainable National Income, General Progress Indicator, Index of Sustainable Economic Welfare, Adjusted Net Savings Genuine Savings, Wellbeing Index, Ecological Footprint, Human Development Index and Environmental Sustainability Index.

Conceptual models are beneficial in clarifying *'what'* to measure, what is expected from the measurements and what kinds of indicators should be used. Such models can be categorized as the following (United Nations, 2007);

- Driving force-state-response (DSR) models: Similar to pressure-state-response models, in these conceptual structures indicators are classified based on being the driving force (positive or negative impact on sustainability), describing the current situation, or reflecting societal actions aimed at moving towards sustainability. However, this classification is often ambiguous and their causal linkages are uncertain.
- Theme-based models: Such models group indicators into various sustainability themes and are able to successfully link indicators to policy processes and targets, where SPE is monitored based on the level of attaining goals.
- Capital models: These models are more suited for national SPE, as they attempt to calculate national wealth with the help of financial, natural, human, social and institutional capital.
- Accounting models: Such models extract their data from a single common database and calculate all indicators accordingly. Such accounts can be described in monetary and physical terms.
- Aggregated (composite) indices: There are various attempts in literature to combine a wide array of variables into one simple number, or ranking, which is easy to understand by Decision Makers (DMs), businesses and the public. There might be difficulties related with composite indicators, such as data availability, methodologies, selection and weighing of variables.
- Other models: There are also other types of models, such as those that are adapted for specific industries/issues (e.g. biodiversity indices), or headline indicators (small core indicator sets used as quick signals).

Some of these conceptual models are developed into widely-used tools in the industry, such as the GRI (2013). It is a renown and pioneering sustainability reporting standard that is extensively used by companies globally and can be adapted for specific needs. It stands out among others in promoting the reporting of sustainability performance for businesses by providing flexible assessment indicators and methods. Despite its shortcomings (McElroy et al., 2008), today GRI has reached its 4$^{th}$ version and has achieved worldwide recognition. It stands out in terms of its high adoption rate, ease of application, flexibility and adaptability to an extensive list of businesses.

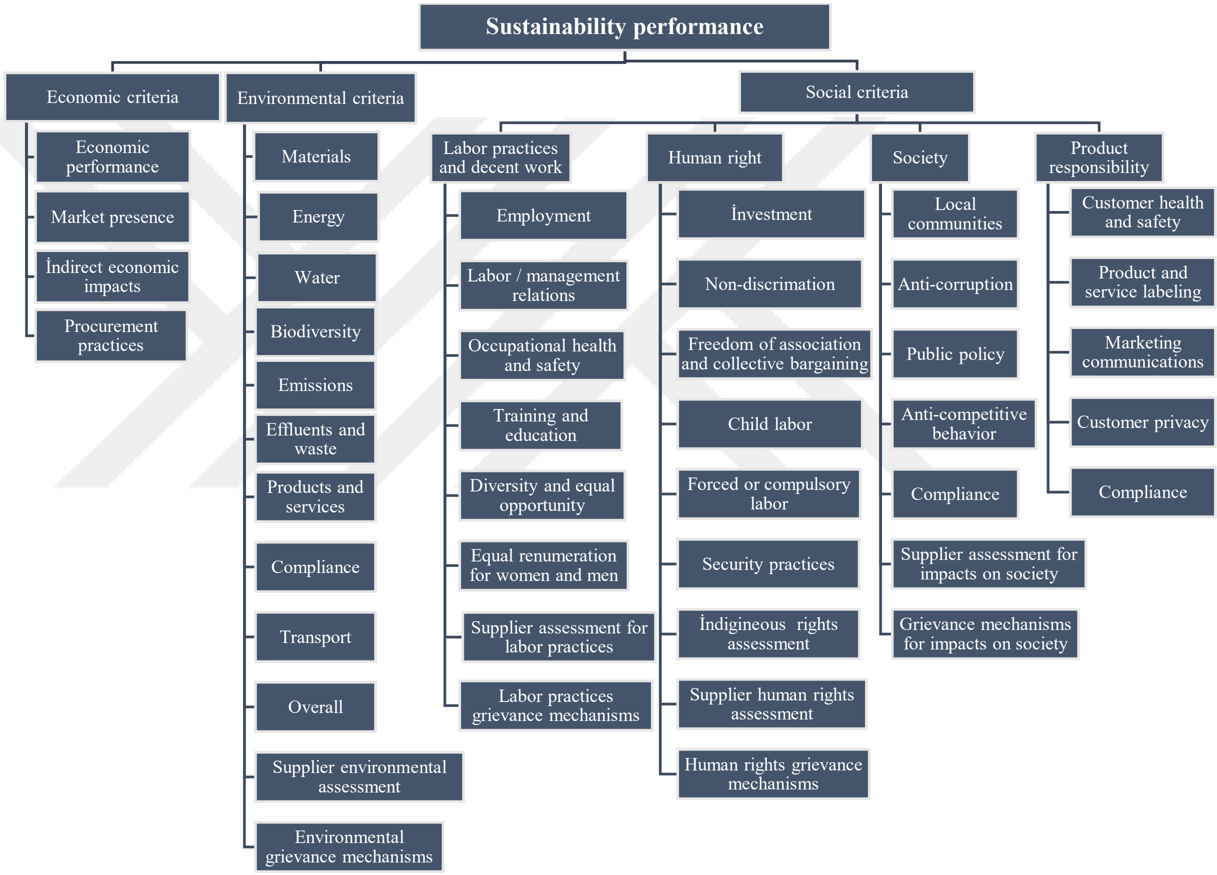


Figure 2.4. Categories of GRI
Source: Global Reporting Initiative (2013)

Another globally recognized SPE framework is Carbon Disclosure Project (CDP, 2014), an international program that works with companies to tackle with climate change, deforestation, sustainable water use and environmental risks in supply chains. DJSI is another recognized example for conceptual SPE frameworks that actively monitors more than 600 publicly traded companies worldwide (DJSI Family

Overview, 2014). Borsa Istanbul Sustainability Index (BISE) also falls into this category. CER Gold Standard (2012) is a project-based, award-winning certification scheme to ensure that projects combating global warming also contribute to sustainability in local and global scale. There are also other conceptual SPE frameworks that are more or less used by businesses. A comparative analysis of these popular SPE frameworks currently used by businesses is listed in ***Table 2.4***. These models can be supported either with analytical techniques or other applicable methods.

Table 2.4. Comparison of Renown SPE Frameworks

| SPE Model | Strengths | Weaknesses |
|---|---|---|
| **ISO Standards (14000, 26000 etc.)** | • Widely known and used by businesses.<br>• Global acceptance across industries.<br>• Definition of basics and overarching principles.<br>• Continuous update and development. | • Partial coverage (no standard for integrated assessment).<br>• Lack of tangible evaluation framework (e.g. criteria etc.) |
| **Carbon Disclosure Project (CDP)** | • Used by largest corporations worldwide.<br>• Credible and standardized sustainability information for corporate investors.<br>• Concrete evaluation tool, ease of use (questionnaire). | • Focus on environmental performance (e.g. carbon footprint, water and energy consumption).<br>• Targets biggest firms (e.g. FT Global 500) for public disclosure. |
| **Global Reporting Initiative (GRI)** | • Global recognition and wide usage across countries and industries.<br>• Provision of evaluation and reporting template.<br>• Ease of use, accumulated experience and continuous development (version 4). | • Flexible criteria selection, leading to over- or under-reporting.<br>• Open to subjective, biased, simplified evaluations.<br>• Primary focus on descriptive reporting, instead of evaluation. |
| **Stock Exchange Sustainability Indices (DJSI, BISE etc.)** | • Provides additional decision parameter for investors.<br>• Incentive for companies to be listed for credibility and increased investor interest.<br>• Standard methodology applicable for all firms. | • Oversimplified sustainability evaluation methodologies.<br>• Limited information disclosure by companies.<br>• Limited focus (mostly environmental management and regulatory compliance). |

**Chronology:** Those articles that mainly discuss literature reviews, conceptual framework and SPE models in the last decade are shortly presented below in chronological order.

In 2004, Cherchye and Kuosmanen (2004) synthesized various existing sustainability indices into a meta-index. In another research, Pope et al. (2004) emphasized the importance to recognize the relationships among the economic, environmental and social dimensions simultaneously, as they might not be completely independent from each other, pointing out to the potential of maximizing win–wins and minimizing trade-offs.

In 2005, Koellner et al. (2005) outlined basic principles for a comparative sustainability rating, based on research about investment fund management. Labuschagne et al. (2005) developed a new SPE framework addressing the manufacturing sector, with particular emphasis on the social dimension of sustainability. By examining SPE metrics that are used by selected companies from Germany, Székely and Knirsch (2005) revealed discrepancy in how businesses evaluate and report corporate sustainability performance. In the same year, Marshall and Toffel (2005) discussed the subjective nature of SPE and argued that beliefs, social values or personal visual preferences should be avoided.

In 2006, Perrini and Tencati (2006) developed an SPE system aiming SMEs. Ugwu et al. (2006) proposed a structured SPE procedure for infrastructure projects and argued the elaboration of suitable sustainability performance metrics. Zhou et al. (2006) compared different aggregating techniques to build a composite sustainability index and suggested that the weighted product method usually causes less information loss, compared to the weighted displaced ideal method.

In 2007, Bebbington et al. (2007) provided a literature review on the connection of SPE and accounting discipline. Another literature review by Böhringer and Jochem (2007) criticized composite index techniques to be highly arbitrary and misleading. They argued that many aggregate indices disregard technical principles that ensure consistency and meaningfulness. A case study published by Adams and McNicholas (2007) discussed the hurdles of corporate sustainability reporting and explored how improved accountability leads to higher sustainability performance. Shen et al. (2007) came up with a checklist for a consistent and holistic SPE. In another article, Fowler and Hope (2007) analyzed the methodologies employed in compiling stock exchange sustainability indices, as well as their impact on companies and the investors. A paper by Ness et al. (2007) clustered SPE tools into three groups; indicators, integrated assessment tools and product focused assessment, where monetary evaluation tools are positioned as an overarching category. In the same year, Wang and Lin (2007) presented their sustainability index system, which consists of seven index sets.

In 2008, Barnett et al. (2008) investigated conceptual and methodological challenges associated with composite indices. Gasparatos et al. (2008) investigated several SPE tools in the literature, such as monetary valuation and biophysical models, sustainability indicators and aggregate indices. Hutchins and Sutherland (2008) developed a blueprint for incorporating social sustainability measures, and demonstrated their application on a supply chain decision-making case. A paper by Mayer (2008) discussed composite sustainability indices, such as the boundaries, scale, transformation and weighing of data, as well as aggregation methods.

In 2009, Brown et al. (2009) examined the GRI framework by performing structured interviews and documentary analysis, and concluded that GRI is a successful institutionalization project. The same year, Gjølberg (2009) developed a composite index for SPE for countries. An article by Hubbard (2009) also proposed a composite index, called Organizational Sustainability Performance Index. Another aggregate index was introduced by Pan and Kao (2009) for establishing a measure to assess inter-generational equity. Waheed et al. (2009) came up with a framework for effective SPE and demonstrated it on a higher educational institution case.

In 2010, a conceptual SPE methodology was described by Chee Tahir and Darton (2010) that facilitates comparison and benchmarking.

In 2011, Searcy (2011) highlighted the dynamic evolution of sustainability aspects and presented a framework how SPE frameworks can be updated over time. Kajikawa et al. (2011) analyzed SPE frameworks developed for buildings and discussed the limitations of SPE. They highlighted the challenge of using a mixture of numerical and subjective criteria, as well as uncertainties associated with weighing them. They further emphasized the vitality of involving different disciplines and interested parties into SPE processes.

In 2012, using a sample of 490 buildings, Berardi (2012) showed that building sustainability rating systems prioritize energy performance above all other criteria (e.g. BREEAM, LEED). The same year, Moldan et al. (2012) argued that SPE should be based on some reference values and targets, emphasizing the role of goal setting. The notion of sustainability governance was introduced by Schneider and Meins (2012) as a dimension of corporate SPE. The article by Searcy (2012) presented key research questions as a guidance for future SPE literature. The literature review by Singh et al. (2012) analyzed how sustainability indices are formulated, i.e. scaled, normalized, weighted and aggregated. In two other literature reviews, Čuček et al. (2012) summarized basic definitions, such as composite sustainability indicators, carbon footprint and ecological footprints. Also in the same year, Tokos et al. (2012) proposed not only GRI-compatible economic, environmental and social indicators, but also integrated indicators to assess sustainability performance of businesses in the brewing industry. Zhou et al. (2012) combined the techniques of normalization, weighing and aggregation in different variations to compare which combination fares better for SPE based on a composite indicator for the construction industry.

In 2013, a structured literature review was published by Goyal et al. (2013) that explored the link of firm performance with sustainability performance. Gatti and Seele (2013) examined the terminology used in the sustainability reports and described the trends in the use of terms and concepts.

In 2014, Ingwersen et al. (2014) proposed the combined use of different tools such as LCA, ecological footprint and green net value added for a broader coverage of sustainability aspects. Searcy (2014) proposed a conceptual SPE framework consisting of key requirements and their sub-requirements on company level.

In 2015, Kim et al. (2015) pointed out the weaknesses of LCA-based frameworks for SPE and presented an innovative decision guidance framework to improve sustainability in manufacturing processes. Kühnen and Hahn (2015) also highlighted the limitations of the current state of SPE research. They argued that there is no unilateral understanding of indicators for measuring businesses social impact.

In 2016, Morioka and de Carvalho (2016) discussed the main contributions and discrepancies in corporate sustainability performance publications. They identified 9 conceptual frameworks, including DJSI and GRI, and then created a list of sub-dimensions for facilitating further research and application. Maas et al. (2016) also discussed recent publications and stated that performance evaluation, financial accounting activities, internal control functions and public disclosure are undertaken in an isolated manner. Then, they proposed an integrated structure for measuring sustainability in link with book-keeping, control and reporting actions. In another recent paper, Poveda and Elbarkouky (2016) introduced a hybrid conceptual model for benchmarking energy industries with a new sustainable rating system. Ferreira and Silva (2016) developed a 5-step balanced scorecard model for SPE of supply chains, based on GRI and ISO 14031 indicators. Rodrigues et al. (2016) extracted 787 SPE indicators from literature and systematically categorized them to come up with their set of KPIs for product development. Miller et al. (2016) introduced another SPE composite index for public transportation.

In 2017, a very recently published literature review by Amui et al. (2017) analyzed the state of the art of contemporary research about the dynamic capabilities for sustainability to explore the gap between practices and the institutional strategies and capabilities. They highlighted the need of further research in emerging economies and mixed methodologies. Another literature review by Kumar et al. (2017) discussed various MCDM techniques used for SPE in renewable energy applications. Also this year, Singh and Vinodh (2017) developed another conceptual framework by integrating five enablers with 25 criteria and 75 attributes. Exploring the connection of SPE with product design, Schöggl et al. (2017) developed a qualitative assessment checklist. The applicability of the framework is tested in a case study with 9 lightweight automotive technologies.

This overview of conceptual SPE models shows that there are various approaches which can be used separately or in combination with others for evaluating business sustainability performance. This can be the case for individual companies, projects, supply chains or whole industries. It is a challenge to cover each and every aspect of sustainability performance with one single solution (Wilson et al., 2007). Publications discussing sustainability's economic, environmental and social perspectives are abundant. However, literature has so far often disregarded the social dimensions (Székely and Knirsch, 2005), as well as the possible linkages among all indicators. The question of which sustainability indicators to contain within a generic, or an industry-adjusted framework is part of the problem. Another part of the problem is how to categorize and hierarchically assign these variables with logical linkages. Many of the proposed conceptual models provide useful insights to these questions, while others subjectively determine these factors with limited thought on the selection methodology. Another challenge is to establish a model that can be adapted to different needs, since the users of such SPE methods come from different industries and aim different goals. To deal with some of these complexities, analytical tools have been integrated into these conceptual models by many researchers, as reviewed in the next section.

### 2.2.3 Analytical Models

Many researchers have proposed numerical approaches to evaluate sustainability performance, where various types of quantitative techniques are utilized. These can be, for instance, statistical tools, optimization, composite index, data envelopment analysis and MCDM, among others (Zhou and Ang, 2008). These models can both introduce a novel model and technique to quantify different aspects of sustainability performance, or use an existing model (e.g. GRI) and apply it on a specific problem. These publications will be chronologically examined in detail.

**Chronology:** Those articles that mainly propose analytical techniques or applications of existing models in the last 10 years are listed in ***Table 2.1*** and shortly presented below in chronological order.

In 2004, Nigim et al. (2004) discussed the use of MCDM tools for ranking local renewable energy alternatives for local communities. In another paper, Andriantiatsaholiniaina et al. (2004) characterized the most valuable variables of the Sustainability Assessment by Fuzzy Evaluation model, an SPE framework.

In 2005, Krajnc and Glavič (2005) presented an analytical model to design an aggregate sustainable development index. In the same year, Ding (2005) described a sustainability index model for SPE with financial return optimization and environmental impact minimization in mind.

In 2006, a case study was presented by Schmidt (2006), who carried out a SPE for two Ford automobile models.

In 2007, a decision model integrated with an analytical SPE methodology was proposed by Ugwu and Haupt (2007) for computing a sustainability index. Begić and Afgan (2007) performed a multi-criteria SPE to rank possible energy system alternatives in Bosnia and Herzegovina. A paper by Singh et al. (2007) presented a method that utilizes Analytic Hierarchy Process (AHP), an MCDM method, for developing an aggregate sustainability index for the steel industry.

In 2008, Parra-López et al. (2008) utilized AHP to improve decision-making procedures and illustrated it in a sustainable olive farming case study. In another article, Karger and Hennings (2009) implemented an AHP hierarchy consisting of 31 criteria on 2$^{nd}$ level and 86 criteria on 3$^{rd}$ level to assess four future scenarios for electricity supply in Germany. Also the same year, Dinh et al. (2009) used AHP to evaluate sustainability performance of feedstock alternatives available for biodiesel production.

In 2009, appropriate SPE indicators were selected by Erol et al. (2009) for grocery retailing, for which AHP was used to rank related sustainability indicators.

In 2010, a hybrid approach was introduced by Awasthi et al. (2010) for assessing city logistics initiatives for improving sustainability performance. In another journal article, Kahraman and Kaya (2010) developed a fuzzy MCDM methodology for identifying suitable energy policies and demonstrated its use in a case study for Turkey. A multi-criteria approach for SPE was also presented by Frangopoulos and Keramioti (2010). Their approach was then used for evaluating and ranking alternative systems. Doukas et al. (2010) used TOPSIS, another MCDM technique, for SPE and integrated it with linguistic variables for renewable energy sources.

In 2011, a SPE simulation model for infrastructure projects was introduced by Yao et al. (2011) focusing both on the construction and the operation phases of such projects. In another paper, Erol et al. (2011) presented their multi-criteria SPE structure for supply chains, including an alert management system. Their proposed framework is then tested on a medium-sized grocery store chain from Turkey. Hu et al. (2011) propositioned a GRI-based SPE approach to evaluate corporate sustainability reports, in which fuzzy AHP technique is employed for finding the relative weights of the selected decision elements. Fuzzy AHP technique is also applied by Liu et al. (2011) in a composite SPE index consisting of 11 indicators for a renewable energy system. The index is then implemented on a case study from Australia.

In 2012, a SPE methodology was proposed by Dai and Blackhurst (2012) using a four-phased AHP–QFD method for the supplier selection problem. Their methodology is then demonstrated with a large retail company example. García-Melón et al. (2007) proposed a SPE methodology for sustainable tourism. This methodology is based on ANP, an MCDM technique, and a Delphi-type participatory procedure to ensure consensus. The usefulness of their analytical model is then illustrated in a case study from Venezuela, using three scenarios and 13 sustainability criteria. In another article, Ghadimi et al. (2012) developed an expert judgment-based weighted fuzzy SPE approach for comparing the sustainability of products and demonstrated its use on the automotive component industry. Traverso et al. (2012) carried out a SPE on the assembly operations of photovoltaic modules. The same year, Wolfslehner et al. (2012) presented a regional forest-wood supply chain case with a multi-criteria approach to capture and improve sustainability performance. Another composite sustainability index is introduced by Li et al. (2012) for manufacturing companies. Bilbao-Terol et al. (2012) approached the same subject from a financial point of view, where they introduced a SPE supported decision-making approach for managing stock portfolios. In their study, conventional funds are compared to socially responsible investment funds with regard to financial, environmental, social and ethical criteria. In the same year, Vinodh and Girubha explored how to improve sustainability performance in a manufacturing company with two articles, where they used ELECTRE II (2012b) and PROMETHEE (2012a), two prominent MCDM methods.

In 2013, Akadiri et al. (2013) proposed an SPE model for construction projects with 6 main factors and 24 criteria. A combination of MCDM and Petri nets is developed by Alves de Albuquerque et al. (2013), who used key indicators such as exergy and global warming potential of emissions for SPE. A review paper by Herva and Roca (2013) highlighted the increased use of, and need for fuzzy logic to deal with imprecision and subjectivity that is present in SPE. A framework of social responsibility performance indicators established on the GRI framework was proposed by Nikolaou et al. (2013) for reverse logistics systems. The same year, Govindan et al. (2013) explored the supplier selection problem with an SPE approach by integrating linguistic values of experts' subjective preferences into decision-making with the help of triangular numbers. Pons and de la Fuente (2013) presented a general SPE tool for the construction industry founded on a notion of value function. With the help of 37 sustainability parameters, Ren et al. (2013) developed a method for mapping cause-effect relationships in hydrogen supply chains. Another article by Costa and Menichini (2013) used a combination of a multi-criteria methodology and fuzzy linguistic variables to integrate monetary and non-monetary sustainability aspects and strategic standpoints. Based on the VIKOR method, a compromise ranking technique, Vinodh et al. (2013) explored how to improve sustainability performance in an assembly enterprise. In a case study, Babcicky (2013) assessed the validity and reliability of a proposed environmental index, revealing that the architecture and SPE approach of the index in question is far from perfect.

In 2014, Chardine-Baumann and Botta-Genoulaz (2014) combined the concept of composite index with multi-criteria approaches for developing a SPE framework. In the same year, a literature review by Gunasekaran et al. (2014) suggested that incorporating operations research tools and techniques is crucial for developing SPE models to capture the trade-offs between the three main aspects of sustainability. Another recent paper by Liu (2014) presented a composite index-type SPE framework for renewable energy systems, based on 11 indicators. The author suggested that discrete evaluation scales are incapable of accurately evaluating sustainability performance. An article by van der Voet et al. (2014) presented a transparent, objective and quantitative MCDM methodology addressing both compensation effects and importance weights in an integrated hierarchical SPE system consisting of indicators. A multi-objective linear programming approach was developed by Ziolkowska (2014) for sustainable biofuel production under limited resources and uncertainty. Pinar et al. (2014) recommended a non-linear aggregation approach for the construction of a sustainability index, composed of 19 indicators. This index is formed by utilizing the Choquet Integral aggregation, a novelty in the field of SPE. The method fulfills the requirements of monotonicity and the non-compensability assumptions. Another original multi-criteria approach was employed by Barata et al. (2014) for evaluating corporate sustainability performance. Zolfani and Saparauskas (2014) showed that SWARA, an MCDM technique, can be a useful SPE tool for selecting energy systems.

In 2015, a hybrid fuzzy TOPSIS method is used by Escrig-Olmedo et al. (2015), who applied their model in the apparel industry, while Tan et al. (2015) studied the connection of sustainability performance with corporate competitive power in the international construction industry. The same year, Rajak and Vinodh (2015) suggested that social sustainability evaluation with performance indicators is rather limited in literature and presented their own approach to fill this gap.

In 2016, Hendriksen et al. (2016) presented an approach to enumerate the overall economic, environmental and social impact that businesses create (and reduce) for the society. Fuzzy TOPSIS is combined with stochastic AHP by Zhao and Li (2016) to evaluate smart power grid planning in China by utilizing 4 criteria and their 12 sub-criteria. Also last year, Maltz et al. (2016) proposed an analytical approach based on statistical process control charts to assess variations in sustainability performance and applied it to benchmark energy companies in the US. Recently, Onat et al. (2016) developed a hybrid life-cycle SPE model for transportation alternatives with the help of TOPSIS and intuitionistic fuzzy methods, while Kolak and Feyzioglu (2016) studied the combination of TOPSIS and Choquet integral techniques. Intuitionistic hesitant fuzzy Choquet integral was implemented by Wibowo and Grandhi (2016) to compare power generation alternatives.

In 2017, a new publication by Pask et al. (2017) presented seven straightforward sustainability indicators to assess industrial oven alternatives with the help of fuzzy set theory and Monte Carlo simulation. The data weights are calculated by industrial experts, upon which alternatives are scored with readily available data. In another paper, Rivera et al. (2017) employed a specific methodological approach based on the fuzzy set theory to measure the economic, environmental and social performance over a selected sample of Spanish listed companies relying on the Thomson Reuters ASSET4 database. Ghadimi et al. (2017) developed a practical fuzzy inference system to evaluate and select the most sustainable suppliers for an automotive spare part manufacturer, while Bottani et al. (2017) deployed a numerical tool to assess the sustainability performance at company level with respect to its three key perspectives of economic, environmental and social parameters. The proposed framework is based on a monotonic hierarchical fuzzy inference tool as an effective means to gather the judgements and scores against the evaluation criteria of each sustainability perspective into an aggregated index. Again this year, Fuente et al. (2017) proposed a new MCDM method based on MIVES for evaluating the sustainability performance of wind-turbine towers with respect to selected economic, environmental and social requirements. Rodger and George (2017) relied on fuzzy set theory to optimize sustainability impacts for natural gas supply chains. Sikdar et al. (2017a) approached SPE with the Euclidean distance, with the indicator values representing a system, while Kamali and Hewage (2017) identified 33 suitable criteria for the sustainability evaluation of modular and conventional construction. The criteria are then weighted by industry experts with the help of a survey. In the finance industry, Raut et al. (2017) developed an integrated MCDM model for the evaluation of the sustainability performance for commercial banks. This model relies on the Balanced Scorecard, fuzzy AHP and fuzzy TOPSIS. They demonstrated the applicability of their model on a real implementation with 6 banks in India.

This overview indicates that there are many different approaches to numerically evaluate sustainability performance. Furthermore, this analysis shows the increasing number of articles in recent years, which can also be observed in ***Figure 2.3***. Especially those papers which are using operations research techniques are becoming more popular in SPE. These findings will be discussed in detail next.

## 2.3 Observations and Analysis of Findings

The success factor in SPE lies in identifying and selecting the most appropriate criteria, as well as developing and applying a suitable methodology for collecting and processing data. Considering the qualitative and quantitative nature of sustainability related themes, sub-themes and indicators, and complexities related to their interactions, subjectivity and priorities, SPE provides a vast research area where operations research tools are crucial for analyzing the trade-offs between the conflicting main perspectives of sustainability (Gunasekaran et al., 2014). Recent research on sustainability is becoming more quantitative (Mayer, 2008), which can be associated with this need. The findings of this review are listed as follows with *no* particular order;

**There does not exist any "one size fits all" SPE model:** Even focusing only on businesses, SPE depends on varying economic, environmental and social sensitivities and expectations. The evaluation framework can change across industries, locations and time; therefore, SPE frameworks need to be customizable for the specific purpose and reviewed over time to adapt to changing circumstances. There exists no unique SPE methodology that would match every expectation for all. For each specific application, the basic pillars of sustainability with their hierarchically structured criteria and sub-criteria need to be treated with different weights and correlations.

**A general SPE framework is needed:** Businesses need to set targets for their sustainability impacts, periodically evaluate their own performance according to these targets and benchmark with the industry and their competitors. The success of the GRI framework, despite critiques because of its high subjectivity, shows this need. Such conceptual SPE models lack analytical aspects, in which literature is showing an increasing interest. Therefore, a generic SPE framework supported with analytical techniques can prove useful. Combining conceptual and analytical tools for SPE in a standard usable framework can give businesses the opportunity to identify gaps and monitor their results in a coherent and consistent way. For this purpose, hierarchical sustainability criteria-trees (similar to GRI, as in ***Figure 2.4***) can be suitable thanks to their simple structure and recognition in literature and industry.

**Sustainability indices have their strengths and weaknesses**: There are advantages and compromises with the use of composite sustainability indices as they are easy to produce, understand and explain the overall sustainability performance of a firm. However, they assume that poor performance of one indicator can be off-set by another well performing indicator. Composite indices basically take the (weighted) average of criteria, which causes information loss during the aggregation step

(Gasparatos et al., 2008). There are also additional complexities associated with dependencies among criteria and scoring of qualitative criteria. Their usability as a decision-making method can also be limited or complicated in some cases. Despite methodological criticism, however, sustainability indices have their advantage when it comes to conveying a simple message to DMs.

**Evaluation of sustainability performance is subjective**: The unavoidable subjectivity embedded in qualitative aspects of sustainability remains a challenge. Despite arguments that personal views should be avoided in SPE (Marshall and Toffel, 2005), it is rather difficult to completely prevent it. Indicators are often evaluated by people, and even industry experts can think differently. Incorporation of fuzzy logic has increased significantly in recent papers, many of them using MCDM techniques, as it can be helpful in problems characterized by imprecision and subjectivity (Herva and Roca, 2013; Liu, 2014). Also depending on one DM can give rise to such issues.

**The traditional understanding of sustainability is losing ground**: Many publications are established on the three basic dimensions of the sustainable development notion. The misconception of sustainability and environmental aspects seems to be fading in recent years, and additional dimensions of sustainability such as governance and institutional aspects are being introduced (Mayer, 2008). The definitive and strict separation of sustainability dimensions is also being questioned. For instance, in the updated UNCSD (United Nations, 2007), sustainability impacts are no longer explicitly categorized into social, economic, environmental and institutional clusters. This study argues that this trend can be attributed to the difficulty to clearly separate sustainability impact across these pillars because of mutual dependencies, subjective understanding of criteria meanings and overlapping impacts. Nevertheless, such hierarchical tree types of criteria structures are useful for businesses to understand and put sustainability performance into perspective. Many such complications can be successfully dealt with MCDM techniques.

The findings discussed above underline the need for a standard generic methodology that is able to adapt to specific needs and circumstances. Criteria-trees can form the fundament for such integrated models, provided that they are supported with robust analytical techniques.

## 2.4 Discussion

In literature, the cumulative economic, environmental and social influences resulting from commercial operations have rarely been referred to as sustainability performance. With the proposed definition of the term SPE, many sustainability-related publications that fit into this definition can be treated as SPE literature. Considering various SPE tools in literature, as well as familiarity of companies with the concept of performance evaluation, it can be expected that business-focused SPE literature will pick up in future. This review underlines the following research gaps;

**Lack of balanced SPE approaches**: Most articles put less emphasis on social aspects of sustainability. Many researchers tend to select and assign weights to sustainability criteria arbitrarily, without the support of experts, which often leads to skewed and biased approaches leaning towards economic and environmental perspectives. New publications can fill this gap by approaching the concept of sustainability with a more balanced approach, by giving similar weights to main dimensions of sustainability. Integration of quantitative methodologies into solid conceptual models can be useful for these purposes. Combinations of different analytical tools also provide potential scientific research areas for researchers.

**Lack of industrial applications**: SPE is not a fully theoretical field of research; SPE frameworks shall actually be adapted for and implemented in the real world. There is very limited work done so far on real case studies and industrial applications. Most publications focus on new models and methods. Papers applying existing methods on specific industrial applications are rare.

**Lack of consideration of the interdependency of criteria**: Consideration of relationships between selection criteria is critical for decision-making. There can always be interdependencies between attributes such as compensation and dominance. If these mutual interactions can be taken into account, it can add value as long as they do not complicate the application of these frameworks.

**Lack of proper methods for criteria weighing**: Many papers subjectively assign weights to decision criteria, sometimes they rely on the assumption of equal weights. Such practices can oversimplify the procedure and lead to imprecise results. An enhanced model should be able to accurately quantify user preferences. In order to reduce user-related bias, a group of experts (i.e. decision makers, DMs) can be integrated into such frameworks. For this reason, GDM techniques can be combined with analytical tools to enhance the framework's capability to better handle such uncertainty stemming from individual subjective opinions.

**Lack of an efficient means to address qualitative parameters and fuzzy expressions in SPE**: A major bottleneck in SPE is the unavoidable subjectivity both in the selection of indicators and their evaluation for each of the decision alternatives. The qualitative nature of many criteria, particularly for the social, institutional and governance related aspects of sustainability, makes SPE a highly subjective practice. Such subjectivity is difficult to prevent completely. Nonetheless, methods such as fuzzy logic (Zadeh, 1965) can provide potential future research areas.

**Lack of common terminology for basic sustainability criteria**: The diverse use of terms and indicators for many similar concepts complicate SPE processes. Many similar variables are formulated in different wordings (e.g. jobs-employment; accidents-occupational health and safety; air pollution-emissions to atmosphere etc.). Merging such terms under inclusive names, and then assigning sub-criteria for specific aspects, can contribute to literature by providing a more common and standard basis.

This review reveals that more than half of all the SPE literature in the last decade is based on analytical methodologies and approximately one third of them are based on conceptual approaches, where the remaining papers are literature reviews and a few case studies. The share of analytical papers indicates an increasing trend in the last years. Moreover, within analytical publications, approximately 80% of the papers proposed their own set of SPE criteria, instead of building upon an existing criteria model. This underlines the lack of established, popular SPE frameworks with which analytical techniques can be easily integrated. More than one third of all the reviewed articles use one or more MCDM methodologies (e.g. AHP, TOPSIS, DEMATEL, ELECTRE, PROMETHEE, ANP, VIKOR etc.), among which AHP and fuzzy set theory techniques are especially popular.

Three main paths in literature have been identified. One of these paths focuses on defining sustainability indicators and conceptual structures for SPE. Another research path aims to create sustainability indices incorporating various weighing, aggregation and normalization techniques. The third path is the analytical approach, where sustainability performance indicators are scored and processed with more advanced quantitative tools for different goals, such as decision-making. Furthermore, a considerable share of published work claims to deal with sustainability but do mostly focus on environmental aspects. This bias leads to arbitrary prioritization of attributes and methodological challenges in evaluating qualitative aspects. This review suggests that although a magical ‘one size fits all’ SPE solution does simply not exist, a generic adaptable SPE framework with integrated analytical methods can be effectively adopted by businesses for various purposes.

This chapter dealt with the research question of “*Which ‘sustainability performance’ shall be evaluated?*”. It is understood that the scope and boundaries need to be well defined (e.g. country, supply chain, company, project, product etc.) not to disregard any significant impacts over the life time of the subject. The ultimate goal of the SPE practice shall be well-defined (e.g. benchmarking-indexing, decision-making, optimization etc.) to overcome such difficulties. Eventually, the target of this study is determined as ‘decision-making support for businesses and projects’. In the next chapter 3, a novel and exhaustive SPE model will be presented to address some of the research gaps identified at this stage.

# 3 SUSTAINABILITY PERFORMANCE EVALUATION (SPE): A MODEL PROPOSITION

In the previous chapter 2, the extensive review of literature revealed that SPE shall be carried out in a balanced way without oversimplifying to environmental impacts only. It is understood that there are very limited industrial and scientific applications in SPE, both in number and scope, despite various potential synergies. Accordingly, SPE is not limited to subjective opinions of DMs that are reported in a descriptive manner, but is also a quantitative practice. This is often the case in current literature due to various reasons, among them the difficulty of establishing geographical and temporal boundaries for the multi-dimensional impacts, as well as the lack of robust methods for evaluating qualitative indicators. For social impact assessment, for instance, there are no existing ISO standards. Existing approaches, such as ISO 14040, 14044, 26000 and 14045 are being adapted by companies for determining their social performance indicators (Roundtable for Product Social Metrics, 2016). Nevertheless, they are far from presenting criteria, and criteria structures in a balanced way. The same holds true for other aspects of sustainability.

## 3.1 Concept of the Proposed SPE Model

There are various SPE approaches in literature. Some of them are devoted to methodological and ideological options about how to approach SPE overall, while other research focuses on real case studies and industry surveys about actual SPE practices across industries, or numerical applications such as statistical methods, MCDM techniques, optimization, composite sustainability indices and alike (Brandenburg et al., 2014). Such quantitative research tools largely depend on the existence of the availability of qualitative frameworks, upon which they can be constructed. Data availability is a major challenge for SPE. In supply chains, for example, corporations often do not publicly report on the impacts with missing data at supply chain level (Ahi and Searcy, 2015). The same difficulty applies for products, where an LCA approach is usually employed, leading to many data gaps. This implies that SPE models need to be flexible enough for their users to adjust them for available data. Also, considering the methodological difficulties in assigning the partial or full responsibility of a sustainability impact to the entity (e.g. reporting company), this study suggests that a practical SPE model shall be able to present its users the ability to select the most suitable criteria according to perceived impacts, data availability and practicality in a flexible manner.

This chapter proposes a conceptual, multi-level SPE model that is founded on the three main dimensions of sustainability. One of the reasons of proposing such a SPE model is its ease of understanding for its users, as it is based on a well-known, widely accepted hierarchical structure with economic, environmental and social criteria differentiation. It is a recognized, well-established approach in the industry and academic literature and can be effectively put into perspective with common sense. To capture the big picture, this chapter suggests that SPE shall both consider how actual economic, environmental and social impacts are dealt with over a chosen monitoring period, and the measures taken by the same company to prevent such future risks. For this purpose, the model aims to assess the past sustainability performance together with other suitable aspects about the future by incorporating the preventive measures how possible sustainability risks are managed and how the corporate culture deals with them, such as governance aspects.

These evaluations shall be taken into account by the DMs. There are many interactions of physical, ecological and social systems that support human life (O'Connell et al., 2013). Human judgment is necessary to account for and evaluate these interactions. In this respect, SPE is an expert-supported process, where expert involvement can be sought in the following three stages:

i. Selection, adjustment or addition of criteria, sub-criteria and indicators. The proposed model provides the basis for these parameters.
ii. Prioritization of criteria and their sub-criteria, mapping and definition of the interactions among them.
iii. Numerical and qualitative evaluation of each of the sub-criteria and their indicators for alternatives in the decision-making. Evaluation can be carried out by one or more experts.

This chapter introduces a feasible solution for this first stage (i). The other two stages will be discussed in chapter 4. The aim of the offered approach is to present the first conceptual step towards developing an extensive SPE framework in the next chapter that can be easily understood and quickly adapted for actual business needs and a wide range of circumstances. A novel exhaustive, inclusive, flexible and generic model is constructed with the help of an extensive analysis of literature. A wide range of sustainability impacts are covered, as much as possible, in an inclusive manner not to disregard significant impacts. It differentiates itself from others by redefining many of the criteria and introducing new ones to present practitioners with a clearer understanding and an alternative platform to develop on. This chapter also contributes to literature by aggregating sustainability criteria into common terms and placing them in an exhaustive 4-level layer framework. This leads to a new way of hierarchy among criteria by defining conceptual constituents of evaluation parameters.

This chapter is structured so that SPE model literature is revisited first to capture the current state of research. After that, the proposed SPE model will be presented, which will be followed by a verification of the model and then another section that analyzes the results and provides research recommendations. Finally, section 3.4 will close this discussion.

## 3.2 Methodology Used for Model Development

The methodology implemented for forming the proposed SPE model is built on consecutive steps, where the overall structure and main criteria are first derived from a detailed literature review, then aggregated under common categories and thereafter subjected to expert validation. Based on expert review, the final model is proposed. The draft model is not given in this section, instead the changes made in the draft model are given in ***Table 3.1***. The key intention of this validation step is to verify the model's integrity, acceptability, structure and general suitability. Expert opinions contributed to lowering the systematic bias in the model, as well as to improving the formulations of the criteria and their definitions. Three industrial experts who are resident in Turkey are interviewed for 1.5 - 2.5 hours on different days, using the same draft model.

Two of the experts have strong sustainability consulting and banking credentials and work closely with companies for monitoring and reporting their sustainability impacts. Expert 1 is an engineer and enjoys 15 years of international experience. In the past, she worked with international development institutions on various projects for formulating sustainable energy plans and developing national policies to stimulate environmental finance. Expert 2 is an engineer and has more than 10 years experience for developing project-specific sustainability indicators for periodic sustainability performance monitoring of renewable energy projects. The third expert is the chief executive of a group of companies, working with sustainability consultants and 3rd party verifiers for evaluating company performance. His role encompasses the selection of suitable economic, environmental and social criteria in collaboration with experts for comparing various effects caused by projects, as well as the companies he is responsible of.

Interviews are conducted as a 'blind exercise' to prevent external influence, and guidance is limited to criteria descriptions and clarifications to questions. Following the description of the interview's objective and expected use of the research, the experts are provided with the draft conceptual model and are kindly asked to comment on the model's overall structure, approach, plausibility, criteria's appropriateness and model's industrial applicability. All opinions are either collected in written form or oral statements are taken as note for later review. Following the introduction of the whole model, the complete structure is shown level by level, once at a time, i.e. the 1st level criteria are given to experts first, who are asked whether the criteria make sense for the SPE exercise. Once feedback is received, then the 2nd, 3rd and 4th level criteria are presented in succession.

After all the three interviews are completed, these specific suggestions of experts are considered for potential changes, removals or additions. Suitable suggestions are integrated into the model accordingly. All changes undertaken are listed in ***Table 3.1***. Based on criteria changes at a higher level, some of their sub-criteria are slightly revised for consistency. Considering the number of revisions and experts' overall feedback, a second round of verification check is not deemed necessary.

In general, the interviewed experts agreed with the overall structure and confirmed the 1st and 2nd level criteria without any changes. For 3rd and 4th criteria, they suggested some improvements, which are considered and integrated into the model. Beside the draft model, experts emphasized the need for specific indicators and metrics and proposed certain potential indicators. As the model at its current state does not extend to metrics and indicators, these comments are duly noted. Based on experts' feedback, the following 3rd and 4th level criteria are revised, as shown in ***Table 3.1***.

Table 3.1. Results of the Validation Exercise

| | **Criterion #** | **Expert #** | **Draft proposed criterion** | **Final criterion (based on expert feedback)** |
|---|---|---|---|---|
| **3rd level** | $C_{131}$ | 3 | Ecosystem | Ecosystem vulnerability |
| | $C_{132}$ | 3 | Habitat loss / species mortality | Critical habitats |
| | $C_{143}$ | 1 | Management commitment and strategy | Environmental governance |
| | $C_{323}$ | 1 | Compensation and best practice costs | Depletion and rehabilitation costs |
| | $C_{332}$ | 2 | Cash flow management | Value creation |
| **4th level** | $C_{1221}$ | 2 | Energy intensity / embodied energy | Energy efficiency and intensity |
| | $C_{1322}$ | 2 | Loss of vegetation cover | Deforestation and vegetation cover |
| | $C_{1323}$ | 3 | Affected species and habitats | Species mortality |
| | $C_{1324}$ | 2,3 | Loss of native species | Extinction risk / vulnerable species |
| | $C_{1332}$ | 2 | - | Sustainable fishing and forestry |
| | $C_{1433}$ | 1 | Corporate identity | Corporate identity and environmental transparency |
| | $C_{2113}$ | 1,3 | Diversity | Diversity and equality |
| | $C_{2413}$ | 1 | Disclosure | Disclosure and social ethics |
| | $C_{2421}$ | 1 | Corporate citizenship | Sponsorships |
| | $C_{2422}$ | 1 | Employee initiatives | Social outreach and support schemes |
| | $C_{3233}$ | 1 | - | Costs of depleted natural resources |
| | $C_{3322}$ | 3 | Risk management | Risk management and adaptive capacity |
| | $C_{3422}$ | 1 | Consumption | Consumer preference |

The number of changes at the 3rd level is 5, out of 37 in total. The number of changes at the 4th level is 13, out of 107 in total. Most of these changes are reformulations or improvements of criteria, rather than outright rejection of the existing criterion or proposition of completely new criteria. All the three experts contributed to the validation in a balanced manner. Considering the percentage and the nature of these changes, it is seen that the revised model shown in the next section is robust, acceptable and plausible.

## 3.3 Proposed SPE Model

As a first step, recent SPE literature is extensively reviewed, in particular those papers that propose hierarchical sustainability assessment criteria-trees or unstructured attributes. In general, an inclusive approach is followed, avoiding exclusion as much as possible, whereby similar criteria are aggregated to the thematically nearest group. Considering that many sustainability criteria in literature address very similar issues in different wordings, they are merged together under inclusive terms. This process of naming, defining and assigning inevitably involves a certain level of subjectivity and requires good understanding of literature and sustainability concept as a whole, which is accomplished by merging business perspective and literature together.

The purpose of the model is not proposing an exhaustive list of parameters with a complicated structure, but rather categorizing them systematically in a user-friendly way that can be used by a wide range of user groups. There might be some criteria which are not mentioned in the proposed model the way they have been exactly defined originally, or at the same model level. In many papers, for instance, defined criteria imply pre-determined judgments (e.g. “zero discharge” instead of “discharge amount”), which are streamlined and converted into neutral criteria definitions to prevent embedded opinions. Some criteria descriptions given in this section are adjusted and merged from different sources, while most of them are originally proposed and defined in this study as original scientific contribution. The model will be presented next, level-by-level.

**1$^{st}$ and 2$^{nd}$ levels of the model**: Based on the categories listed in ***Table 2***, the 1$^{st}$ level of the introduced model is composed of sustainability concept’s well-known ‘triple bottom line’ branches. From this point onward, the criteria found in literature are assigned into one of these three categories. The 1$^{st}$ and 2$^{nd}$ level criteria are provided in ***Table 3.2***, including their proposed descriptions and references. Considering that many of the criteria names are newly introduced, their definitions are also new.

Table 3.2. 1st and 2nd Levels of the Proposed SPE Model

| 1st level criteria | 2nd level criteria | Description | References |
|---|---|---|---|
| $C_1$: Environmental | $C_{11}$: Pollutants | Burdening emissions by anthropogenic sources to the atmosphere, soil and water resources in terms of air pollution, greenhouse gases, solid and liquid effluents and other pollutants. | (Andriantiatsaholiniaina et al., 2004; Labuschagne et al., 2005; UNCSD, 2007; Kahraman and Kaya, 2010; GS Foundation, 2012; Chuang, 2014; Ingwersen et al., 2014) |
| | $C_{12}$: Resource efficiency | Intensity of resource depletion/conservation rates of fresh water, energy and raw materials related to raw material extraction/harvest, manufacturing, packaging, logistics, product consumption and recycling practices. | (IChemE, 2002; Shen et al., 2007; Guillez, 2009; Karger and Hennings, 2009; Bilbao-Terol et al., 2012; Li et al., 2012; Schneider and Meins, 2012; Akadiri et al., 2013; Govindan et al., 2013; Cobb et al., 2014) |
| | $C_{13}$: Biodiversity and ecological impacts | Direct and indirect impacts on the environment in terms of ecosystem balance, loss in habitat, protected areas, species mortality rates, sustainable agriculture and human health. | (Shen et al., 2007; Parra-López et al., 2008; Bilbao-Terol et al., 2012; GS Foundation, 2012; Global Reporting Initiative, 2013; ROBECOSAM's Corporate Sustainability Assessment Methodology, 2014; Ziolkowska, 2014) |
| | $C_{14}$: Environmental management | Environmental schemes in organizations, such as environmental management systems, certifications, compliance with environmental legislation, managerial commitment for environment friendly practices and green supply chains. | (Paquette, n.d.; Dias-Sardinha and Reijnders, 2001; Shen et al., 2007; Bilbao-Terol et al., 2012; Chuang, 2014; Cobb et al., 2014) |
| $C_2$: Social | $C_{21}$: Employment | Creation and retaining of permanent direct and indirect jobs in terms of personnel number, job satisfaction, labor practices, decent work, benefits, diversity, equal treatment, occupational safety, as well as personnel training and investment in skills. | (Shen et al., 2007; Yao et al., 2011; Govindan et al., 2013) |
| | $C_{22}$: Life quality and society | Impacts on the society and residents' life quality in terms of social acceptance, cohesion, public health and safety, human rights, cultural practices, local sensitivities and community welfare. | (Atmaca and Basar, 2012; Global Reporting Initiative, 2013) |
| | $C_{23}$: Product stewardship | Product responsibility, grievance mechanisms, consumer satisfaction, local procurement practices, product labeling, customer care and other benefits and hazards related to product use. | (Global Reporting Initiative, 2013; Cobb et al., 2014) |

Table 3.2. 1st and 2nd Levels of the Proposed SPE Model (Cont'd)

| | | | |
|---|---|---|---|
| | $C_{24}$: Social governance | Contributions to community, corporate social responsibility practices and other impacts caused by social commitments governed by corporate principals. | (Bilbao-Terol et al., 2012; ROBECOSAM's Corporate Sustainability Assessment Methodology, 2014; Rajak and Vinodh, 2015) |
| **$C_3$: Economic** | $C_{31}$: Business continuity | Investing to the future of the business and risk reduction through technology/R&D, innovation, resilient supply chain, supply security, productivity, brand value, continuous improvement, crisis management and codes of conduct. | (Kahraman and Kaya, 2010; Global Reporting Initiative, 2013) |
| | $C_{32}$: Costs | Cost of making business paid for capital investments, suppliers, service providers, overhead and production, depletion and rehabilitation costs which may be of fixed or variable nature. | (Shen et al., 2007; Awasthi et al., 2010; Akadiri et al., 2013; Govindan et al., 2013) |
| | $C_{33}$: Financial performance | Bottom line results of business operations, such as cash flow, stability of income, solvency, value creation, share price and investor appeal. | (Epstein and Wisner, 2001; Labuschagne et al., 2005; Yao et al., 2011) |
| | $C_{34}$: Product performance | Fulfillment of customer expectations from products and services, such as delivery time, customer relationships, convenience, product quality and durability. | (New Zealand Business Council for Sustainable Development, 2003; Akadiri et al., 2013; Global Reporting Initiative, 2013) |

**3rd level of the proposed model**: Following the same approach explained for the 2nd level criteria, the proposed model gives the 3rd level criteria as sub-ordinates to each of the 2nd level criterion. These 3rd level criteria and their definitions are itemized in ***Table 3.3*** - ***Table 3.5***.

**4th level of the proposed model**: Similarly, the proposed 4th level criteria are developed with the help of literature and a successive expert validation. The sources used are illustrated in ***Table 3.6***. The ultimate model is presented in ***Figure 3.1*** up to its 3rd level. The 4th level criteria are not illustrated in this ***Figure 3.1*** due to space limitations and are instead listed in ***Table 3.7***.

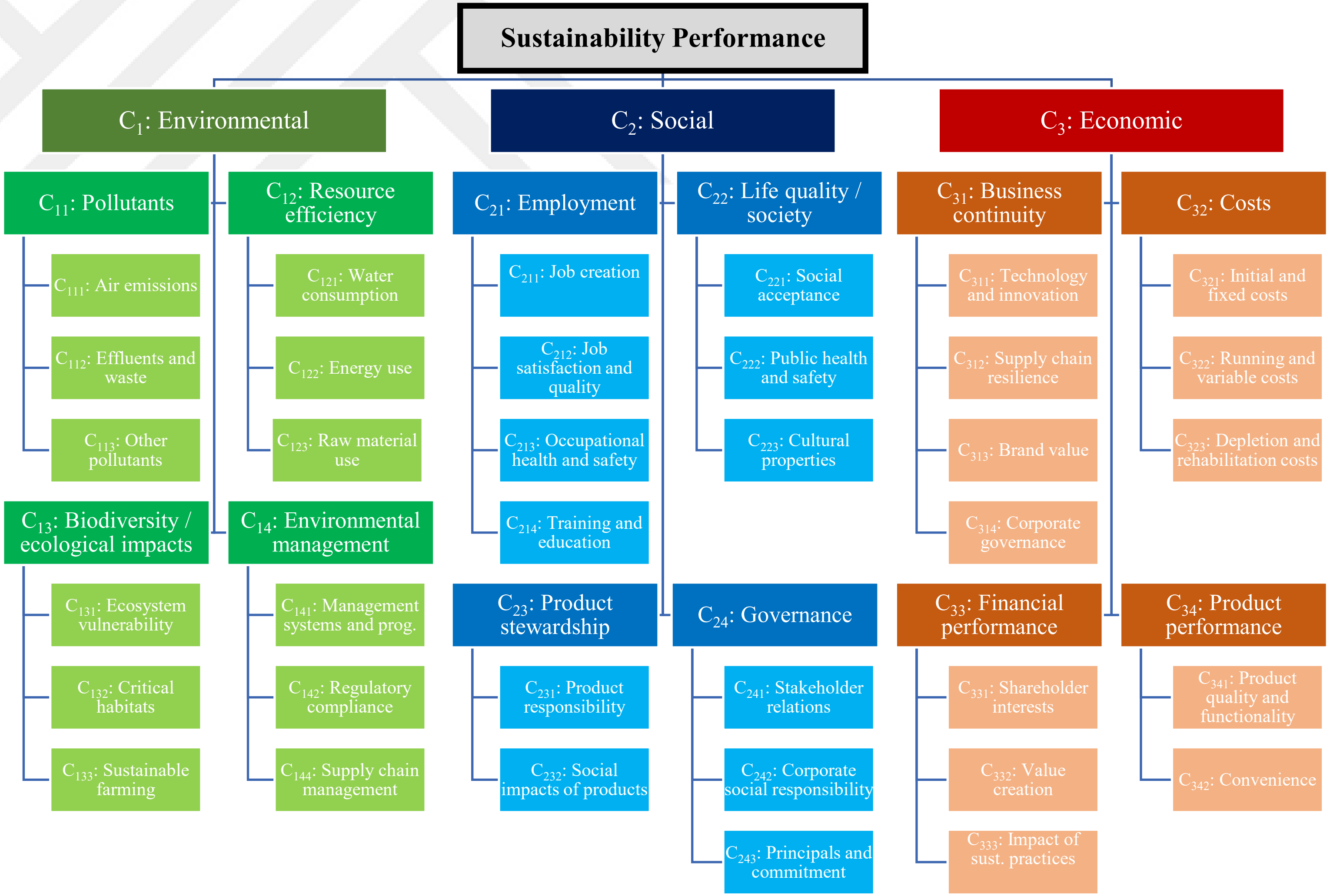


Figure 3.1. Overall Structure of the Proposed Model (first three levels)

Table 3.3. 3rd Level Environmental Criteria

| | 2nd level criteria | 3rd level criteria | Definition | References |
|---|---|---|---|---|
| **$C_1$: Environmental** | $C_{11}$: Pollutants | $C_{111}$: Air emissions | Air pollutants that deteriorate ambient air quality, harm ozone layer or contribute to climate change, such as smog, particulate matter, carbon dioxide emissions etc. | (Heravi et al., n.d.; Epstein and Wisner, 2001; Andriantiatsaholiniaina et al., 2004; Shen et al., 2007; GS Foundation, 2012) |
| | | $C_{112}$: Effluents and Waste | Solid waste, hazardous waste and wastewater emissions in terms of amount, concentration and toxicity, as well as waste management practices. | (Epstein and Wisner, 2001; Labuschagne et al., 2005; Lu et al., 2007; Shen et al., 2007; GS Foundation, 2012) |
| | | $C_{113}$: Other pollutants | Undesired emissions of noise, radioactivity, electromagnetic interference, as well as land use related pollution such as erosion and dust. | (Ghadimi et al., 2012; Jawahar et al., 2015) |
| | $C_{12}$: Resource efficiency | $C_{121}$: Water consumption | Intensity of use of water resources in terms of fresh and recycled/reused water, taking local water availability, sustainability of reservoirs/catchment areas and competing users into account. | (Epstein and Wisner, 2001; IChemE, 2002; Shen et al., 2007, Erol et al., 2009, 2011) |
| | | $C_{122}$: Energy use | Amount of fossil fuels and renewable energy sources consumed for business activities, also taking supply chain's energy intensity and energy efficiency into account. | (Epstein and Wisner, 2001; IChemE, 2002; Lu et al., 2007; Shen et al., 2007; UNCSD, 2007; Erol et al., 2009, 2011; Guillez, 2009; Jayal et al., 2010; Bilbao-Terol et al., 2012; Li et al., 2012; Global Reporting Initiative, 2013; Hsueh and Yan, 2013; Chuang, 2014) |
| | | $C_{123}$: Raw material use | Amount of raw materials used, such as minerals, ores, processed metals, chemicals, harvested resources (agricultural products, timber etc.), also considering the sustainability and indirect environmental impacts of mining and harvesting operations. | (IChemE, 2002; Lu et al., 2007; Shen et al., 2007; Karger and Hennings, 2009; Li et al., 2012; Global Reporting Initiative, 2013; Pons and de la Fuente, 2013) |
| | $C_{13}$: Biodiversity and ecological impacts | $C_{131}$: Ecosystem vulnerability | Ecologic impacts (e.g. desertification, acidification, flow regime changes etc.) on systems of land, oceans, rivers, seas and coasts as a whole that interact with communities of living organisms. | (UNCSD, 2007; Ingwersen et al., 2014) |

Table 3.3. 3rd Level Environmental Criteria (Cont'd)

| | | | |
|---|---|---|---|
| | $C_{132}$: Critical habitats | Violations of sensitive habitats, interruption of migration routes, deforestation, loss of vegetation cover, damage to vulnerable species and other threats to biological diversity and native organisms. | (Heravi et al., n.d.; Epstein and Wisner, 2001; Shen et al., 2007; Ugwu and Haupt, 2007; Manzini et al., 2011; Yao et al., 2011; GS Foundation, 2012) |
| | $C_{133}$: Sustainable farming | Impacts of agriculture, such as over-irrigation, soil salinization, contamination of underground and surface waters with fertilizer and pesticides, deforestation for farming / timber production, monoculture farming, fish stocks etc. | (Heravi et al., n.d.; UNCSD, 2007) |
| $C_{14}$: Environmental management | $C_{141}$: Management systems and programs | Integration of environmental management systems (e.g. ISO 14001), personnel training for environmental consciousness, commitment to voluntary environmental programs, eco-label schemes and green initiatives. | (Paquette, n.d.; Bilbao-Terol et al., 2012; ROBECOSAM's Corporate Sustainability Assessment Methodology, 2014) |
| | $C_{142}$: Regulatory compliance | Compliance with legal environmental liabilities, precautionary approach, transparency and gradual improvement in environmental risk management. | (Dias-Sardinha and Reijnders, 2001; IChemE, 2002; Andriantiatsaholiniaina et al., 2004; Akadiri et al., 2013; Cobb et al., 2014) |
| | $C_{143}$: Environmental governance | Disclosed corporate commitments for environmental best practice, continuous monitoring of sustainability impacts of business operations, transparent communication and reporting of sustainability performance. | (Dias-Sardinha and Reijnders, 2001; Cobb et al., 2014) |
| | $C_{144}$: Supply chain management | Green procurement, supplier selection and monitoring, collaborative and eco-design, green (reverse-) logistics and other supply chain related activities with direct environmental aspects. | (Bilbao-Terol et al., 2012; Hsueh and Yan, 2013; Cobb et al., 2014) |

Table 3.4. 3rd Level Social Criteria

| | 2nd level criteria | 3rd level criteria | Definition | References |
|---|---|---|---|---|
| **$C_2$: Social** | $C_{21}$: Employment | $C_{211}$: Job creation | Direct and indirect permanent employment opportunities in terms of number, local labor, recruitment practices, enabling of skilled people, diversity, gender equality, non-discrimination etc. | (Kahraman and Kaya, 2010; Atmaca and Basar, 2012; Liu, 2014; Ziolkowska, 2014) |
| | | $C_{212}$: Job satisfaction and quality | The level of personnel satisfaction in terms of employment quality, personnel turnover, fair promotion practices, workplace environment, complaints management / grievance mechanism, social rights, compensation etc. | (Epstein and Wisner, 2001; GS Foundation, 2012; Li et al., 2012; Jawahar et al., 2015) |
| | | $C_{213}$: Occupational health and safety | Safe business processes, occupational safety for workers, risk of injuries, medical sickness and work-related premature deaths, employee training, safety equipment, social security, precautionary approach and economic coverage against risks. | Bilbao-Terol et al., 2012; Erol et al., 2009; Global Reporting Initiative, 2013; Govindan et al., 2013; Guillez, 2009; Heravi et al., n.d.; International Labour Standards, 2014; Karger and Hennings, 2009; Labuschagne et al., 2005; Rajak and Vinodh, 2015; Measuring Intangibles, 2014; Shen et al., 2007; Ugwu and Haupt, 2007; Ziolkowska, 2014 |
| | | $C_{214}$: Training and education | Investing in skills, such as mentoring schemes, vocational guidance, career development, education-support, work training programs etc. | Erol et al., 2009; Global Reporting Initiative, 2013; Measuring Intangibles, 2014; Roundtable for Product Social Metrics, n.d. |
| | $C_{22}$: Life quality and society | $C_{221}$: Social acceptance | Existence of community complaints, integrated social grievance mechanism, impacts on social welfare (e.g. taxes paid, public grants received etc.) and physical infrastructure (e.g. traffic congestion, power shortages etc.). | (Kahraman and Kaya, 2010; Atmaca and Basar, 2012) |
| | | $C_{222}$: Public health and safety | Impact on public health and safety, such as large scale accidents/spills, resilience to natural hazards, disaster preparedness, healthcare services, local fatality and sickness rates. | Akadiri et al., 2013; Erol et al., 2009; International Labour Standards, 2014; Jayal et al., 2010; Labuschagne et al., 2005; Roundtable for Product Social Metrics, n.d.; Shen et al., 2007 |

Table 3.4. 3rd Level Social Criteria (Cont’d)

| | | | |
|---|---|---|---|
| | $C_{223}$: Cultural properties | Conservation of cultural heritage, extent of encroachment to sensitive sites, precautionary approach, preservation of local cultural practices and social cohesion. | (Labuschagne et al., 2005; GS Foundation, 2012) |
| $C_{23}$: Product stewardship | $C_{231}$: Product responsibility | Local sourcing, procurement from females and minorities, fair purchasing practices, product safety, assurance systems and recall / replacement of non-compliant products. | (Global Reporting Initiative, 2013) |
| | $C_{232}$: Social impacts of products | Direct and indirect social impacts of products on individual, community, region, national and international level, such as comfort, facility, efficiency, productivity, reliability, coverage of basic needs, access to public services, etc. | (Shen et al., 2007) |
| $C_{24}$: Social governance | $C_{241}$: Stakeholder relations | Stakeholder involvement in decision making procedures, engagement with communities, cultural and social participation, adaptation to local circumstances, information sharing with and disclosure to stakeholders. | International Labour Standards, 2014, Measuring Intangibles, 2014; Schneider and Meins, 2012 |
| | $C_{242}$: Corporate social responsibility | Corporate citizenship, sponsorships, social outreach and support schemes, employee initiatives and voluntary social engagement. | (Global Reporting Initiative, 2013; Cobb et al., 2014) |
| | $C_{243}$: Principals and commitment | Compatibility with local agenda, coherence with policies, corporate reputation in the community, commitment to human rights and dignity, voluntary recognition of international labor standards, etc. | (Rajak and Vinodh, 2015) |

Table 3.5. 3rd Level Economic Criteria

| | 2nd level criteria | 3rd level criteria | Definition | References |
|---|---|---|---|---|
| **$C_3$: Economic** | $C_{31}$: Business continuity | $C_{311}$: Technology and innovation | Competitive advantage through innovation management, technological self-reliance, creation of local knowhow and R&D activities. | (Heravi et al., n.d.; UNCSD, 2007; Ghadimi et al., 2012; Cobb et al., 2014) |
| | | $C_{312}$: Supply chain resilience | Supply chain's flexibility, speed, visibility and collaboration among its members against possible disruptions and shocks. | (Murino et al., 2011; Jüttner and Maklan, 2013) |
| | | $C_{313}$: Brand value | Customer expectations from the products and their satisfaction level in relation to corporate reputation, sensitivities in the market and customer relationship management. | (ROBECOSAM's Corporate Sustainability Assessment Methodology, 2014) |
| | | $C_{314}$: Corporate governance | Ownership structure, shareholder concentration, management profile, social responsiveness and corporate preparedness to vulnerabilities for changing economic, social and ecologic circumstances. | (ROBECOSAM's Corporate Sustainability Assessment Methodology, 2014) |
| | $C_{32}$: Costs | $C_{321}$: Initial and fixed costs | Capital expenditures (e.g. equipment and facilities), overhead expenses (e.g. accounting, advertising, insurance, legal fees etc.), other fixed and/or initial costs. | (Atmaca and Basar, 2012; Akadiri et al., 2013; Liu, 2014) |
| | | $C_{322}$: Running and variable costs | Production costs (e.g. raw materials, fuels, direct personnel etc.), logistics costs (transportation, warehousing, distribution etc.) and other running and/or variable costs. | (Atmaca and Basar, 2012) |
| | | $C_{323}$: Depletion and rehabilitation costs | Expenses related to extraordinary events, such as environmental accidents, community lawsuits, anti-competitive behavior, depletion of resources, land rehabilitation etc. | (Ugwu and Haupt, 2007; Ingwersen et al., 2014) |
| | $C_{33}$: Financial performance | $C_{331}$: Shareholder interests | Economic performance indicators that directly affect company value (i.e. share price), such as sales, turnover, cost of debt, capacity usage ratio etc. | (Erol et al., 2009) |

Table 3.5. 3rd Level Economic Criteria (Cont'd)

| | | | |
|---|---|---|---|
| | $C_{332}$: Value creation | Information that reflects how sustainable a company's cash flow in long-term is, such as customer base, stability of revenues, risk management (e.g. hedging, insurance etc.), investment strategy, adaptive capacity to market disruptions etc. | (Krajnc and Glavič, 2005; Karger and Hennings, 2009) |
| | $C_{333}$: Impact of sustainable practices | Reaction of investors and customers to corporate sustainability-related actions, such as appeal to green products, green/ethical funds, stock exchange sustainability indices etc. | |
| $C_{34}$: Product performance | $C_{341}$: Product quality and functionality | Direct economic gains related to product durability (i.e. resistance to fire, water, weather) and product eco-efficiency (lifelong electricity consumption, fuel performance etc.) | (Parra-López et al., 2008; Guillez, 2009; Chee Tahir and Darton, 2010; Jayal et al., 2010; Govindan et al., 2013) |
| | $C_{342}$: Convenience | Indirect economic gains related to ease of manufacturing, servicing and maintaining, predictability of performance, local availability etc. in terms of client preference, production and consumption habits. | (New Zealand Business Council for Sustainable Development, 2003; UNCSD, 2007) |

Table 3.6. 4th Level Criteria

| **4th Level Environmental criteria** | **Reference** | **4th Level Social Criteria** | **Reference** | **4th Level Economic Criteria** | **Reference** |
|---|---|---|---|---|---|
| $C_{1111}$: Ambient air quality | (UNCSD, 2007; GS Foundation, 2012; Akadiri et al., 2013) | $C_{2111}$: Labor sources and recruitment | (Labuschagne et al., 2005; Parra-López et al., 2008) | $C_{3111}$: Innovation management | (Erol et al., 2009; Govindan et al., 2013; ROBECOSAM's Corporate Sustainability Assessment Methodology, 2014) |
| $C_{1112}$: Air pollutants and ozone protection | (Shen et al., 2007; Parra-López et al., 2008; Awasthi et al., 2010; Yao et al., 2011; Bilbao-Terol et al., 2012; GS Foundation, 2012; Akadiri et al., 2013; Ingwersen et al., 2014) | $C_{2112}$: Enabling skilled people | (Shen et al., 2007) | $C_{3112}$: Research and development | (ROBECOSAM's Corporate Sustainability Assessment Methodology, 2014) |
| $C_{1113}$: Climate change | (Heravi et al., n.d.; Labuschagne et al., 2005; UNCSD, 2007; Erol et al., 2009; Karger and Hennings, 2009; Bilbao-Terol et al., 2012; GS Foundation, 2012; Ingwersen et al., 2014) | $C_{2113}$: Diversity and equality | (Epstein and Roy, 2001; Erol et al., 2011; Schneider and Meins, 2012; Global Reporting Initiative, 2013; Rajak and Vinodh, 2015) | $C_{3113}$: Technological self-reliance | (GS Foundation, 2012) |
| $C_{1121}$: Water pollution and waste water quality | (New Zealand Business Council for Sustainable Development, 2003; Shen et al., 2007; UNCSD, 2007; GS Foundation, 2012) | $C_{2121}$: Personnel turnover | (Erol et al., 2011; Li et al., 2012; Rajak and Vinodh, 2015) | $C_{3121}$: Flexibility | (Jüttner and Maklan, 2013) |

Table 3.6. 4th Level Criteria (Cont'd)

| | | | | | |
|---|---|---|---|---|---|
| $C_{1122}$: Effluent quantity | (GS Foundation, 2012) | $C_{2122}$: Workplace environment | (IChemE, 2002) | $C_{3122}$: Velocity | (Jüttner and Maklan, 2013) |
| $C_{1123}$: Solid waste | (New Zealand Business Council for Sustainable Development, 2003; Lu et al., 2007; Ugwu and Haupt, 2007; Yao et al., 2011; GS Foundation, 2012; Chuang, 2014) | $C_{2123}$: Complaints | (Epstein and Wisner, 2001; Erol et al., 2009, 2011) | $C_{3123}$: Visibility | (Jüttner and Maklan, 2013) |
| $C_{1124}$: Hazardous waste | (Andriantiatsaholiniaina et al., 2004; Ugwu and Haupt, 2007; Jayal et al., 2010; GS Foundation, 2012; Li et al., 2012) | $C_{2124}$: Social rights and compensation | Epstein and Wisner, 2001; Erol et al., 2009, 2011; Labuschagne et al., 2005; Rajak and Vinodh, 2015; Roundtable for Product Social Metrics, n.d. | $C_{3124}$: Collaboration | (Jüttner and Maklan, 2013) |
| $C_{1125}$: Management practices | (Dias-Sardinha and Reijnders, 2001) | $C_{2131}$: Worker safety | Cobb et al., 2014; GS Foundation, 2012; Jayal et al., 2010; Labuschagne et al., 2005; Pons and de la Fuente, 2013; Roundtable for Product Social Metrics, n.d. | $C_{3131}$: Customer satisfaction | (Li et al., 2012) |
| $C_{1131}$: Land use | (Labuschagne et al., 2005; Ugwu and Haupt, 2007; UNCSD, 2007; Erol et al., 2009; Guillez, 2009; GS Foundation, 2012; Ziolkowska, 2014) | $C_{2132}$: Process safety | (Epstein and Wisner, 2001; Shen et al., 2007; Cobb et al., 2014) | $C_{3132}$: Reputation | (Epstein and Wisner, 2001) |
| $C_{1132}$: Electromagnetic interference and radiation | (GS Foundation, 2012) | $C_{2133}$: Protection against risks | (International Labour Standards, 2014) | $C_{3141}$: Vulnerability / preparedness | (UNCSD, 2007) |

Table 3.6. 4th Level Criteria (Cont'd)

| | | | | | |
|---|---|---|---|---|---|
| $C_{1133}$: Radioactivity | (Atmaca and Basar, 2012; Bilbao-Terol et al., 2012) | $C_{2141}$: Investing in skills | | $C_{3142}$: Transparency | (Dias-Sardinha and Reijnders, 2001; Erol et al., 2009; Rajak and Vinodh, 2015) |
| $C_{1134}$: Noise emissions | (Heravi et al., n.d.; Shen et al., 2007; Erol et al., 2009; Yao et al., 2011; GS Foundation, 2012) | $C_{2142}$: Career development | (Labuschagne et al., 2005; Erol et al., 2009) | $C_{3143}$: Stakeholder involvement | |
| $C_{1211}$: Total water usage | (Labuschagne et al., 2005; UNCSD, 2007; Dinh et al., 2009; Li et al., 2012; Global Reporting Initiative, 2013) | $C_{2211}$: Community complaints | (Epstein and Wisner, 2001; Erol et al., 2009, 2011; Jayal et al., 2010) | $C_{3144}$: Management structure | |
| $C_{1212}$: Water recycled and reused | (IChemE, 2002; Ugwu and Haupt, 2007; Li et al., 2012; Global Reporting Initiative, 2013) | $C_{2212}$: Public wealth / community welfare | (Andriantiatsaholiniaina et al., 2004; Labuschagne et al., 2005; Kolak et al., 2011; Rajak and Vinodh, 2015) | $C_{3211}$: Capital investment | (Shen et al., 2007; Guillez, 2009; Karger and Hennings, 2009; Atmaca and Basar, 2012) |
| $C_{1221}$: Energy efficiency and intensity | (Akadiri et al., 2013; Global Reporting Initiative, 2013; Liu, 2014) | $C_{2213}$: Physical infrastructure | (Heravi et al., n.d.; Shen et al., 2007; Awasthi et al., 2010; Rajak and Vinodh, 2015) | $C_{3212}$: Overhead costs | (New Zealand Business Council for Sustainable Development, 2003) |
| $C_{1222}$: Renewable energy | (Erol et al., 2009; Jayal et al., 2010; Li et al., 2012; Liu, 2014) | $C_{2221}$: Healthcare / wellbeing | (UNCSD, 2007; Roundtable for Product Social Metrics, 2016) | $C_{3213}$: Other costs | |
| $C_{1223}$: Non-renewable energy and fossil fuels | (Heravi et al., n.d.; Ingwersen et al., 2014) | $C_{2222}$: Hazards | (Epstein and Wisner, 2001; Shen et al., 2007; Awasthi et al., 2010; Atmaca and Basar, 2012; Chuang, 2014) | $C_{3221}$: Production costs | (Jayal et al., 2010; Ziolkowska, 2014) |

Table 3.6. 4th Level Criteria (Cont'd)

| | | | | | |
|---|---|---|---|---|---|
| $C_{1231}$: Renewable raw materials | (Heravi et al., n.d.; New Zealand Business Council for Sustainable Development, 2003; Shen et al., 2007; Ghadimi et al., 2012) | $C_{2223}$: Resilience to natural hazards | (UNCSD, 2007) | $C_{3222}$: Logistics costs | (Shen et al., 2007) |
| $C_{1232}$: Non-renewable raw materials | (Ghadimi et al., 2012) | $C_{2231}$: Conservation of cultural heritage | (Heravi et al., n.d.; Shen et al., 2007; Ugwu and Haupt, 2007; Yao et al., 2011) | $C_{3223}$: Disposal cost | (Shen et al., 2007; Jayal et al., 2010; Akadiri et al., 2013) |
| $C_{1233}$: Recycled and reused materials | (Heravi et al., n.d.; IChemE, 2002; Shen et al., 2007; Jayal et al., 2010; Erol et al., 2011; Akadiri et al., 2013; Global Reporting Initiative, 2013; Chuang, 2014) | $C_{2232}$: Social cohesion | (Labuschagne et al., 2005; Rajak and Vinodh, 2015) | $C_{3231}$: Sustainability management costs | |
| $C_{1311}$: Land ecosystems | (Ugwu and Haupt, 2007) | $C_{2311}$: Procurement Practices | (Global Reporting Initiative, 2013) | $C_{3232}$: Rehabilitation costs | (Shen et al., 2007; Global Reporting Initiative, 2013; Tuzkaya, 2013) |
| $C_{1312}$: River ecosystems | (GS Foundation, 2012) | $C_{2312}$: Engagement of value chain partners | (Cobb et al., 2014) | $C_{3233}$: Costs of depleted natural resources | |
| $C_{1313}$: Oceans, seas and coasts | (UNCSD, 2007) | $C_{2313}$: Assurance System | (Cobb et al., 2014) | $C_{3311}$: Solvency | (Labuschagne et al., 2005) |
| $C_{1321}$: Violation of animals' territory | (Heravi et al., n.d.) | $C_{2321}$: Directly affected communities | (IChemE, 2002; Liu, 2014) | $C_{3312}$: Economic performance | (Labuschagne et al., 2005; UNCSD, 2007; Li et al., 2012; Schneider and Meins, 2012; Global Reporting Initiative, 2013) |

Table 3.6. 4th Level Criteria (Cont'd)

| | | | | | |
|---|---|---|---|---|---|
| $C_{1322}$: Deforestation and vegetation cover | (Andriantiatsaholiniaina et al., 2004; UNCSD, 2007; Manzini et al., 2011) | $C_{2322}$: Indirectly affected communities | (IChemE, 2002; Liu, 2014) | $C_{3321}$: Stability of income | (Parra-López et al., 2008; Karger and Hennings, 2009) |
| $C_{1323}$: Species mortality | (Manzini et al., 2011; GS Foundation, 2012) | $C_{2411}$: Dialogue in decision making | (Epstein and Roy, 2001; Erol et al., 2011; Rajak and Vinodh, 2015) | $C_{3322}$: Risk management and adaptive capacity | (Karger and Hennings, 2009; ROBECOSAM's Corporate Sustainability Assessment Methodology, 2014) |
| $C_{1324}$: Extinction risk / vulnerable species | (UNCSD, 2007; GS Foundation, 2012; Global Reporting Initiative, 2013) | $C_{2412}$: Local engagement | (Global Reporting Initiative, 2013; ROBECOSAM's Corporate Sustainability Assessment Methodology, 2014) | $C_{3331}$: Investor appeal | (New Zealand Business Council for Sustainable Development, 2003) |
| $C_{1331}$: Agricultural practices | (Heravi et al., n.d.; UNCSD, 2007) | $C_{2413}$: Disclosure and social ethics | (Dias-Sardinha and Reijnders, 2001; Jayal et al., 2010) | $C_{3332}$: Sustainable products | (Tuzkaya, 2013; Cobb et al., 2014) |
| $C_{1332}$: Sustainable fishing and forestry | (Andriantiatsaholiniaina et al., 2004; UNCSD, 2007) | $C_{2421}$: Sponsorships | (Global Reporting Initiative, 2013) | $C_{3411}$: Product life | (Epstein and Roy, 2001; UNCSD, 2007; GS Foundation, 2012; Rowley et al., 2012; Jüttner and Maklan, 2013; Chuang, 2014) |
| $C_{1411}$: Environmental Management Systems | (Paquette, n.d.; Dias-Sardinha and Reijnders, 2001; Erol et al., 2011; Govindan et al., 2013; Cobb et al., 2014) | $C_{2422}$: Social outreach and support schemes | (Epstein and Roy, 2001; Erol et al., 2009; Global Reporting Initiative, 2013) | $C_{3412}$: Life cycle eco-efficiency | (Epstein and Wisner, 2001) |

Table 3.6. 4th Level Criteria (Cont'd)

| | | | | | |
|---|---|---|---|---|---|
| $C_{1412}$: Commitment to voluntary codes | (Cobb et al., 2014) | $C_{2431}$: Compatibility with policies | (Kahraman and Kaya, 2010) | $C_{3421}$: Production and consumption habits | (UNCSD, 2007) |
| $C_{1413}$: Internal knowhow and capacity development | (Shen et al., 2007) | $C_{2432}$: Recognition in the community | (Cobb et al., 2014) | $C_{3422}$: Consumer preference | Erol et al., 2009; Guillez, 2009; Roundtable for Product Social Metrics, n.d. |
| $C_{1421}$: Legal environmental liabilities | (Cobb et al., 2014) | $C_{2433}$: International labor standards | (Epstein and Wisner, 2001; New Zealand Business Council for Sustainable Development, 2003; Bilbao-Terol et al., 2012) | $C_{3423}$: Indirect product benefits | (Epstein and Roy, 2001) |
| $C_{1422}$: Environmental risk management | (Guillez, 2009; GS Foundation, 2012) | $C_{2434}$: Corporate strategy | (Schneider and Meins, 2012; ROBECOSAM's Corporate Sustainability Assessment Methodology, 2014; Cobb et al., 2014) | | |
| $C_{1431}$: Disclosed commitments and goals | (Dias-Sardinha and Reijnders, 2001; Cobb et al., 2014) | | | | |
| $C_{1432}$: Sustainability reporting and communication | (Shen et al., 2007; Erol et al., 2009; ROBECOSAM's Corporate Sustainability Assessment Methodology, 2014; Cobb et al., 2014) | | | | |

Table 3.6. 4th Level Criteria (Cont'd)

| | | | |
|---|---|---|---|
| $C_{1433}$: Corporate identity and environmental transparency | (Dias-Sardinha and Reijnders, 2001; Shaun M. Powell, 2011) | | |
| $C_{1441}$: Sustainable procurement | (Ugwu and Haupt, 2007; Global Reporting Initiative, 2013; Hsueh and Yan, 2013) | | |
| $C_{1442}$: Green design and manufacturing | (Paquette, n.d.; Shen et al., 2007; Jayal et al., 2010; Govindan et al., 2013; Chuang, 2014) | | |
| $C_{1443}$: Green sourcing / manufacturing | (Shen et al., 2007; Tuzkaya, 2013; ROBECOSAM's Corporate Sustainability Assessment Methodology, 2014; Chuang, 2014) | | |
| $C_{1444}$: Green logistics and disposal | (Paquette, n.d.; Erol et al., 2009; Chuang, 2014) | | |

Table 3.7. Overall Proposed Model

| 1st Level | | 2nd Level | | 3rd Level | | 4th Level | |
|---|---|---|---|---|---|---|---|
| $C_1$ | Environmental | $C_{11}$ | Pollutants | $C_{111}$ | Air emissions | $C_{1111}$ | Ambient air quality |
| | | | | | | $C_{1112}$ | Air pollutants and ozone protection |
| | | | | | | $C_{1113}$ | Climate change |
| | | | | $C_{112}$ | Effluents and Waste | $C_{1121}$ | Water pollution and waste water quality |
| | | | | | | $C_{1122}$ | Effluent quantity |
| | | | | | | $C_{1123}$ | Solid waste |
| | | | | | | $C_{1124}$ | Hazardous waste |
| | | | | | | $C_{1125}$ | Management practices |
| | | | | $C_{113}$ | Other pollutants | $C_{1131}$ | Land use |
| | | | | | | $C_{1132}$ | Electromagnetic radiation and interference |
| | | | | | | $C_{1133}$ | Radioactivity |
| | | | | | | $C_{1134}$ | Noise emissions |
| | | $C_{12}$ | Resource efficiency | $C_{121}$ | Water consumption | $C_{1211}$ | Total water usage |
| | | | | | | $C_{1212}$ | Water recycled and reused |
| | | | | $C_{122}$ | Energy use | $C_{1221}$ | Energy efficiency and intensity |
| | | | | | | $C_{1222}$ | Renewable energy |
| | | | | | | $C_{1223}$ | Non-renewable energy and fossil fuels |
| | | | | $C_{123}$ | Raw material use | $C_{1231}$ | Renewable raw materials |
| | | | | | | $C_{1232}$ | Non-renewable raw materials |
| | | | | | | $C_{1233}$ | Recycled and reused materials |
| | | $C_{13}$ | Biodiversity and ecological impacts | $C_{131}$ | Ecosystem vulnerability | $C_{1311}$ | Land ecosystems |
| | | | | | | $C_{1312}$ | River ecosystems |
| | | | | | | $C_{1313}$ | Oceans, seas and coasts |

Table 3.7. Overall Proposed Model (Cont'd)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | $C_{132}$ | Critical habitats | $C_{1321}$ | Violation of animals' territory |
| | | | | | | $C_{1322}$ | Deforestation and vegetation cover |
| | | | | | | $C_{1323}$ | Species mortality |
| | | | | | | $C_{1324}$ | Extinction risk / vulnerable species |
| | | | | $C_{133}$ | Sustainable farming | $C_{1331}$ | Agricultural practices |
| | | | | | | $C_{1332}$ | Sustainable fishing and forestry |
| | | $C_{14}$ | Environmental management | $C_{141}$ | Management systems and programs | $C_{1411}$ | Environmental Management Systems |
| | | | | | | $C_{1412}$ | Commitment to voluntary codes |
| | | | | | | $C_{1413}$ | Internal knowhow and capacity development |
| | | | | $C_{142}$ | Regulatory compliance | $C_{1421}$ | Legal environmental liabilities |
| | | | | | | $C_{1422}$ | Environmental risk management |
| | | | | $C_{143}$ | Environmental governance | $C_{1431}$ | Disclosed commitments and goals |
| | | | | | | $C_{1432}$ | Sustainability reporting and communication |
| | | | | | | $C_{1433}$ | Corporate identity and environmental transparency |
| | | | | $C_{144}$ | Supply chain management | $C_{1441}$ | Sustainable procurement |
| | | | | | | $C_{1442}$ | Green design and manufacturing |
| | | | | | | $C_{1443}$ | Green logistics and disposal |
| $C_2$ | Social | $C_{21}$ | Employment | $C_{211}$ | Job creation | $C_{2111}$ | Labor sources and recruitment |
| | | | | | | $C_{2112}$ | Enabling skilled people |
| | | | | | | $C_{2113}$ | Diversity and equality |
| | | | | $C_{212}$ | Job satisfaction and quality | $C_{2121}$ | Personnel turnover |
| | | | | | | $C_{2122}$ | Workplace environment |

Table 3.7. Overall Proposed Model (Cont’d)

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | $C_{2123}$ | Complaints |
| | | | | | $C_{2124}$ | Social rights and compensation |
| | | | $C_{213}$ | Occupational health and safety | $C_{2131}$ | Worker safety |
| | | | | | $C_{2132}$ | Process safety |
| | | | | | $C_{2133}$ | Protection against risks |
| | | | $C_{214}$ | Training and education | $C_{2141}$ | Investing in skills |
| | | | | | $C_{2142}$ | Career development |
| | $C_{22}$ | Life quality and society | $C_{221}$ | Social acceptance | $C_{2211}$ | Community complaints |
| | | | | | $C_{2212}$ | Public wealth / community welfare |
| | | | | | $C_{2213}$ | Physical infrastructure |
| | | | $C_{222}$ | Public health and safety | $C_{2221}$ | Healthcare / wellbeing |
| | | | | | $C_{2222}$ | Hazards |
| | | | | | $C_{2223}$ | Resilience to natural hazards |
| | | | $C_{223}$ | Cultural properties | $C_{2231}$ | Conservation of cultural heritage |
| | | | | | $C_{2232}$ | Social cohesion |
| | $C_{23}$ | Product stewardship | $C_{231}$ | Product responsibility | $C_{2311}$ | Procurement Practices |
| | | | | | $C_{2312}$ | Engagement of value chain partners |
| | | | | | $C_{2313}$ | Assurance System |
| | | | $C_{232}$ | Social impacts of products | $C_{2321}$ | Directly affected communities |
| | | | | | $C_{2322}$ | Indirectly affected communities |
| | $C_{24}$ | Social governance | $C_{241}$ | Stakeholder relations | $C_{2411}$ | Dialogue in decision making |
| | | | | | $C_{2412}$ | Local engagement |
| | | | | | $C_{2413}$ | Disclosure and social ethics |

Table 3.7. Overall Proposed Model (Cont’d)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | $C_{242}$ | Corporate social responsibility | $C_{2421}$ | Sponsorships |
| | | | | | | $C_{2422}$ | Social outreach and support schemes |
| | | | | $C_{243}$ | Principals and commitment | $C_{2431}$ | Compatibility with policies |
| | | | | | | $C_{2432}$ | Recognition in the community |
| | | | | | | $C_{2433}$ | International labor standards |
| | | | | | | $C_{2434}$ | Corporate strategy |
| $C_3$ | Economic | $C_{31}$ | Business continuity | $C_{311}$ | Technology and innovation | $C_{3111}$ | Innovation management |
| | | | | | | $C_{3112}$ | Research and development |
| | | | | | | $C_{3113}$ | Technological self-reliance |
| | | | | $C_{312}$ | Supply chain resilience | $C_{3121}$ | Flexibility |
| | | | | | | $C_{3122}$ | Velocity |
| | | | | | | $C_{3123}$ | Visibility |
| | | | | | | $C_{3124}$ | Collaboration |
| | | | | $C_{313}$ | Brand value | $C_{3131}$ | Customer satisfaction |
| | | | | | | $C_{3132}$ | Reputation |
| | | | | $C_{314}$ | Corporate governance | $C_{3141}$ | Vulnerability / preparedness |
| | | | | | | $C_{3142}$ | Transparency |
| | | | | | | $C_{3143}$ | Stakeholder involvement |
| | | | | | | $C_{3144}$ | Management structure |
| | | $C_{32}$ | Costs | $C_{321}$ | Initial and fixed costs | $C_{3211}$ | Capital investment |
| | | | | | | $C_{3212}$ | Overhead costs |
| | | | | | | $C_{3213}$ | Other costs |
| | | | | $C_{322}$ | Running and variable costs | $C_{3221}$ | Production costs |

Table 3.7. Overall Proposed Model (Cont’d)

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | $C_{3222}$ | Logistics costs |
| | | | | | $C_{3223}$ | Disposal cost |
| | | | $C_{323}$ | Depletion and rehabilitation costs | $C_{3231}$ | Sustainability management costs |
| | | | | | $C_{3232}$ | Rehabilitation costs |
| | | | | | $C_{3233}$ | Costs of depleted natural resources |
| | $C_{33}$ | Financial performance | $C_{331}$ | Shareholder interests | $C_{3311}$ | Solvency |
| | | | | | $C_{3312}$ | Economic performance |
| | | | $C_{332}$ | Value creation | $C_{3321}$ | Stability of income |
| | | | | | $C_{3322}$ | Risk management and adaptive capacity |
| | | | $C_{333}$ | Impact of sustainable practices | $C_{3331}$ | Investor appeal |
| | | | | | $C_{3332}$ | Sustainable products |
| | $C_{34}$ | Product performance | $C_{341}$ | Product quality and functionality | $C_{3411}$ | Product life |
| | | | | | $C_{3412}$ | Life cycle eco-efficiency |
| | | | $C_{342}$ | Convenience | $C_{3421}$ | Production and consumption habits |
| | | | | | $C_{3422}$ | Consumer preference |
| | | | | | $C_{3423}$ | Indirect product benefits |

## 3.4 Discussion

Renown conceptual SPE reporting frameworks, such as CDP, GRI and DJSI are based on simple sets of indicators, which may lead to easy but poor representation of actual sustainability performance. As an extension to such frameworks, a structured, 4-level criteria-tree is developed that is suitable for both conceptual and analytical SPE by practitioners and researchers alike. The distribution of the proposed criteria is shown in ***Figure 3.2***.

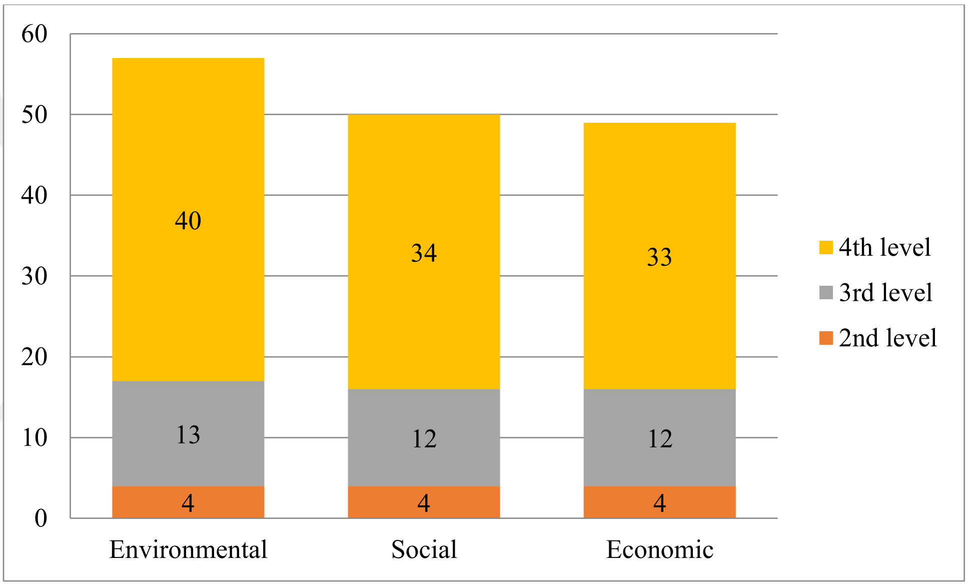


Figure 3.2. Balanced Distribution of the Proposed Criteria

SPE models vary significantly, due to the complex nature of sustainability that is open to subjective opinions, as well fragmented terminology across publications that can lead to confusion. Some models are not structured according to thematic hierarchy, but instead on the basis of perceived criteria importance and their priority, embedding prior judgments even before the actual SPE. Thus, in many papers SPE models omit those criteria that are deemed of low importance for that specific use. The literature review also revealed a clear lack of balanced 4-level SPE criteria trees. The proposed model addresses these three issues by introducing an impartial and reasonable structure across the three main elements of sustainability that is suitable for analytical techniques (e.g. MCDM) so that subjectivity of evaluations can be dealt with available numerical methods.

There are very few attempts in literature that explore a 4-level sustainability model. None of the conceptual SPE models presented in literature so far has a sufficiently wide coverage and thematic depth in a balanced way, adjusted for numerical input and optimized for analytical techniques. Many existing models simply consist of arrays of metrics. In this section, this gap is addressed. The presented 1st and 2nd level criteria address general, common dimensions that are usable in a comprehensive collection of industries and activities, whereas the 3rd and 4th level criteria are intended for selection or adaptation for specific purposes and fields. The lower two levels represent more detailed and purpose-oriented aspects and are therefore adaptable by its users. Users can also define and assign additional (5th level) metrics and indicators to the 4th level sub-criteria, if need be.

Sustainability performance evaluation is frequently limited to 'green' themed articles, e.g. adverse environmental impacts in the industry. To address this scope limitation, this section explored how environmental management can be better combined with social and economic aspects. For actual use by business managers, the model shall be extended with numerical methods and to a specific industry by first prioritizing (weighing) the criteria and then by scoring each criterion for each alternative. This weighing and scoring can be effectively accomplished with analytical techniques, such as MDCM methods.

This chapter dealt with two research questions. The first question was "*What needs to be measured to capture the sustainability performance?*". It is understood that certain economic, environmental and social impacts of any company, project, product etc. cannot be completely isolated from the other impacts. Inevitably, there will be interacting aspects, overlapping connotations, causal relations and changes over time, even if these sustainability criteria are clearly distinguished and well defined. Assigning clear, easily understandable and standardized evaluation parameters can address these challenges. These criteria need to cover the wide extent of impacts, as much as possible. The second research question was "*How shall the criteria be determined?*". It is discussed that every problem cannot be evaluated with the same criteria. Relationships and influence of criteria will also change. Standardization of criteria and their adaptation to specific circumstances are conflicting objectives.

Another issue is who will decide on the criteria and their importance in the overall SPE. To alleviate these difficulties, hierarchical, level-by-level type criteria tree structures are presented in literature. These are well-known and intuitive and can be expanded in each lower level to achieve high coverage of sustainability impacts. Some criteria levels can be fixed for standardization, while lower levels can be adjustable by adding and removing criteria item-by-item. Criteria structures and their adaptation shall be carried out with support from a group of experts, instead of limited literature reviews or one single expert. In this chapter, a hierarchical criteria tree structure is proposed with upper (fixed) and lower (adaptable) levels.

In the next chapter 4, this model will be combined with MCDM methods to set the model into operation. The priorities (i.e. criteria weights) can vary for different stakeholders. Governments will have a public interest point of view, financiers will have an economic performance perspective, academia and NGOs may have higher environmental and social motivations, while investors will want to balance their financial returns with operational, legal and reputational risks related to environmental and social performance. These stakeholders may have similar decision criteria on their agenda, but with different weights in their prioritization. In extreme cases, some criteria can also be completely irrelevant. Such differences in sustainability perspectives do not only exist for different stakeholders. They can also be captured for different companies, industries, supply chains etc. Therefore, the proposed SPE model is usable for most industries and stakeholders only by appointing other criteria weights and then applying it to evaluate different alternatives in pre-defined decision-making problems. This also implies that SPE for businesses shall principally proceed on an analytical basis. Descriptive reporting of sustainability criteria is useful for investor and public relations purposes, but are mostly inadequate in objectively and periodically reflecting the status and evolution of the overall sustainability performance. Numerical methods shall be applied to score all criteria of a conceptual model. This integration will follow next in chapter 4, where a novel SPE framework will be built on this model.

# 4 PROPOSED SUSTAINABILITY PERFORMANCE EVALUATION FRAMEWORK

The goal of this study is to formulate a generic solution that can be brought into operation on selected decision-making problems. Following an exhaustive analysis of literature, this model is first elaborated in the previous section 3.3 and then validated by expert opinions. In this chapter, the framework as a whole will be proposed. Performance measurement for any company, project, product, supply chain etc. shall be based on numerical values, as long as the aim is to consistently follow up the progress of performance over time and to make sound comparisons with competitors. Principally, performance evaluation consists of three consecutive stages;

i. Model development (chapter 3),
ii. Criteria weighing for a selected decision-making problem,
iii. Evaluations of performance for available alternatives (companies, projects, products, supply chains etc.).

This chapter explores '*how'* the stages (ii) and (iii) can be carried out methodologically. The next chapters 5 and 6 will exemplify how the actual weighing and evaluations can be carried for a selected industry numerically by following these three steps one after other. MCDM methods are particularly capable in handling such numerical analyses. They generate successful results when a number of conflicting criteria are structured in hierarchical levels for ultimately selecting one or more alternative among a set of others. Therefore, MCDM methods will be integrated to the previously proposed SPE model. These methods will be introduced next.

## 4.1 Multi-Criteria Decision Making and Sustainability

Many articles propose analytical models to support procedures involving conflict management. A feasible solution for conflict management can be achieved with MCDM. It is a recognized and familiar division of decision-making literature within the field of operations research for studying selection problems in the face of several parameters. These approaches can be the individual or combined application of priority-based, outranking or distance-based techniques that work well with conflicting criteria, unique units and challenges in choosing the alternatives. These tools can also be categorized as deterministic, stochastic and fuzzy methods. Every one of these techniques many have their own strengths and weaknesses.

In businesses, the ultimate decision does not solely rely on technical aspects. MCDM is a dynamic process consisting of managerial and engineering levels, where the managerial level highlights decisions' multi-criteria nature, identifies the objectives and determines the optimum choice (Duckstein and Opricovic, 1980). The engineering level defines the available choices and analyzes the possible outcomes of opting, or eliminating, one alternative over the others in the light of pre-defined criteria. DMs are at the heart of decision-making; they are entitled to refuse or give consent to the resolution suggested by the engineering level. In MCDM, experts determine the most feasible solution according to the evaluation parameters. In reality, many problems are defined with conflicting factors that are hardly commensurable. This means that there will be no one single solution that maximizes all criteria at once. MCDM can guide experts in identifying a sufficiently satisfactory solution in the presence of many alternatives and multiple objectives that are associated with uncertainty, conflicting goals, various information formats, numerous interests and different standpoints (Løken, 2007; Wang et al., 2009; Liao et al., 2015).

An advantage of MCDM is that it allows different methods be combined to achieve the intended objectives (Gal et al., 2013). MCDM techniques are very potent in dealing with complex decision problems that need to be processed with regard to conflicting criteria by breaking down complex problems into manageable bits that are then handled one by one. Nevertheless, these methods largely depend on experts' capability, expertise and knowledge, as well as consensus motivation, availability and willingness to express personal opinions. No matter which method is selected, the results (i.e. criteria weights and alternatives' scoring) will be very much dependent on DMs' inevitably subjective preferences. MCDM techniques propose analytical mechanisms to settle final solutions based on compromise for imperfect solutions that best fit DMs' expectations. These techniques have many different strengths and weaknesses, complexities and simplicities, which need to be combined in the most optimal way for the specific decision-making problem. Some of these techniques, as previously mentioned, are AHP, ANP, TOPSIS, VIKOR, PROMETHEE, ELECTRE, DEMATEL and MOORA, to name a few.

MCDM techniques grow to be gradually prevalent in decision-making literature, including SPE. One reason for that is the multidimensional character of the sustainability notion and the complicated interactions between economic activities, social expectations and biophysical systems (Wang et al., 2009). Sustainability involves many subjective areas which cannot be simply measured in numbers. Many criteria, in particular social aspects, are of a qualitative nature and can only be assessed subjectively by thematic experts who have a good understanding of the topic. GDM can help in decreasing the bias and skewed responses. Involving highly capable and experienced DMs is the key to successful results.

In literature, there are many studies that process sustainability problems with MCDM tools. For example, Pietersen (2006) used MCDM techniques to introduce sustainability perceptions into groundwater management by combining the value function method with the outranking method to explore alternative courses of action. Haralambopoulos et al. (2006) used MCDM for renewable energy planning and presented a comparative performance matrix. Tsai and Chou (2009) deployed DEMATEL in the first step and then combined ANP with zero-one goal programming (ZOGP) method for selecting the best sustainability management system. Büyüközkan and Çifçi developed a novel approach for sustainable supply chains based on fuzzy ANP under incomplete preference relations (2011a) and another QFD method in a fuzzy GDM environment for the same purpose (2013). In the same field of sustainable supply chains, Büyüközkan and Berkol (2011) presented another decision framework that integrated ANP with QFD and ZOGP models. Feyzioglu et al. (2008) focused on the sustainable urban transportation problem and used Choquet Integral method to overcome the difficulties related with inter-dependencies among decision criteria. Negotiation, quantification and communication of criteria and their weights are also easier in MCDM. Considering that sustainability is all about trade-offs and balancing different impacts, MCDM provides very suitable tools to take account of sustainability performance.

## 4.2 Utilized Techniques

The decision criteria are already defined in the previously proposed and expert-validated SPE model. This model will be extended to a framework by combining it with MCDM techniques. The result is a GDM-supported analytical framework, the applicability of which will be confirmed in two separate case studies in the next two chapters. The general structure of this study is illustrated in ***Figure 4.1***.

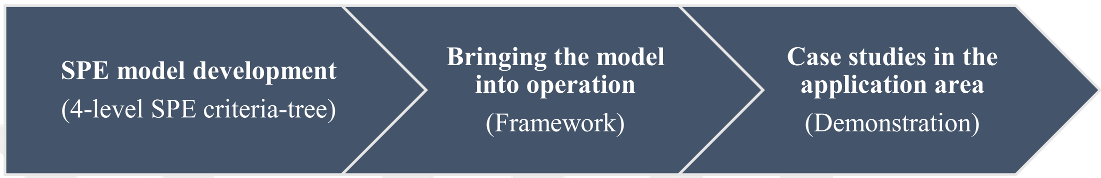


Figure 4.1. Overall Structure of the Study

This work combines two MCDM techniques as its proposed framework; AHP and VIKOR. These two methods are integrated into the previously introduced SPE criteria model, so that they as a whole represent a standalone SPE framework. In this setting, the priorities of the proposed SPE criteria are calculated with AHP. Then, the selected alternatives are assessed for their sustainability performance, and ranked accordingly. The highest rank corresponds to the best sustainability performance. This latter evaluation and ranking process is carried out with VIKOR. Considering the subjectivity of criteria given in chapter 3, all criteria weighing and alternative ranking judgments are collected from several DMs. All evaluations are collected with GDM. These techniques will be exhaustively described in sections 4.2.1 - 4.2.3.

In literature, many researchers have used this combination for different purposes. To name a few, Kaya and Kahraman (2010) combined VIKOR and AHP for determining the most suitable energy generation sites for Istanbul city, while Tzeng et al. (2005) employed the same techniques to identify the most applicable fuel for public transportation. These two methods were also combined by Büyüközkan and Görener (2015), who selected the best product development partners on this basis. AHP and VIKOR are also integrated for many other purposes in literature, including locating manufacturing plans, ranking industrial robots, comparing power plant technologies, evaluating universities etc.

The three stages of the proposed framework will be recalled next, after which AHP, VIKOR and GDM methods will be explained in detail.

i. **Model Development**: In this 1st stage of the proposed framework, the identification of criteria and their hierarchy is accomplished. These criteria are introduced and defined in chapter 3 as a scientific contribution. They are expert-validated criteria and present the basis of the proposed framework. This model is shown in ***Figure 6.2***, the definitions of all the proposed evaluation criteria are given in ***Table 3.3 - Table 3.5***.

ii. **Criteria weighing for a selected decision-making problem**: In this 2nd stage, the determination of criteria weights is accomplished with AHP. Once the criteria and their hierarchical structure are determined, AHP is employed to calculated the criteria weights, as shown in ***Figure 4.2***. As explained, more than one sustainability expert will be involved in this process to end up with less-subjective priority values. To achieve this, AHP will be combined with GDM. Criteria weights depend on expert evaluations and may differ depending on the industry, timing, geography and experts' background, inter alia. Weight values ($w_i$), i standing for the number of sub-criteria at that level under their main criteria, will be between 0 and 1, and their sum will be equal to 1. A higher weight implies an important contribution of that factor to the overall sustainability performance. This weighing will be repeated for each level, and the global weights of each criterion will be found by multiplying all the level-specific weights.

iii. **Evaluations of performance for available alternatives**: In the 3rd stage, the ranking of alternatives is performed with VIKOR. Once all criteria have their weight values, the individual alternatives will be scored for these criteria. Two types of evaluations are collected from the DMs: i) paired criteria comparisons to identify the weights of decision criteria, ii) score of each alternative for every criterion. Once these alternatives' scores are collected, they are processed with VIKOR to identify their ranking.

Integrating these techniques, the steps of the overall proposed SPE framework is displayed in ***Figure 4.2***. It shows that the framework starts with determining the evaluation parameters, then continues with calculation of criteria weights with the help AHP based on pairwise comparisons collected from multiple experts, and then comes to an end with the alternative evaluations found with VIKOR. It should be noted that AHP assumes that the evaluation criteria are independent from each other.

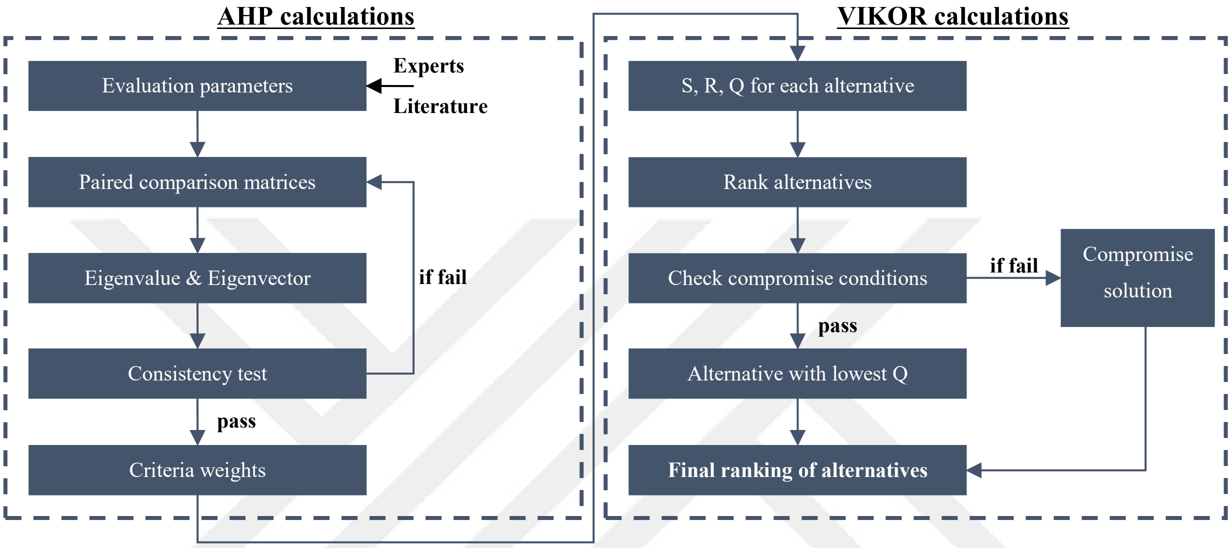


Figure 4.2. Workflow of the Integrated AHP-VIKOR Methodology

### 4.2.1 Analytic Hierarchy Process (AHP)

In decision-making literature, a popular approach for assigning the priorities of evaluation criteria is AHP. It is a simple mathematical method used by experts for comparing tangible and intangible criteria against each other for simulating their levels of importance. It is built upon the pair-wise comparison approach, where DMs receive a questionnaire that they fill in for comparing the relative significance of two criteria with respect to each other with different scales. The opinions are then fused and the results are normalized (i.e. adding up to 1). This method helps to show the difference in criteria's importance.

This process starts with simplifying the evaluation model down to a related decision elements. The proposed model's criteria structure is suitable in this perspective. In this hierarchy, evaluation parameters are paired, i.e. pair-wise comparison matrices are formed for each element in each level. These pairs are evaluated by each DM, where they weigh the criteria against each other, so that the entire scheme is mathematically tied together. Then, individual DMs' comparisons will be merged into one group comparison. AHP is a simple method that assumes uncorrelated and unidirectionally influenced decision criteria that are placed in a hierarchical relationship. This technique is advantageous if the DMs prefer to make comparative judgements among factors instead of a direct weight allocation. It is important to emphasize that AHP assumes evaluation parameters to be independent.

The prioritization in AHP is carried out with a comparison scale originally developed by Saaty (1980), as listed in ***Table 4.1***. It guides experts for rating the comparative significance of criteria pairs. Each of these pair-wise comparison matrices are evaluated by DMs according to this scale. Since individual DM judgments usually do not perfectly agree, the extent of consistency of the paired comparisons is checked to understand if the comparisons are contradicting with each other. The procedural steps of AHP are stated next.

Table 4.1. AHP Pair-wise Comparison Scale

| **Intensity** | **Explanation** |
|---|---|
| 1 | Two criteria contribute equally to the objective. |
| 3 | Experience and judgment slightly favored one criteria over another. |
| 5 | Experience and judgment strongly favor one criteria over another. |
| 7 | A criterion is favored very strongly over another; its dominance demonstrated in practice. |
| 9 | The evidence favoring one criteria over another is of the highest possible order of affirmation. |
| 2, 4, 6, 8 | Used to represent compromise between the priorities listed above |
| Reciprocals of the numbers above | Used for inverse comparison. |

Source: Saaty *(1980)*

**Step 1.** Decomposing the decision problem into hierarchical sub-problems: This step aims to develop the hierarchical criteria structure and break down the problem. AHP method will be applied to the decision-making problem level-by-level, in a hierarchy, which often includes the overall goal, main evaluation criteria, sub-criteria and alternatives.

**Step 2.** Determining the weight of each criterion at every level of the criteria-tree with paired comparisons: Here the pair-wise comparisons will be evaluated for an array of criteria. For this purpose, a paired comparison matrix is formed first. DMs' judgments are incorporated into this matrix as relative importance values according to the standardized comparison scale given in ***Table 4.1***. This process mainly consists of the following activities:

The set of evaluation criteria is defined as $C = \{C_j \mid j = 1, 2, ..., n\}$ and the matrix of paired comparisons for n-many criteria is formulated as:

$$D = \begin{bmatrix} C_1/C_1 & \cdots & C_1/C_n \\ \vdots & \ddots & \vdots \\ C_n/C_1 & \cdots & C_n/C_n \end{bmatrix} \tag{1}$$

The result of these paired comparisons are represented with the evaluation matrix A in the form of (n x n). Elements of A are denoted as $a_{ij}$ (i, j = 1, 2, ..., n), standing for the relative importance value, expressed as:

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix} \tag{2}$$

**Step 3.** Assessing the alternatives by integrating the criteria weights: This step involves the calculation of comparative criteria weights. In this procedure, the priorities of decision criteria are considered, where each matrix is normalized. Calculated comparative weights are represented by their corresponding eigenvector (w), which is basically the largest eigenvalue ($\lambda_{max}$):

$$A_w = \lambda_{max} * w \tag{3}$$

In the ideal case, where DMs evaluate each paired comparison matrix in a perfectly consistent way, the matrix A has rank 1 and the eigenvector is equal to n. Then, the weights are found by normalizing A's rows or columns. The level of success of the findings of AHP is closely related how consistent the paired comparisons are. The extent of the consistency of A's elements is found with CR, the consistency ratio. It is a function of CI, the Consistency Index:

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{4}$$

$$R = \frac{CI}{CR} \tag{5}$$

The parameter CR determines whether the evaluations by the DMs are sufficiently consistent with each other. The random index (RI) is related with the number of criteria and an index table is proposed by Saaty (1980), which can be seen in ***Table 4.2***. The upper limit for CR is 0.10, any final CR value that exceeds this threshold leads to the repetition of the comparison exercise by DMs.

Table 4.2. Random Index

| **n** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
|---|---|---|---|---|---|---|---|---|
| **RI** | 0.00 | 0.00 | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 |

### 4.2.2 VIKOR

The developed MCDM method first generates decision alternatives, then establishes evaluation criteria, followed by the calculating of criteria weights, and the subsequent application of VIKOR, a compromise ranking technique, to rank the alternatives. Here, compromise stands for an accord founded by joint concessions. Once the weights are allocated for all criteria, the alternatives shall be scored by DMs and then processed with VIKOR, a technique fully described by Opricovic (1998). The methodological steps will be discussed next.

VIKOR is an MCDM method used for optimization of multifaceted decision problems. It is a numerical decision-support tool for DMs to guide them in reaching a final decision and is particularly useful when the DMs are unable to express their judgments at the beginning of the decision process. It generates a list for the ranking of alternatives, which is a compromise solution, accompanied by additional information on the preference stability. VIKOR ranks and selects alternatives when there are many contradictory criteria.

VIKOR establishes a multi-criteria ranking value on the grounds of the closeness of an alternative to the ideal result under given conditions. DMs evaluate the alternatives according to each criterion function. Consequently, the distance of an available choice to the theoretical best solution is used to rank them. This technique comes up with a ranking as a solution, which integrates the compromises by providing the highest group utility for the 'majority' while maintaining the lowest individual regret of the 'opponent'. VIKOR may be used under the following conditions (Opricovic and Tzeng, 2007):

- The decision problem (i.e. conflict) can be resolved by compromising.
- DMs agree to accept the ideal result.

- Each criterion function is linearly related to DMs' utility.
- Evaluation parameters have contradictory elements and separate units.
- Alternatives are assessed for all of the evaluation criteria.
- DM's preferences are expressed by weights.
- DMs are responsible for approving the final solution.
- DMs' preferences must be included.

The technical procedure of VIKOR is explained next. (Tzeng et al., 2005)A decision problem is defined with $m$ alternatives as $a_1, a_2, \ldots, a_m$ *and* $n$ evaluation criteria as $c_1, c_2, \ldots, c_n$. For each alternative, $f_{ij}$ is the value of $i^{th}$ criteria for the alternative $a_j$.

**Step 1.** Calculation of the best ($f_i^*$) and the worst ($f_i^-$) figures of all evaluation criteria: A decision criterion either has a positive or a negative effect on the outcome. For a beneficial criterion i, the best and worst values are calculated as the following;

$$f_i^* = max_j f_{ij} \; ; \; f_i^- = min_j f_{ij} \tag{6}$$

**Step 2.** Calculation of $S_j$ and $R_j$ for $j = 1, \ldots, m$: Here $S_j$ denotes the mean group score, while $R_j$ is the worst group score for alternative $a_j$ and $w_i$ stands for the weights of evaluation criteria, i.e. their relative importance.

$$S_j = \sum_{i=1}^{n} w_i(f_i^* - f_{ij}) / (f_i^* - f_i^-) \tag{7}$$

$$R_j = max_i[\frac{w_i(f_i^* - f_{ij})}{(f_i^* - (f_i^-)}] \tag{8}$$

**Step 3.** Computation of $Q_j$ values for $j = 1, \ldots, m$: The Q value is another parameter used for ranking the alternatives, which is found with the following formula;

$$Q_j = v\,(S_j - S^*) / (S^- - S^*) + (1 - v)(R_j - R^*) / (R^- - R^*) \tag{9}$$

$$S^* = min_j\, S_j;\; S^- = max_j\, S_j;\; R^* = min_j\, R_j;\; R^- = max_j\, R_j$$

Here, an additional parameter $v$ is introduced to identify how the compromise will be reached. This compromise can be reached either with majority ($v > 0.5$), with consensus ($v = 0.5$) or with veto ($v < 0.5$). It is an arbitrary value that is generally taken as 0.5 (Opricovic and Tzeng, 2004; Tzeng et al., 2005).

**Step 4.** Ranking of the decision alternatives: This step is about arranging the *S, R* and *Q* values in increasing order, resulting in three ranking records.

**Step 5.** Determination of the best solution: The alternative that has the lowest *Q* value is nominated as the most suitable choice (a'). For this result to be a viable solution, the following conditions shall be met;

**Condition 1.** 'Acceptable advantage': $Q(a'') - Q(a') \geq DQ$, where $a''$ is the 2nd ranked alternative by its *Q* value. $DQ = 1 / (m - 1)$ and *m* is the number of alternatives. ($DQ = 0.25$ if $m \leq 4$).

**Condition 2.** 'Acceptable stability in decision-making': Alternative $a'$ must remain stable in the decision-making process, it must also correspond to the 1st ranked *S* or *R* values.

If both Condition 1 and Condition 2 are met, then the alternative $a'$ is identified as a compromise solution (i.e. the 1st rank by the *Q* value). However, in case at least one of these two conditions is not met, then a compromise solutions set will be found instead of one single solution. This compromise set includes;

i. Alternatives a' and a'' (if only Condition 2 is not satisfied), or;
ii. Alternatives a', a'', . . ., $a^k$ (if the Condition 1 is not satisfied). Here, $a^k$ is determined by the relation $Q(a^k) - Q(a') < DQ$ for the maximum k (the positions of these alternatives are in closeness).

### 4.2.3 Group Decision Making (GDM)

In real problems, usually not one single individual decides on various aspects. Different groups of DMs bring along different points of view (Pohekar and Ramachandran, 2004). GDM methods can be interesting in simulating decision practices in real-life problems. A GDM process is characterized by its involvement of two or more industry specialists who differ in their preferences but have the same access to information. In such a setting, each DM is characterized by her/his own perceptions, attitudes, motivations, and personalities. In order to call this collaborative process a GDM, DMs need to recognize the existence of a common problem and have common interest in reaching a collective decision (Herrera et al., 1995). In such a setup, DMs are expected to score many quantifiable and non-quantifiable criteria. The objectives usually involve conflicting elements. This makes the determination of a ‘best compromise’ solution a highly subjective and dependent practice, which strongly relates to personal preferences of DMs.

An expert might not possess sufficient knowledge of part of the problem and, as a consequence, he/she might not always provide all the needed information. Relying on a single DM can pose risks in decision-making because of individual limitations on experiences, preferences or biases. When more than one DM can be consulted, there can be DMs who provide information even if other DMs are not able to evaluate the importance of a particular criterion (Büyüközkan and Çifçi, 2012). Experts frequently approach a problem in different ways and may provide imprecise and unquantifiable information they have acquired from different sources (Düğenci, 2016). GDM is therefore often preferred to a single DM to evade the prejudice and subjectivity linked to individual experience and imprecision.

In many MCDM problems, DMs are faced with the question about how to reach consensus. Assuming that each group member in a decision committee provides a complete set of judgments, a method is needed to combine individual judgments into one single score. There are principally two possible approaches to find group preferences; a group selection process and a consensus process (Carlsson et al., 1992). In a group selection process the group judgment will be determined with algebraic consensus calculations of some sort of a mean value that is representative of individual DM preferences. In a consensus process, in contrast, one solution to this challenge is to approach the committee with a Delphi-based method to resolve their differences by seeking a common decision through discussion (Liberatore and Nydick, 1997). Here, the measure of distance between individual opinions is the primary concern and DMs are invited to re-evaluate their judgments until a common group evaluation is formed. Moving closer to a common agreement then depends upon the DMs' inclination to settling and making concessions. GDM techniques can help reduce the preconceptions that might prevent DMs to take objective decision. While the main principles of GDM are presented here, there are many different consensus or algebraic methods that are actually used in the business world.

In the presented framework, algebraic calculations will be used. More specifically, the geometric average of DM opinions will be taken for developing a group choice, because geometric mean performs superior to arithmetic mean in GDM (Saaty, 1980; Aczél and Saaty, 1983).

## 4.3 Discussion

In this chapter, the proposed evaluation framework is fully presented. This framework is established on a 4-level hierarchical criteria-tree which is introduced in chapter 3. AHP is employed to weigh the criteria. Once all the priorities of the criteria are known, then VIKOR is applied to process DMs' judgments on the sustainability performance of each alternative. All evaluations are collected from a group of DMs, so that the whole process is run in a GDM environment. This combination of AHP and VIKOR under GDM with the proposed SPE hierarchy model together constitute the proposed SPE evaluation framework.

This extensive framework is built upon 3 basic dimensions, distributed over 12 $2^{nd}$ level criteria, 37 $3^{rd}$ level criteria and 107 $4^{th}$ level criteria. The methods of AHP, VIKOR and GDM are presented step by step to guide practitioners and researchers to effectively apply it to real life SPE problems. The model furthermore allows adaptations for specific needs; DMs can adjust the $3^{rd}$ and $4^{th}$ level criteria by adding new criteria or removing existing ones.

This chapter dealt with two research question. Firstly, the answer to "*How shall the criteria be assessed?*" is explored. It is understood that each criterion can have different importance values, depending on local priorities, time and industry, and need to be determined anew for the specific use. If more than one alternative is scored, they can be assessed against each other and accordingly ranked for their sustainability performance. GDM can improve the quality of experts' inputs. The second research question this chapter has dealt with is "How shall the criteria assessments aggregated to reach a result?". Identifying the prominence of the decision criteria, and how well the alternatives fare in these criteria requires massive data collection. This large amount of valuable information needs to be processed and merged. If one certain industry is selected, the model can be weighed for this application area. Eventually, a framework is proposed consisting of a GDM-supported integrated MCDM method for ranking the best alternative project or company in a specific industry.

In this chapter, an MCDM-supported framework is proposed as a solution to successfully measure the sustainability performance of businesses, projects, products, supply chains and other clearly defined subjects. This framework can be implemented in any of these fields. To better illustrate the framework's usability and to give meaningful results, its criteria will be prioritized for a selected industry. For this purpose, the 'energy' industry is chosen as an application area. In chapters 5 - 6, two real case studies for selecting energy projects will provide sufficient means to test the framework.

# 5 CASE 1: APPLICATION OF FRAMEWORK TO ENERGY PROJECT SELECTION

In chapter 4, the proposed SPE framework is presented with methodological steps in order to bring the SPE model into operation. The framework is applicable in various fields, such as companies, projects, products, supply chains etc. The weighing of criteria and the subsequent alternative evaluation, however, require a concrete field of application. At this point, the framework will be demonstrated in the application area of 'energy' industry. In this setting, the proposed framework is adapted to the goal of selecting the most sustainable energy generation project. This does not imply that the use of the previously proposed model is limited to energy projects only. It can be widely used and adapted to various industries, provided that the criteria are weighed. A more detailed look into energy projects will be presented next in order to better understand the industry and its needs.

## 5.1 Energy Industry as Application Area

Energy industry is a very promising area for the proposed framework, especially when the need for clean, sustainable energy supply is considered. An increasing portion of approximately 1.8 trillion USD of annual investment in the energy industry is shifting towards clean energy production, while the opposite is true in the oil and gas markets. Subsidies for fossil fuel consumption is decreasing globally, while traditional power generation structures will always have their strengths. Nevertheless, the energy industry will undergo a significant renewables transformation. Design and security in the markets will also support this shift. Despite hundreds of millions of people without access to electricity, forecasts for 2040 predict a 30% increase in global energy demand, a rapid expansion largely to be led by renewables, and natural gas to some extent. International Energy Agency (2015) predicts that approx. 60% of new power generation capacity will use renewable energy sources by 2040, which will be mostly due to decreasing costs of renewables. Solar thermal (hot water) is already competitive in China, South Africa, Israel and Turkey. For solar PV (electricity generation), the cost of installing new capacity is expected to decrease by 40-70% by 2040. The balance between power generation capacity and energy production will change in the coming decades, mostly due to lower capacity utilization ratio of renewables. This will necessitate higher investment costs, which will be compensated by renewables' lower operation and maintenance costs.

Turkey's expanding economy makes it one of the most rapidly developing energy markets worldwide. The growth in the natural gas and electricity demand ranks $2^{nd}$ globally, following China. Total primary energy consumption of Turkey is projected to reach 218 Mtoe by 2023, a significant jump from today's 125 Mtoe, of which only 2.5% is currently being met with renewables. Also for electricity, domestic demand has reached 264 TWh in 2015, a large increase from previous years. Official forecasts expect this figure to reach 416 TWh by 2023 (MFA, 2016). As a net energy importer, this trend leads to a continued trade deficit, relatively high carbon intensity and supply insecurity, among others. Today, approximately a quarter of total energy demand is covered by domestic resources. Therefore, Turkey aims to diversify its energy mix by increasing the share of renewables and its base of suppliers. Following the privatization program in the last two decades, power generation and distribution are being managed mostly by privately held players, increasing Turkey's energy industry's competitiveness and its potential of further growth of current 74 GW of installed electricity capacity to 120 GW by 2023. The share of independent private producers has risen from 32% in 2002 to 75% in 2015 (Invest in Turkey, 2016). A considerable part of this expansion is observed in the renewables capacity. To support these efforts, Turkey offers investors various incentives for hydro, wind, solar, geothermal and other forms of renewable energy generation facilities. These support mechanisms include guaranteed feed-in-tariffs in foreign exchange, connection priorities, license exemptions and simplified procedures, depending on the technology and utilization rate of domestically manufactured equipment. Turkey prioritizes renewable energy sources with an objective to increase its share to an ambitious 30% by 2023, a strategy that is also closely integrated with municipal waste management, environmental protection and greenhouse gas reductions (Renewable Energy & Environmental Technologies, 2013).

Fossil fuel holdings are devaluing and feasibility of renewables is growing throughout the world, giving investors strong signals about the direction energy markets are headed to (Watson, 2016). Nevertheless, identifying renewables as ‘good’ and others as ‘bad’ would clearly be an oversimplification of the problem. Energy has an economic, environmental and social footprint; investors and policy makers need to ensure that they select the best mix of this footprint by balancing environmental pollution, resource use, contribution to local economy, employment, technology transfer, stakeholder reaction and ecologic damage, beside many other aspects (Investing in Renewable Energy: The GEF Experience, 2009). Energy companies and financing institutions are inevitably concerned with which energy project to select from different alternative projects. Investors are increasingly interested in the continued viability of their investments, while environmental degradation and climate change is changing the scene. Stakeholders urge nations to gear up renewable energy investments by establishing a carbon pricing plan, phasing out fossil fuels, supporting renewable energy, and enacting energy efficiency initiatives (UNFCCC, 2016).

Different stakeholders can have different points of view for energy investments. Policy makers, for example, are interested in energy technologies, national priorities and impacts of energy projects as a whole, instead of single, individual projects. Investors and financiers, on the other hand, are less interested in national long-term strategies and are more interested in financial profitability of a specific energy project. NGOs are mostly focused in energy projects’ impacts on the environmental and nearby communities. Thus, sustainability performance of individual energy projects differs for different actors. Investors construct and operate clearly-defined energy projects that perform well in terms of economic feasibility and financial viability. They are less interested in the ‘best technology’ for the country, or the region. In most cases, investors pay attention whether the project under consideration can obtain all licenses and if there are any significant environmental or social risks that could result in construction delays, local reactions or remediation costs. In this study, the SPE problem is approached with an investor perspective, because in most instances investors are the ones who decide on which energy project to realize under given conditions. The focus will be on specific energy projects, rather than energy technologies.

A brief literature analysis on MCDM-supported energy project selection with sustainability perspectives will follow next. Then, in section 5.3.1 the framework's functioning will be demonstrated. Finally, the last section contains the discussion of findings.

## 5.2 Energy Project Selection Literature

Energy is fundamental to economic growth, wealth creation, environmental integrity and social equity. Lack of energy can impede development, lead to lower quality of life and slow down social and industrial progress. Nowadays, 1.06 billion people continue their lives without electricity. The rate of electrification worldwide is low; at current rate, 92% of global population will have access to electricity by 2030. Furthermore, another 3 billion of people use biomass for cooking and heating purposes, which causes poor air pollution and therefore millions of premature deaths each year (World Bank, 2017). Increasing electricity generation and spreading its coverage is therefore vital. Considering ecologic damage, stakeholder sensitivities and financial hurdles, the best energy projects need to be identified and deployed. These risks can be reduced by carefully assessing and selecting energy project alternatives by thoroughly considering various financial, ecologic and societal aspects together. Such aspects can be effectively analyzed with analytical methods, such as MCDM tools, which are extensively applied to compare and rank different energy technologies with a sustainability perspective in literature (Wang et al., 2009; Kaya and Kahraman, 2010; Hsueh and Yan, 2013). Only few of these publications discuss energy projects, while most of them study renewables, national energy policies, optimization of energy mix or comparison of energy technologies. These will be shortly mentioned next.

An example for MCDM use in the field of energy is published by Onar et al. (2015), who identified the best wind energy technology with the help of fuzzy MCDM techniques from an investor point of view. A literature view on MCDM methods for sustainable energy systems is published by Wang et al. (2009), who analyzed the procedures for identifying, weighing, evaluating and aggregating the decision criteria. Kowalski et al. (2009) also used an MCDM approach to identify power generation from natural gas as the most sustainable technology. Kahraman et al. (2009) joined AHP with Axiomatic Design and fuzzy sets to reveal the most suitable renewable energy alternative. In another article, Chaaban et al. (2004) analyzed the economic effects of emission reductions caused by electricity generation facilities, while Garg et al. (2007) compared a number of fossil-fuel powered plants with the TOPSIS method. Chatzimouratidis and Pilavachi worked in this field extensively. In one of their studies (2007), 10 power generation technologies are analyzed for 5 environmental parameters. The same authors (2008) used AHP to assess 10 plants with regard to their environmental performance. In another article (2009), they again deployed AHP to study energy technologies with technological, economic and sustainability criteria to conclude that that renewable energy sources are more sustainable than fossil-fuel powered facilities. Similarly, Pilavachi et al. (2009) studied 9 energy technologies run with natural gas or hydrogen with the help of 7 evaluation parameters. They applied AHP and found out that combined cycle plants fueled with natural gas are superior to others. The same MCDM method, AHP, is also employed by Lee et al. (2009), who introduced another evaluation model for identifying the best wind power plant. Seeking optimal energy systems are also popular in literature. In one paper, Iniyan and Sumathy (2000) came up with an optimization method for energy technologies to minimize the cost/efficiency ratio, while Suganthi and Williams (2000) introduced a new model to allocate renewable energy technologies in the economically most optimal way. The concept of project scales is brought forward by Burton and Hubacek (2007), who compared the sustainability performance of small-scale and large-scale energy projects. Streimikiene et al. (2012) integrated two MCDM techniques, MULTIMOORA and TOPSIS, to rank electricity production technologies according to their sustainability performances. ELECTRE, another MCDM methodology was applied by Beccali et al. (2003) to find out how to best spread renewable energy technologies at regional scale. Haralambopoulos and Polatidis (2003) applied PROMETHEE II in their study of renewable energy technologies.

Apart from these technology-focused papers, many researchers have discussed the same topic from a regional or country perspective. An example of this is the study by Zhang et al. (2015), who combined fuzzy measure to assess renewable energy alternatives. They found out that the solar PV technology is the best option for Jiangsu province, China. In another study, Nixon et al. (2014) proposed a goal programming framework to determine how to best set up biogas power plants in Punjab, India. The same country was also discussed in another paper by Nixon et al. (2013), who compared alternative waste-to-energy technologies with MCDM. Renewable energy alternatives for Greece were explored by Polatidis and Haralambopoulos (2004), who introduced a GDM-MCDM method. A comparable structure is presented by Tsoutsos et al. (2009) for the island of Crete, Greece. They proposed an expert-supported MCDM method to assess different energy options with economic, technical, social and environmental parameters. Cavallaro and Ciraolo (2005) compared different wind power plant sites for Italy with the help of MCDM methods, while Krukanont and Tezuka (2007) made use of a stochastic approach consisting of two stages to optimize the energy portfolio of Japan. A similar objective was pursued by Cristóbal (2011) for Spain, who integrated AHP with VIKOR to find out that a biomass plant would be the best option among other renewable energy alternatives.

In addition to global and regional studies, many researchers dealt with the same research question for Turkey. For example, energy policies are reviewed by Topcu and Ulengin (2004) with the help of MCDM methods to come up with the most appropriate policies for Turkey. In another paper, Kahraman et al. (2009) deployed the fuzzy AHP technique for determining the best renewable energy alternative for Turkey and identified wind power systems as the most promising results. Kaya and Kahraman (2011) developed a novel fuzzy TOPSIS approach for improved planning of energy sources. Önüt et al. (2008) used ANP, an MCDM method that considers the relations among criteria, to study energy supply options in the manufacturing industries of Turkey. ANP was also utilized by Köne and Büke (2007) to optimize the domestic fuel mix for power generation for the national electricity grid. Again, ANP was applied by Atmaca and Başar (2012) to compare 6 power plants with regard to the factors of life quality, technology and sustainability, economical suitability, and socio-economic aspects to eventually rank nuclear power as the best technology for Turkey. The same technique was employed by Kabak and Dağdeviren (2014), who took account of the advantages, prospects, required investments and associated risks of different energy generation technologies in order to rank them. Recently, Büyüközkan and Güleryüz (2016) combined DEMATEL with ANP for determining the best renewable energy source for Turkey with an investor point of view, while Büyüközkan and Karabulut (2017) combined AHP with VIKOR to assess and rank the sustainability performance of similarly sized energy projects. In this article, the authors examined the literature to propose an extensive SPE framework and then applied it to show its strengths.

There are a multitude of MCDM-based studies for assessing energy alternatives on local, regional and global scale. The following observations are deducted from this review:

- Evaluating energy projects or technologies are made on the basis of multiple criteria. Despite their key role, arbitrary identification of these evaluation criteria is most common in literature. Expert-supported criteria selection can improve this practice.
- Although many papers aim to capture the overall sustainability performance of energy alternatives, they often fail to balance the economic, environmental and social dimensions. Environmental aspects are usually more emphasized, leading to biased and distorted results.
- Researchers are mostly interested in energy technologies, while usually ignoring concretely defined individual energy projects. Considering vastly different project-dependent properties in terms of sustainability, studying generic energy technologies may lead to over-simplification of the problem. Consequently, findings can be valuable for policy makers, but misleading and overly-generalized for investors.
- The scale and size of energy projects is largely ignored in literature. Many researchers, for instance, have compared nuclear power to solar PV installations, for example, which actually have very different installed capacities. Many economic, environmental and social impacts are actually proportional to installations' size. Therefore, such comparisons may lead to incorrect findings. Similarly-sized projects shall be compared, or their impacts shall be scaled first.

These papers indicate that these analytical SPE models are frequently applied on cases in order to validate their methodological usefulness, instead of investigating specific real industrial problems. Next, the proposed framework will be applied to select energy projects, as given by Büyüközkan and Karabulut (2017)[1].

[1] This article (Büyüközkan and Karabulut, 2017) is based on the works developed during the preparation stage of this thesis. For this reason, the case study in the article is used in this study as it is.

## 5.3 Definition of the Problem, Criteria and Alternatives

The framework that will be applied is presented in chapter 4. It consists of a hierarchy model with 4 layers of structured criteria, and two integrated MCDM techniques, AHP and VIKOR, run with a GDM approach. The framework is tested for the energy project selection problem as a real case study, where 4 real energy projects located in Turkey will be evaluated and ranked for their sustainability performance. The purpose of this exercise is to demonstrate how the proposed SPE framework works in the energy project selection problem.

As suggested earlier, the proposed framework can be applied as a whole, or can be truncated to higher levels for simplicity and speed. To exemplify this adapted use, the first 3 levels of the hierarchy will be applied in this case study. The $4^{th}$ level criteria will *not* be assessed by DMs. This also speeds up the GDM application, considering the high number of criteria to be evaluated by the DMs for each of the 4 project alternatives.

The evaluation will be carried out for economic, environmental and social perspectives. Therefore, availability and quality of sustainability data is most vital for the selected project alternatives. Moreover, these energy projects shall be of similar size and scale for better comparability. After a careful study of well-documented energy projects from Turkey, a balanced project portfolio is established. Four possible energy projects ($A_1$, $A_2$, $A_3$, $A_4$) are determined as alternatives. This portfolio is given in ***Table 5.1***. This selection is made arbitrarily without any bias or prejudice, while ensuring sufficient project documentation is provided to the DMs. These projects include renewable energy and thermal power plants with similar installed capacities, in megawatts. Their names and shareholder structures are not disclosed. The selected project alternatives are already in operation. The framework is suitable for comparing energy projects before or after implementation.

Table 5.1. Energy Project Alternatives

| # | Technology | Installed capacity | Region |
|---|---|---|---|
| **$A_1$** | Wind power plant | 20 MW | Marmara |
| **$A_2$** | Hydropower plant | 19.9 MW | Marmara |
| **$A_3$** | Biogas power plant | 25 MW | Central Anatolia |
| **$A_4$** | Natural gas power plant | 19.4 MW | Aegean |

Three DMs are involved in this SPE evaluation. The first expert, $DM_1$, works on the development of sustainability indicators for energy projects since more than 12 years. The second expert, $DM_2$, has experience in the development of renewable energy projects in Turkey for the last 7 years. The third expert, $DM_3$, has 4 years of experience with reporting of environmental and social performance of energy projects. They are all knowledgeable about sustainability aspects of energy projects. These DMs will first score the importance of the selection criteria and then evaluate the energy projects for the first 3 levels of criteria proposed in chapter 3, i.e. for 3 dimensions, distributed over 12 2$^{nd}$ level criteria and 37 3$^{rd}$ level sub-criteria. Next, the stages of the proposed SPE framework will be applied step by step for illustration. The general structure of the presented evaluation framework is given in ***Figure 4.2***. These steps illustrate the computation procedures given in sections 4.2.1 - 4.2.3.

### 5.3.1 Development of Energy Project Evaluation Model

The proposed SPE model to be studied is shown in ***Figure 5.1***. Accordingly, the goal of this decision-making case study is placed at the top of this setting. The evaluation criteria are situated in lower levels in a strict hierarchy; i.e. multiple sub-criteria are assigned to one single upper-level criterion, layer by layer. The lowest level consists of the energy project alternatives. The investment decision will be taken based on their sustainability performance rankings.

At this first stage, evaluation criteria are identified. To demonstrate the proposed framework, no new criteria are added to the 3$^{rd}$ level and no criteria are omitted. The names of these 3$^{rd}$ level criteria are not explicitly shown in ***Figure 5.1*** due to space limitations. Their names and definitions are extensively presented in section 3.3.

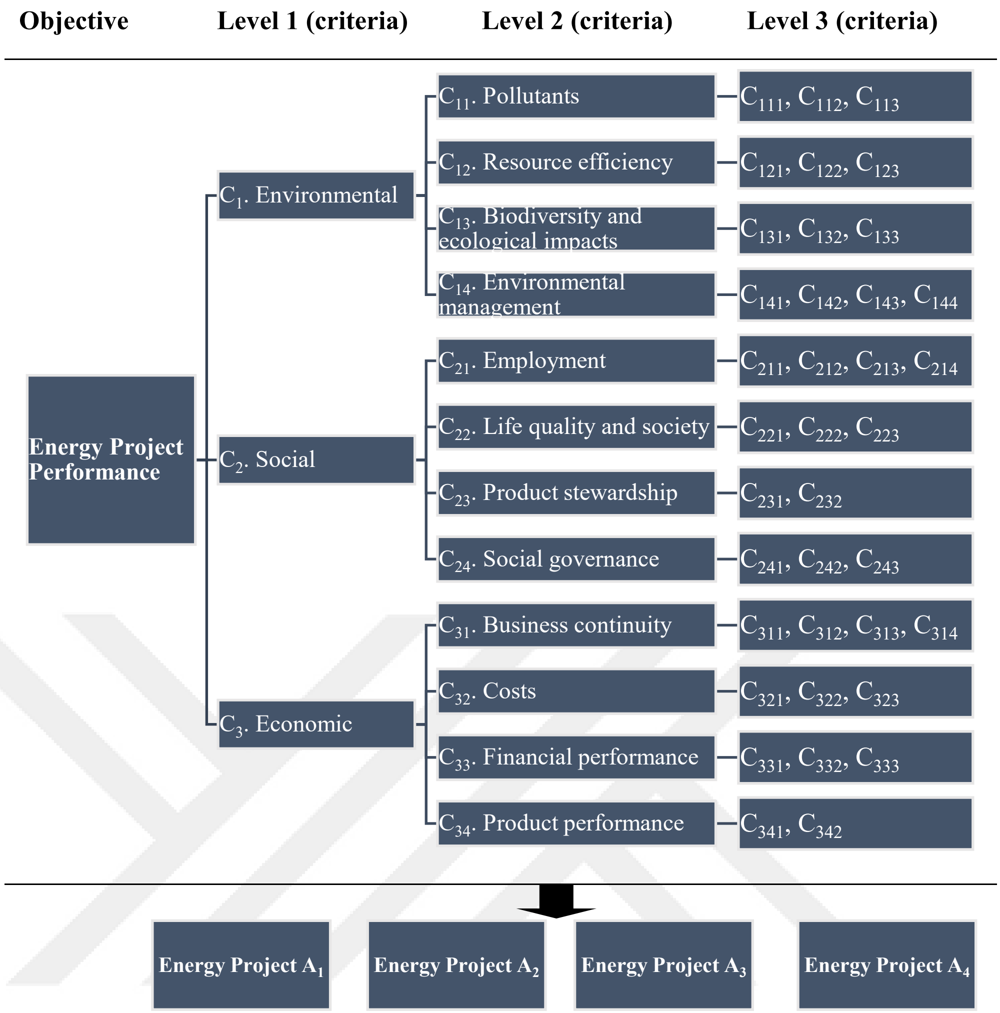


Figure 5.1. Proposed Evaluation Criteria Hierarchy

### 5.3.2 Weighing Evaluation Criteria with AHP

AHP technique is based on comparisons of paired criteria. These comparisons are given by a number of experienced DMs. Once comparison tables are filled in by the DMs, they are aggregated with a GDM approach, and then their consistency is checked. Following that, the weights of all criteria are computed.

Pair-wise comparison matrices for the 1$^{st}$ level are collected from the three DMs. These AHP comparison matrices provided by the DMs are given in ***Table 5.2 - Table 5.4***. Collected data are then merged with geometrical average (Aczél and Saaty, 1983) into a single group pair-wise matrix. They are then processed with AHP. The aggregated 1$^{st}$ level criteria weights are given in ***Table 5.5***. Since the calculation procedures are explained in sections 4.2.1 - 4.2.3, they will not be repeated here.

Instead, the application results for the case study will be provided. Next, the 1st level criteria pairs are taken to their 64th power to find their priority vectors. After that, the consistency of the expert evaluations is checked by confirming that CR≤0.10. Some inconsistency is natural. If, however, this inconsistency exceeds this threshold, DMs shall be re-consulted. For the collected DM evaluations, all CRs values happen to be less than 0.10, implying that DMs provided sufficiently consistent evaluations. The CR for the weights given in ***Table 5.5*** is approximately 0.01. The same procedure is then repeated for the 2nd and 3rd level criteria. It is seen that all their CR values are less than 0.10 and there is no need for a renewed criteria evaluation cycle.

Table 5.2. Level 1 - Pair-wise Comparison Matrix of $DM_1$

| Criteria | $C_1$ Environmental | $C_2$ Social | $C_3$ Economic |
|---|---|---|---|
| $C_1$ Environmental | 1 | 2 | 1/2 |
| $C_2$ Social | 1/2 | 1 | 1/3 |
| $C_3$ Economic | 2 | 3 | 1 |

Table 5.3. Level 1 - Pair-wise Comparison Matrix of $DM_2$

| Criteria | $C_1$ Environmental | $C_2$ Social | $C_3$ Economic |
|---|---|---|---|
| $C_1$ Environmental | 1 | 2 | 1 |
| $C_2$ Social | 1/2 | 1 | 1/2 |
| $C_3$ Economic | 1 | 2 | 1 |

Table 5.4. Level 1 - Pair-wise Comparison Matrix of $DM_3$

| Criteria | $C_1$ Environmental | $C_2$ Social | $C_3$ Economic |
|---|---|---|---|
| $C_1$ Environmental | 1 | 1 | 1/2 |
| $C_2$ Social | 1 | 1 | 1 |
| $C_3$ Economic | 2 | 1 | 1 |

Table 5.5. Aggregated Level 1 Criteria Weights

| Criteria | Overall weight |
|---|---|
| $C_1$ Environmental | 0.320 |
| $C_2$ Social | 0.225 |
| $C_3$ Economic | 0.455 |

Following these calculations, the details of which are omitted here for clarity and focus, the normalized specific and global criteria weights are computed. These priorities are listed in ***Table 5.6***.

Table 5.6. Specific and Overall Weights of Energy Project Evaluation Criteria

| Main Criteria | Sub-Criteria | Priority within the Cluster | Overall Priority |
|---|---|---|---|
| **Environmental** (0.320) | $C_{11}$ Pollutants | 0.311 | 0.099 |
| | $C_{111}$: Air emissions | 0.465 | 0.046 |
| | $C_{112}$: Effluents and Waste | 0.360 | 0.036 |
| | $C_{113}$: Other pollutants | 0.175 | 0.017 |
| | $C_{12}$ Resource efficiency | 0.220 | 0.070 |
| | $C_{121}$: Water consumption | 0.414 | 0.029 |
| | $C_{122}$: Energy use | 0.232 | 0.016 |
| | $C_{123}$: Raw material use | 0.355 | 0.025 |
| | $C_{13}$ Biodiversity and ecological impacts | 0.336 | 0.107 |
| | $C_{131}$: Ecosystem vulnerability | 0.436 | 0.047 |
| | $C_{132}$: Critical habitats | 0.346 | 0.037 |
| | $C_{133}$: Sustainable farming | 0.218 | 0.023 |
| | $C_{14}$ Environmental management | 0.133 | 0.042 |
| | $C_{141}$: Management systems and programs | 0.288 | 0.012 |
| | $C_{142}$: Regulatory compliance | 0.200 | 0.009 |
| | $C_{143}$: Environmental governance | 0.348 | 0.015 |
| | $C_{144}$: Supply chain management | 0.164 | 0.007 |
| **Social** (0.225) | $C_{21}$ Employment | 0.238 | 0.053 |
| | $C_{211}$: Job creation | 0.187 | 0.010 |
| | $C_{212}$: Job satisfaction and quality | 0.220 | 0.012 |
| | $C_{213}$: Occupational health and safety | 0.413 | 0.022 |
| | $C_{214}$: Training and education | 0.180 | 0.010 |
| | $C_{22}$ Life quality and society | 0.382 | 0.086 |
| | $C_{221}$: Social acceptance | 0.369 | 0.032 |
| | $C_{222}$: Public health and safety | 0.471 | 0.040 |
| | $C_{223}$: Cultural properties | 0.159 | 0.014 |
| | $C_{23}$ Product stewardship | 0.212 | 0.048 |
| | $C_{231}$: Product responsibility | 0.558 | 0.027 |
| | $C_{232}$: Social impacts of products | 0.442 | 0.021 |
| | $C_{24}$ Social governance | 0.169 | 0.038 |
| | $C_{241}$: Stakeholder relations | 0.367 | 0.014 |
| | $C_{242}$: Corporate social responsibility | 0.286 | 0.011 |
| | $C_{243}$: Principals and commitment | 0.347 | 0.013 |
| **Economic** (0.455) | $C_{31}$ Business continuity | 0.349 | 0.159 |
| | $C_{311}$: Technology and innovation | 0.314 | 0.050 |
| | $C_{312}$: Supply chain resilience | 0.431 | 0.068 |
| | $C_{313}$: Brand value | 0.064 | 0.010 |
| | $C_{314}$: Corporate governance | 0.192 | 0.030 |
| | $C_{32}$ Costs | 0.153 | 0.070 |
| | $C_{321}$: Initial and fixed costs | 0.514 | 0.036 |
| | $C_{322}$: Running and variable costs | 0.335 | 0.023 |
| | $C_{323}$: Depletion and rehabilitation costs | 0.151 | 0.011 |
| | $C_{33}$ Financial performance | 0.368 | 0.168 |
| | $C_{331}$: Shareholder interests | 0.413 | 0.069 |
| | $C_{332}$: Value creation | 0.260 | 0.044 |
| | $C_{333}$: Impact of sustainable practices | 0.327 | 0.055 |
| | $C_{34}$ Product performance | 0.129 | 0.059 |
| | $C_{341}$: Product quality and functionality | 0.558 | 0.033 |
| | $C_{342}$: Convenience | 0.442 | 0.026 |

In this 2$^{nd}$ stage, the criteria weights are successfully calculated. Although these criteria weights are collected in this case study for the energy project selection problem, they can also be used in similar decision-making problems.

### 5.3.3 Ranking of Project Alternatives with VIKOR

In this 3rd stage, the aim is to collect DMs' opinions about how well each energy project alternative performs at each of the evaluation criterion. The DMs' judgments are merged first with a GDM approach. Specific weights are assigned to each of the experts, since in typical decision-making problems different members of a decision committee usually have different overall influence on the final outcome. These influence levels can be attributed to members' experience, technical expertise, academic rank, business title, time spent on the subject etc. The set of DMs is defined as D = {$DM_1$, $DM_2$, . . . , $DM_k$}, where the influence level of $DM_k$ is defined as $\lambda_k$, with $\lambda_k \in [0,1]$ and $\sum_{k=1}^{K} \lambda_k = 1$. Considering experts' different experience levels, the following weights are assigned to the DMs: $\lambda_1$=0.50, $\lambda_2$=0.30, $\lambda_3$=0.20.

The individual project evaluations are first merged with the help of these DM weights. Then, the evaluation scores are used for calculating each project's sustainability performance, so that they can be ranked in ascending order to identify the most sustainable energy project. The evaluation results are listed in ***Table 5.7***. This table helps to find the best and the worst values, as displayed in ***Table 5.8***.

Table 5.7. Aggregated Criteria Evaluations for Energy Project Alternatives

| | $C_{111}$ | $C_{112}$ | $C_{113}$ | $C_{121}$ | $C_{122}$ | $C_{123}$ | $C_{131}$ | $C_{132}$ | $C_{133}$ | $C_{141}$ | $C_{142}$ | $C_{143}$ | $C_{144}$ | $C_{211}$ | $C_{212}$ | $C_{213}$ | $C_{214}$ | $C_{221}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $A_1$ | 3.98 | 3.15 | 1.61 | 2.92 | 1.50 | 2.40 | 3.94 | 3.12 | 1.83 | 1.22 | 0.85 | 1.27 | 0.64 | 0.60 | 0.94 | 1.81 | 0.93 | 2.72 |
| $A_2$ | 3.70 | 2.15 | 0.87 | 0.87 | 1.44 | 1.30 | 1.59 | 1.86 | 0.66 | 1.00 | 0.65 | 0.80 | 0.56 | 0.76 | 0.75 | 2.03 | 0.81 | 0.76 |
| $A_3$ | 4.35 | 3.58 | 1.64 | 2.27 | 1.08 | 2.20 | 4.12 | 3.27 | 1.83 | 1.15 | 0.85 | 1.21 | 0.60 | 0.92 | 0.75 | 1.32 | 0.93 | 2.53 |
| $A_4$ | 1.39 | 1.72 | 0.70 | 1.46 | 1.14 | 0.60 | 1.78 | 2.23 | 1.45 | 0.93 | 0.68 | 0.86 | 0.56 | 0.72 | 0.80 | 1.90 | 0.73 | 1.77 |

| $C_{222}$ | $C_{223}$ | $C_{231}$ | $C_{232}$ | $C_{241}$ | $C_{242}$ | $C_{243}$ | $C_{311}$ | $C_{312}$ | $C_{313}$ | $C_{314}$ | $C_{321}$ | $C_{322}$ | $C_{323}$ | $C_{331}$ | $C_{332}$ | $C_{333}$ | $C_{341}$ | $C_{342}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4.04 | 1.37 | 2.49 | 1.98 | 1.17 | 0.91 | 1.24 | 4.79 | 6.84 | 0.85 | 2.56 | 2.16 | 2.20 | 0.84 | 6.23 | 4.36 | 5.49 | 3.15 | 2.35 |
| 3.15 | 0.85 | 2.17 | 1.01 | 0.53 | 0.72 | 0.92 | 3.49 | 4.79 | 0.48 | 1.77 | 2.80 | 2.06 | 0.89 | 6.23 | 2.79 | 2.53 | 2.37 | 1.88 |
| 4.04 | 1.20 | 2.23 | 1.98 | 1.17 | 0.91 | 1.11 | 4.59 | 5.47 | 0.95 | 2.56 | 1.87 | 1.87 | 0.84 | 6.65 | 4.36 | 5.17 | 3.09 | 1.93 |
| 2.10 | 1.12 | 1.33 | 0.84 | 0.98 | 0.44 | 0.63 | 2.49 | 3.97 | 0.69 | 1.77 | 3.02 | 0.65 | 0.67 | 5.82 | 1.83 | 1.54 | 2.30 | 1.62 |

Table 5.8. Best ($f_i^*$) and Worst ($f_i^-$) Values of Evaluation Criteria

| | $C_{111}$ | $C_{112}$ | $C_{113}$ | $C_{121}$ | $C_{122}$ | $C_{123}$ | $C_{131}$ | $C_{132}$ | $C_{133}$ | $C_{141}$ | $C_{142}$ | $C_{143}$ | $C_{144}$ | $C_{211}$ | $C_{212}$ | $C_{213}$ | $C_{214}$ | $C_{221}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $f_i^*$ | 4.35 | 3.58 | 1.64 | 2.92 | 1.50 | 2.40 | 4.12 | 3.27 | 1.83 | 1.22 | 0.85 | 1.27 | 0.64 | 0.92 | 0.94 | 2.03 | 0.93 | 2.72 |
| $f_i^-$ | 1.39 | 1.72 | 0.70 | 0.87 | 1.08 | 0.60 | 1.59 | 1.86 | 0.66 | 0.93 | 0.65 | 0.80 | 0.56 | 0.60 | 0.75 | 1.32 | 0.73 | 0.76 |

| $C_{222}$ | $C_{223}$ | $C_{231}$ | $C_{232}$ | $C_{241}$ | $C_{242}$ | $C_{243}$ | $C_{311}$ | $C_{312}$ | $C_{313}$ | $C_{314}$ | $C_{321}$ | $C_{322}$ | $C_{323}$ | $C_{331}$ | $C_{332}$ | $C_{333}$ | $C_{341}$ | $C_{342}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4.04 | 1.37 | 2.49 | 1.98 | 1.17 | 0.91 | 1.24 | 4.79 | 6.84 | 0.95 | 2.56 | 3.02 | 2.20 | 0.89 | 6.65 | 4.36 | 5.49 | 3.15 | 2.35 |
| 2.10 | 0.85 | 1.33 | 0.84 | 0.53 | 0.44 | 0.63 | 2.49 | 3.97 | 0.48 | 1.77 | 1.87 | 0.65 | 0.67 | 5.82 | 1.83 | 1.54 | 2.30 | 1.62 |

Following these tables, the parameters $S_j$, $R_j$ and $Q_j$ for each of the energy project alternatives are calculated with Eqs. 7 - 9. For these calculations, *v* is taken as 0.5, as usual. The S, R and Q values are listed in ***Table 5.9***.

Table 5.9. S, R and Q Values

| | $S_j$ | $R_j$ | $Q_j$ |
|---|---|---|---|
| $A_1$ | 0.105 | 0.035 | 0.000 |
| $A_2$ | 0.659 | 0.049 | 0.573 |
| $A_3$ | 0.189 | 0.036 | 0.075 |
| $A_4$ | 0.859 | 0.069 | 1.000 |

Alternatives are ranked by sorting their S, R and Q values in increasing order. The most sustainable energy project is the one that has the lowest Q value, provided that both 'acceptable advantage' and 'acceptable stability in decision making' conditions are met. The Q values and the associated ranks are shown in ***Table 5.10***.

Table 5.10. Ranking of Alternatives

| | A1 | A2 | A3 | A4 |
|---|---|---|---|---|
| $Q_j$ | 0.000 | 0.573 | 0.075 | 1.000 |
| **Rank** | 1 | 3 | 2 | 4 |

These calculations indicate that the difference of Q values between the first-ranked alternative, $A_1$, and the second-ranked alternative, $A_3$, is less than DQ. This results in a set of compromise solutions, instead of a clear single winner. This means that the best-ranked energy project alternative is a solution set with the wind project ($A_1$) and the biogas ($A_3$) project. The ranking list is given in ***Table 5.11***;

Table 5.11. Final Ranking of Energy Project Alternatives

| Rank | Project | |
|---|---|---|
| **1** | $A_1$ | Wind project |
| **1** | $A_3$ | Biogas project |
| **3** | $A_2$ | Hydro project |
| **4** | $A_4$ | Natural gas project |

In this list, the hydropower plant option has the 3$^{rd}$ best sustainability performance, while the natural gas option is clearly the least sustainable option in this case. It should be noted that this ranking is specific to these selected energy projects and shall not be generalized to their technologies.

## 5.4 Discussion

Energy investors look for favorable conditions when deciding on which energy project to invest in. These conditions may include economic profitability, social acceptability and ecologic impacts. This case study verifies that the framework is a new, feasible way for investors to forecast, or to report on the sustainability performance of their energy project investments.

The results of the case study become more meaningful when compared to the results of another technique. The plausibility of the results is checked with a comparison obtained with AHP only. Its results are given in ***Table 5.12,*** illustrating that AHP-VIKOR and AHP provide the same rankings for this case study, verifying the usability of the proposed framework. ***Table 5.10*** shows that both AHP and AHP-VIKOR rankings distinctively prioritize wind ($A_1$) and biogas ($A_3$) projects over the hydropower ($A_2$) and natural gas ($A_4$) projects. On the other hand, the results are not to be perceived to be exactly the same. In AHP, there is one single individual 1$^{st}$ rank, $A_1$, while AHP-VIKOR proposes a solution set consisting of $A_1$ and $A_3$. This means that in this case study with the evaluated project portfolio, the wind and biogas power plants ($A_1$ and $A_3$) have similar sustainability performance, while the hydroelectric project ($A_2$) has a significantly poorer sustainability performance and the thermal power plant ($A_4$) project performs the worst.

Table 5.12. Comparison of Rankings Obtained with AHP and AHP-VIKOR

| | **$A_1$** | **$A_2$** | **$A_3$** | **$A_4$** |
|---|---|---|---|---|
| **AHP Score** | 90.4 | 64.0 | 86.6 | 55.2 |
| **AHP Rank** | 1 | 3 | 2 | 4 |
| **AHP-VIKOR Rank** | 1 | 3 | 1 | 4 |

Since the proposed framework gives a similar result, its added value shall be discussed. The ranking index obtained with VIKOR maximizes the group utility and minimizes the individual regret of the opponent (Jerry Ho et al., 2011) at the same time. This property of VIKOR enables DMs to process this decision-making problem from different points of view, rather than simply selecting the highest score. VIKOR integrates the concept of stability into the ranking index in the form of compromise solutions as a means of improving the decision quality (Rojas-Zerpa and Yusta, 2015).

Combining AHP with VIKOR provides these advantages for the energy project selection problem. AHP-VIKOR accurately recognizes the small sustainability performance difference between $A_1$ and $A_3$ and names both as compromise solutions, which is a superior interpretation of the findings.

This result shall also be compared to literature. Energy project selection problem is not a popular theme in literature. As one of similar articles, Büyüközkan and Güleryüz (2014) made energy technology comparisons with DEMATEL and ANP methods. Although their focus is on technologies, their geographic coverage of Turkey provides good insights. In their review, wind energy ranked first, followed by solar, biomass, geothermal and hydraulic, respectively. Kahraman et al. (2009) used fuzzy AHP and fuzzy AD methods to compare 5 energy technologies and found out that wind energy scores best, followed by solar, geothermal, biomass and hydropower. In another paper, Kahraman and Kaya (2010) ranked 9 different energy technologies for sustainability impacts with fuzzy AHP method. They ranked wind, biomass, hydropower and natural gas, respectively. Kaya and Kahraman (2010) used AHP-VIKOR in a fuzzy environment to compare renewable energy policies and their possible locations in Istanbul. Their ranking is wind, solar, biomass, geothermal, hydropower, in descending order. All these publications prioritize wind and biomass over others, which support the results of this case study.

Corporate decision-making processes are usually run with a group of experts. Moreover, many proposed criteria are of a qualitative character, that are difficult to measure and assign numeric values to. These subjective decision criteria can best be assessed by industry specialists. To improve this process, a GDM approach is implemented both for finding the criteria weights and evaluating the alternatives. To simulate real life decision-making approaches, DMs are assigned with different influence levels on the eventual decision. At this point, the impact of DMs' weights on the final rankings is also checked to understand how far these values affect the results. This sensitivity analysis, the details of which are omitted here, indicate that the 1st and 2nd ranks ($A_1$ and $A_3$) are quite unresponsive to DM weights in this case study, strengthening the model's findings.

This case study emphasizes the evaluation of similarly-sized energy projects, instead of generic technology-based comparisons. This approach can guide investors in how to detach from a technology-focused assessment and move towards a project-based evaluation practice. Thus, investors can better forecast, monitor and report on the sustainability performance of potential or implemented energy projects. Although the case study has compared few small-scale energy projects, this application can also be repeated with many larger-scale projects, as long as DMs have sufficient project-specific data.

This chapter demonstrated a real case in which the proposed combined framework is tested for an effective energy project selection model with a sustainability perspective. The previously proposed SPE model in section 3.3 is taken as it is for its first 3 levels. This preference indicates that the model can be used as a whole, or partially, depending on the need. In the next chapter 5, the SPE model will be used as one branch only to present another alternative use of the proposed framework.

# 6 CASE 2: APPLICATION OF THE ENVIRONMENTAL DIMENSION OF THE PROPOSED FRAMEWORK TO EVALUATE WASTE-TO-ENERGY PROJECTS

In this chapter, one branch of the SPE model, the ‘environmental’ dimension, will be implemented again in another real case study to demonstrate its usability and adapted partial application for comparing the so-called ‘Waste-to-Energy’ projects.

## 6.1 Energy from Waste as Application Area

Despite a growing need for energy services and many available power generation technologies, it remains a global challenge to provide the world with electricity due to associated ecologic degradation, high initial costs and social sensitivities and local priorities (Vera and Langlois, 2007). This lack of energy services leaves hundreds of millions of people worldwide not only in the dark, but also limited to basic fuels, leading to lower quality of daily life, poor indoor air quality and related hazards. Developing countries today are not only facing energy-related challenges, such as energy access, affordability, climate change and air pollution, but also public acceptance for different types of energy projects with regard to various trade-offs, co-benefits and competing priorities (International Energy Agency, 2015).

Another challenge developing economies are faced with is a growing municipal solid waste management problem. Growing populations, rapidly transforming economies and urbanization increase manufacturing and consumption patterns of goods both per capita and in absolute terms. These activities generate large amounts of municipal solid waste, which need to be reduced, reused and recycled, and the rest disposed of in a sustainable manner. Solid waste management is becoming an increasingly popular topic because of exponentially increasing amounts of waste, limited space for waste disposal activities in urban areas, ecologic threats, stricter legal requirements, availability of novel technologies, intensive public awareness and health reasons (Shekdar, 2009).

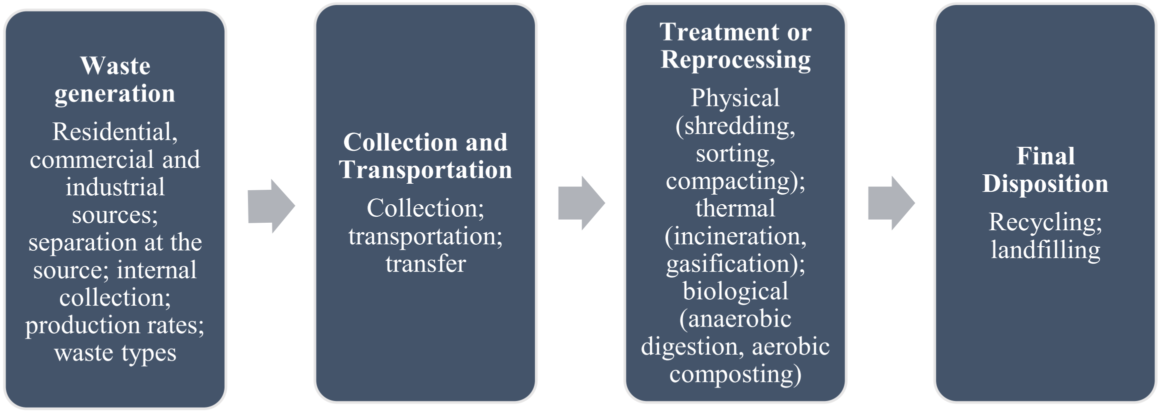


Figure 6.1. Solid Waste Management in Urban Areas
Source: Demirbas (2011)

Waste management can involve the creation, storage, gathering, transportation, treatment and disposal stages (Singh et al., 2011). Local governments have different technological options to deal with this challenge by addressing their energy and waste management problems all at once. Waste is becoming a synonym for raw materials nowadays; the recovery and reuse of waste can be accomplished by extraction or reprocessing of raw materials in terms of physical or biological reprocessing, as well as energy recovery by converting the calorific value into electricity (Demirbas, 2011). Thus, generating electricity from urban waste can be a viable multi-purpose solution to cities' energy and waste management needs by lowering the environmental footprint of waste disposal, by improving life quality and contributing to municipal budget. Waste disposal technologies have different magnitudes of environmental impacts, which can increase, in order, by reducing, reusing, recycling, composting, incinerating and landfilling (Siddique et al., 2008). Nevertheless, these so-called Waste-to-Energy (WtE) projects can result in many direct and indirect economic, environmental and social effects that need a deeper review. Selecting the most suitable WtE option in a city can maximize economic benefits, while minimizing environmental threats and impacts on the society.

Turkey is a developing country and faces many of these municipal waste management and energy supply challenges. Due to its rapidly growing urban population and industrializing economy, the domestic energy demand and waste management problem are becoming a priority on the local agenda.

In Turkey, municipalities are responsible for collecting, processing and disposing of household waste, while industries are liable for properly disposing of their hazardous waste. The Turkish energy market is largely liberalized after 2001, meaning that public and private power producers can sell their electricity to individual, commercial and industrial customers in an efficiently run electricity market (Büyüközkan and Karabulut, 2017). Under these circumstances, many municipalities are engaged with power generation from municipal waste. Nevertheless, affordable and reliable electricity is a growing domestic concern that becomes even more complicated due to public awareness about ecologic deterioration and social aspects. The national strategy is to build up a robust mix of different energy generation technologies to satisfy this demand sustainably by considering the availability of natural resources, financial profitability, ecosystems and technical requirements (Ministry of Energy and Natural Resources). These interesting energy supply and demand dynamics under sustainability constraints makes Turkey a good example of how to select the best energy projects.

Local governments highly regard public opinions and put great emphasis on environmental impacts and the continuity of ecosystem services when deciding on their municipal investments. Proper solid waste management aims to obtain the highest possible benefit out of it and to produce the least amount of waste disposed for landfilling. WtE projects can be a very promising candidate to address these needs simultaneously. Efficient and well-designed WtE projects can reduce external environmental costs of both waste management and energy generation, catalyze resource efficiency and contribute to a sustainable urban infrastructure (Investing in Renewable Energy: The GEF Experience, 2009). However, there is not one single type of technology for such projects. Environmental impacts and benefits of incineration, anaerobic digestion, composting and gasification can greatly differ not only based on the technology, but also on the project specifications themselves. This makes the selection of the most appropriate energy recovery project from waste a significant concern for local governments, which will assess different project alternatives and invest in the most sustainable project. They mostly seek the best fitting WtE project for their region in a practical manner rather than a 'best technology'. Municipalities therefore expect a WtE project to perform superior in terms of regulatory compliance, institutional practices, efficiency and environmental integrity, beside others.

Considering these needs, this chapter applies the previously proposed SPE framework on the WtE project selection problem. This case study application will only take the environmental branch of the SPE model. It is different than the previous case study in the sense that it is extended to the $4^{th}$ criteria level, instead of 3 levels as in the previous case. Thus, this study will have a narrower but deeper evaluation focus. This application will present the usability of the framework as a decision support tool for municipalities. Measuring and ranking similarly sized and concretely defined project alternatives can provide stronger decision support to local governments for balanced comparisons. The overall aim is again the application of the proposed framework in another setting to assess and compare concretely defined energy projects. This application provides a developing country perspective for dealing with waste management and energy provision together, both of which are main challenges for many cities in developing countries across the world. The results intend to guide local governments and researchers to effectively forecast WtE projects' overall environmental performance and take their decisions accordingly. It shall be noted that the proposed framework is suitable for comparing WtE projects before or after implementation.

This chapter will continue with a brief literature review on WtE project assessment with environmental perspective. After that, a real case study will be exhibited to validate the framework's usefulness. In the next chapters, managerial implications and concluding remarks will be discussed.

## 6.2 Waste-to-Energy Project Selection Literature

Solid waste consists of durable and non-durable goods, packaging, food scraps, garden trimmings, wastewater treatment sludge and other waste from residential, commercial, and industrial sources. It can include large amounts of embedded energy. Waste can be converted into energy through direct combustion (i.e. incineration and pyrolysis) or can be transformed into other combustible fuels, such as methane, hydrogen and synthetic fuels (i.e. anaerobic digestion, mechanical-biological treatment or refuse-derived fuel) (Cheng and Hu, 2010). In this article, the following four technologies will be reviewed closer: landfill gas utilization, incineration, gasification and anaerobic digestion. These technologies are shortly presented next.

**Landfilling** is a low-cost waste management option to slow down the degradation of organic material and store waste in a relatively controlled area. Sanitary landfills may lead to the contamination of soil, surface water and groundwater resources for poorly designed and managed landfills. Organic waste decomposes into a mix of largely methane and carbon dioxide, called landfill gas, which can be partially captured and then combusted to generate electricity (Bove and Lunghi, 2006). **Incineration** is the direct combustion of mostly dry solid waste to generate electricity. As a thermal waste management alternative, it reduces the waste mass and volume, destroys contaminants and hazardous waste, concentrates inorganic contaminants and recovers energy (Sabbas et al., 2003). Its energetic efficiency increases as the water content of waste decreases. **Gasification** is a thermochemical conversion of carbon-based materials (e.g. mixed plastic, forest industry waste and agricultural residues) into a mix of combustible gases under high temperature by the addition of a gasification agent. This reaction generates a sufficient amount of energy to maintain the high process temperature. The combustible gas can then be converted into electrical power and supplied to the energy grid (Belgiorno et al., 2003). **Anaerobic digestion** is another technology that converts organic materials into the so-called ‘biogas’, a mixture of largely methane and carbon dioxide gases, which are combusted for generating power and heat. These bio-methanization plants generate this gas mixture in controlled environments, called bio-digesters, to optimize microbiologic activities that result in the decomposition of input materials and the formation of a liquid slurry that can be potentially used for fertilization purposes. They are particularly effective for waste with high water content, such as manure, sewage sludge and waste from the food industry (Balat, 2010).

Energy generation is on the global agenda as industrialization and urbanization take up in the developing world (World Bank, 2016). Addition of new electricity production capacity may imply environmental pollution, hazardous emissions and ecologic harms. WtE provides environmental benefits with regards to the baseline scenario. To understand these widely dispersed benefits, WtE projects need to be evaluated with structured multi-dimensional approaches. In literature, there are many analytical methods for comparing and ranking WtE technologies with an environmental focus. MCDM is one of these methodologies (Su et al., 2007; Tseng, 2009). Life Cycle Assessment (LCA), Multi Objective Programming (MOP) and Cost–Benefit Analysis (CBA) are also used (Su et al., 2007; Karmperis et al., 2013; Allesch and Brunner, 2014). While many papers deal with energy generation technologies and municipal solid waste management, a limited number of them focus on selecting WtE technologies. There is not any study so far that discusses concretely defined WtE projects in the field of decision-making. A short literature review on recent publications is provided next.

Bove and Lunghi (2006) emphasized the use of end life products as fuel, since large amounts of waste end up in landfills. They analyzed different WtE options for landfills, including traditional and innovative technologies for their technical, economic and environmental aspects. Cheng and Hu (2010) reviewed the WtE industry and discussed the barriers against incineration in China with regard to investment and operational costs, technical difficulties, fly ash and air pollutants.

Related publications have so far appeared mostly under solid waste management literature. Hung et al. (2007) analyzed different decision-making models for municipal solid waste management and developed a model to overcome these shortcomings by combining MCDM with a consensus analysis structure. Cheng et al. (2002) suggested that WtE selection problems can be explored with SAW, TOPSIS and ELECTRE techniques. Norese (2006) proposed ELECTRE III as a capable tool that is compatible with GDM approaches. Khan and Faisal (2008) presented an assessment methodology for local governments for prioritizing and selecting suitable municipal solid waste management options with the help of ANP to assess the comparative attractiveness of disposal alternatives by utilizing value judgments as stakeholder inputs. Tseng (2009) integrated ANP and DEMATEL to support expert evaluations for selecting solid waste management solutions. They found out that the best solution for the analyzed cities is to adapt available thermal process technologies to their specific needs, instead of landfills. In another paper, Su et al. (2007) employed a new decision-making model to predict the possible impacts of solid waste policies in Taiwan. Karmperis et al. (2013) discussed the pros and cons of MCDM methods for decision support purposes in selecting WtE. In a recent article, Mir et al. (2016) deployed a TOPSIS-based method to identify the best WtE option by assessing and ranking different alternative scenarios and then compared the results with a sensitivity analysis based on VIKOR. Contreras (2008) combined AHP with LCA to compare different WtE alternatives for Boston, USA and identified the greenhouse gas emissions and landfill capacity limitations to be more important decisive factors, compared to economic parameters. Pires et al. (2011) applied AHP and TOPSIS together with interval-valued fuzzy (IVF) method for evaluating and ranking WtE alternatives to help local governments in Portugal. They also indicated that PROMETHEE and GAIA are useful for WtE decisions. While PROMETHEE is a simple and efficient non-parametric ranking technique, accordingly GAIA can visually complement PROMETHEE (2008). Singh et al. (2011) analyzed the state of art of literature to evaluate the current status of WtE technologies. Soltani et al. (2015) analyzed the relevant literature about the application of MCDM methods in solid waste management. Accordingly, the most common techniques used in the 68 reviewed articles are TOPSIS, ELECTRE, PROMETHEE, ANP and AHP; about 40% of these publications deal with WtE selection. Allesch and Brunner (2014) reviewed 151 papers in the solid waste literature and found out that approximately 10% of them utilize MCDM methods, mostly ELECTRE and PROMETHEE. None of these recent literature reviews mention VIKOR as one of the utilized techniques. Nevertheless, Liu et al. (2013) proposed a fuzzy VIKOR-based method for comparing healthcare waste disposal methods. Uğurlu and Kahraman (2011) used VIKOR for evaluating different hazardous waste treatment technology alternatives for Istanbul city under fuzzy environment with respect to economic, risk and technical sub-criteria. Cristóbal (2011) combined AHP with VIKOR to compare different renewable energy technologies, including some biomass scenarios. A comparable method was implemented by Dai et al. (2012), who used VIKOR to rank ten different renewable energy technologies, including biomass and biogas.

Renewable energy technology selection articles abound in literature, nevertheless there are only a few studies that only focus on WtE technologies. This review highlights the following research gaps:

- In literature, there are waste-themed or energy-themed comparisons. For instance, biogas or biomass energy plants are frequently included in renewable energy technology comparisons. However, they are thematically not focused on sustainability performance evaluation of only WtE systems.

- The multi-objective, multi-functional character of WtE technologies for waste treatment and simultaneous energy generation is not discussed in detail. They are either treated for energy generation or waste management, but not both in an inclusive manner. Evaluation criteria structures for WtE are therefore very limited in scope and scale.
- The methods to select and weight criteria and evaluate alternatives are vitally important. The majority of literature, however, arbitrarily selects and weights evaluation criteria with limited or no input from industrial experts. Nor is GDM extensively used.
- AHP and VIKOR are seldom combined to study WtE technologies. Furthermore, there is no MCDM study that focuses on the selection of concretely defined WtE projects with respect to environmental impacts only. Available publications either deal with generic WtE technologies, or location problems.

Addressing these literature findings, the proposed framework presents an innovative, balanced and practical solution for local governments to evaluate their WtE projects. AHP and VIKOR have so far not been applied to compare the environmental performance of WtE project alternatives. The proposed evaluation procedure will be applied in the following 3 stages, as illustrated in ***Figure 4.2***:

i. Identification of environmental evaluation criteria and their hierarchy;
ii. Determination of criteria weights with AHP under GDM;
iii. Evaluating WtE projects' environmental performance and ranking them with VIKOR under GDM.

In section 3.3, all criteria names are provided, along with their definitions up to 3$^{rd}$ level. However, the verbal definitions of the 4$^{th}$ level criteria were omitted. These definitions of these environmental 4$^{th}$ level criteria are supplied in ***Table 6.2***.

### 6.3 Definition of the Problem, Criteria and Alternatives

The evaluation framework presented in this study is applied on a real case, where actual WtE project designs developed in Turkey are compared. The exact names and locations of these projects are undisclosed and the project information is scaled for confidentiality. A Turkish metropolitan municipality is planning a new WtE project to meet the growing amounts of municipal solid waste and to also generate energy. Municipality's environmental team is responsible for the development of project designs with the help of external technology providers. The municipality considers 4 different alternative WtE projects that are based on different technologies and installed capacities (in tons/day, and megawatts). Since projects' size can affect the magnitude of environmental impacts, DMs are asked to adjust these projects to similar waste processing and energy capacity for fair comparison. The municipality considers 4 WtE projects, all of which are taken here as they are without any prejudice or modification. The available WtE project options are given in ***Table 6.1***.

Table 6.1. Description of WtE Alternatives

| # | Technology | Capacity | Description |
|---|---|---|---|
| **$A_1$** | Gasification | 10 MW | This compact plant will be a first of its kind in Turkey and will generate syngas from organic waste at high temperatures, and some packaging waste to lesser extent. Syngas will be combusted for power generation, which will then be supplied to the national grid. |
| **$A_2$** | Anaerobic digestion | 6 MW | This new bio-methanization unit will be run with selected organic waste, where carbon-based materials will be fermented to generate methane gas to later convert it into electrical energy. This efficient process produces liquid slurry as output, which can also be used as fertilizer and soil conditioner in city parks. |
| **$A_3$** | Landfill gas | 13.5 MW | The existing landfill site will be expanded by laying additional gas collection pipes and installing new internal combustion engines. Collection pipes in the waste will capture naturally developing methane gas before it escapes to the air. Collected gas will be pre-treated and used for electricity production. |
| **$A_4$** | Incineration | 17.5 MW | This plant will have a higher electrical capacity than the other projects. It will be run at high temperatures to completely burn different types of mixed municipal waste and hazardous waste. Depending on the humidity of waste, fossil fuels can be consumed to a limited extent. The plant will generate small amounts of fly ash. |

For the GDM procedure, 5 experts are selected, who all belong to the environmental team of the municipality. They are knowledgeable about solid waste management, R&D and legal compliance, project designs and technical information, among others. The first expert, $DM_1$, has more than 14 years of equipment and operational experience and managerial responsibilities for solid waste management. The second expert, $DM_2$, has more than 11 years of experience for environmental permits and technical design for municipal waste solutions. The third expert, $DM_3$, has 9 years of experience with landfill site operation and landfill gas flaring. The fourth expert, $DM_4$, has 5 years of environmental management and technical planning experience in the municipal solid waste management department. The fifth expert, $DM_5$, is an environmental engineer with approximately 17 years of experience for environmental management practices across different municipal departments. All these DMs are intensively involved in the defined projects.

The proposed environmental performance evaluation framework is shown in ***Figure 6.2***. The objective of the decision problem, i.e. environmental performance, is placed at the highest level of this hierarchy. In lower levels, the main and sub-criteria are assigned. The lowest level belongs to the four WtE project alternatives.

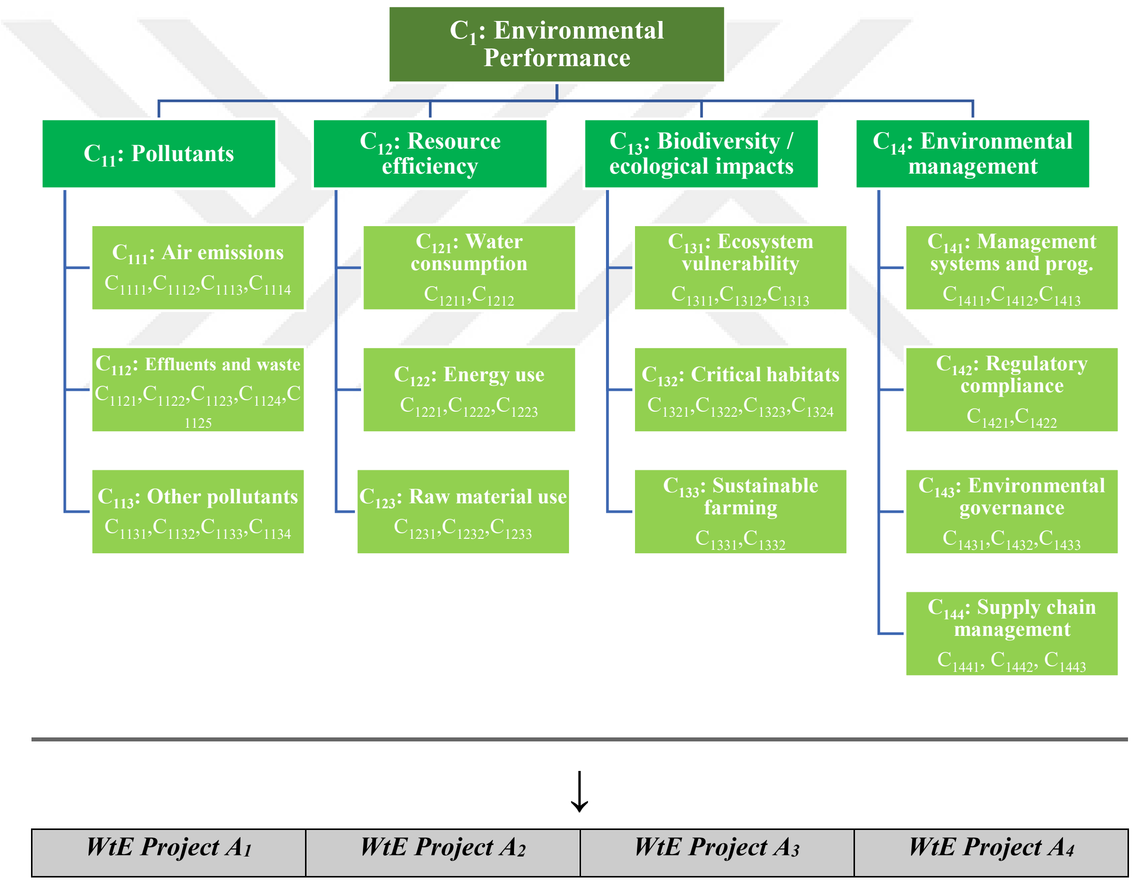


Figure 6.2. Proposed Environmental Evaluation Criteria Hierarchy

**<u>Stage 1:</u>** At this 1st stage, the criteria are presented. In this case study, only the environmental branch of the proposed SPE framework is applied to capture the environmental performance of WtE projects. They are used without any modification in this case study to exemplify the application of the original framework. The framework's criteria are given in ***Table 6.2***.

Table 6.2. Definitions of 3rd and 4th Level Environmental Criteria

| | Sub-criteria | Definition |
|---|---|---|
| $C_{11}$: Pollutants | $C_{111}$: Air emissions | Air pollutants that deteriorate air quality. |
| | $C_{1111}$: Ambient air quality | Dust, smog and smell of air. |
| | $C_{1112}$: Air pollutants and ozone protection | Pollutants in the air with public health hazards. |
| | $C_{1113}$: Climate change | Greenhouse gas emissions. |
| | $C_{112}$: Effluents and waste | Solid / hazardous waste and wastewater emissions. |
| | $C_{1121}$: Water pollution and waste water quality | Visual, chemical and biologic qualities of wastewater. |
| | $C_{1122}$: Effluent quantity | Wastewater discharge. |
| | $C_{1123}$: Solid waste | Amount of solid waste. |
| | $C_{1124}$: Hazardous waste | Amount, leakage and spillage of toxic waste. |
| | $C_{1125}$: Management practices | Knowhow and internal training for pollution management. |
| | $C_{113}$: Other pollutants | Other undesired emissions and land use. |
| | $C_{1131}$: Land use | Eroded, degraded and occupied land area. |
| | $C_{1132}$: Electromagnetic radiation and interference | Impacts on human comfort. |
| | $C_{1133}$: Radioactivity | Nuclear waste storage. |
| | $C_{1134}$: Noise emissions | Level of noise and proximity to sensitive areas. |
| $C_{12}$: Resource efficiency | $C_{121}$: Water consumption | Intensity of use of water resources. |
| | $C_{1211}$: Total water usage | Surface and ground water withdrawals. |
| | $C_{1212}$: Water recycled and reused | Rainwater and recycled water used. |
| | $C_{122}$: Energy use | Consumption of fossil fuels and renewable energy sources. |
| | $C_{1221}$: Energy efficiency and intensity | Intensity of consumed energy for the same output. |
| | $C_{1222}$: Renewable energy | Energy generated or consumed from renewable resources. |
| | $C_{1223}$: Non-renewable energy and fossil fuels | Amount of coal, natural gas, petroleum etc. used. |
| | $C_{123}$: Raw material use | Consumption of raw materials used. |
| | $C_{1231}$: Renewable raw materials | Certified timber, eco-labelled paper etc. |
| | $C_{1232}$: Non-renewable raw materials | Life cycle impacts of mining, quarrying and extraction activities. |
| | $C_{1233}$: Recycled and reused materials | Recovery of glass, metal, plastic etc. |
| $C_{13}$: Biodiversity and ecological impacts | $C_{131}$: Ecosystem vulnerability | Ecologic impacts on the nature. |
| | $C_{1311}$: Land ecosystems | Desertification. |
| | $C_{1312}$: River ecosystems | Flow regime, diversion and water extraction from rivers etc. |
| | $C_{1313}$: Oceans, seas and coasts | Eutrophication and aquatic reserves |
| | $C_{132}$: Critical habitats | Violations of sensitive habitats. |
| | $C_{1321}$: Violation of animals' territory | Habitat fragmentation, wildlife crossings, connectivity with hinterland etc. |
| | $C_{1322}$: Deforestation and vegetation cover | Tree felling and soil cover change. |
| | $C_{1323}$: Species mortality | Protected areas, national parks, species conservation. |
| | $C_{1324}$: Extinction risk / vulnerable species | Mortality rate and threatened species. |
| | $C_{133}$: Sustainable farming | Impacts of agriculture, forestry and fishing activities. |
| | $C_{1331}$: Agricultural practices | Cropland utilization, fertilizer accumulation and pesticide contamination. |
| | $C_{1332}$: Sustainable fishing and forestry | Feeding grounds, forest areas, natural fish reserves etc. |

Table 6.2. Definitions of 3rd and 4th Level Environmental Criteria (Cont'd)

| | | |
|---|---|---|
| **$C_{14}$: Environmental management** | $C_{141}$: Management systems and programs | Commitments to environmental management systems and green initiatives. |
| | $C_{1411}$: Environmental Management Systems | Certification standards, internal procedures etc. |
| | $C_{1412}$: Commitment to voluntary codes | Green schemes, ecolabel programs, voluntary initiatives. |
| | $C_{1413}$: Internal knowhow and capacity development | Green office programs, technical knowhow and technology transfer. |
| | $C_{142}$: Regulatory compliance | Compliance with legal environmental liabilities. |
| | $C_{1421}$: Legal environmental liabilities | Effectiveness and efficiency of acquiring environmental permits |
| | $C_{1422}$: Environmental risk management | Risk of environmental non-compliance, reputation and proactive expenditures. |
| | $C_{143}$: Environmental governance | Corporate commitments for best practice. |
| | $C_{1431}$: Disclosed commitments and goals | Communication of sustainability goals and institutional policies. |
| | $C_{1432}$: Sustainability reporting and communication | Monitoring and disclosure of environmental footprint. |
| | $C_{1433}$: Corporate identity and environmental transparency | Environmental incidents concerning products and openness. |
| | $C_{144}$: Supply chain management | Green procurement, eco-design and logistics. |
| | $C_{1441}$: Sustainable procurement | Environmental supplier audits and green procurement procedures. |
| | $C_{1442}$: Green design and manufacturing | Product design and manufacturing with lower life cycle footprint. |
| | $C_{1443}$: Green logistics and disposal | Recycled packaging, reverse logistics and energy-efficient transportation. |

**Stage 2:** The proposed framework's 2$^{nd}$ stage is the calculation of criteria weights with the help of GDM and AHP, as already explained in section 4.2. First, the pair-wise comparison matrices for Level 2 are gathered from the five DMs, these comparisons for $C_{11}$-$C_{14}$ provided by the five DMs are given in ***Table 6.3***. The lower values in these matrices indicate the reciprocals of the upper values.

After evaluations are collected, the consistency of DM judgments is verified by computing the Consistency Ratio (CR) to confirm that it remains below 0.10. If consistent, the weights of the criteria are computed by taking pair-wise group matrices to their 64$^{th}$ power. The aggregated criteria weights are given in ***Table 6.5***.

Table 6.3. Paired Comparison Matrices of $DM_1$-$DM_5$ for $C_{11}$-$C_{14}$

| Criteria | $C_{11}$ | $C_{12}$ | $C_{13}$ | $C_{14}$ |
|---|---|---|---|---|
| **$C_{11}$** | **1** | 1 | 2 | 2 |
| **$C_{12}$** | 1 | **1** | 2 | 2 |
| **$C_{13}$** | 1/2 | 1/2 | **1** | 1 |
| **$C_{14}$** | 1/2 | 1/2 | 1 | **1** |

| Criteria | $C_{11}$ | $C_{12}$ | $C_{13}$ | $C_{14}$ |
|---|---|---|---|---|
| **$C_{11}$** | **1** | 1 | 2 | 2 |
| **$C_{12}$** | 1 | **1** | 2 | 2 |
| **$C_{13}$** | 1/2 | 1/2 | **1** | 1 |
| **$C_{14}$** | 1/2 | 1/2 | 1 | **1** |

| Criteria | $C_{11}$ | $C_{12}$ | $C_{13}$ | $C_{14}$ |
|---|---|---|---|---|
| **$C_{11}$** | **1** | 1 | 2 | 3 |
| **$C_{12}$** | 1 | **1** | 2 | 2 |
| **$C_{13}$** | 1/2 | 1/2 | **1** | 1 |
| **$C_{14}$** | 1/3 | 1/2 | 1 | **1** |

| Criteria | $C_{11}$ | $C_{12}$ | $C_{13}$ | $C_{14}$ |
|---|---|---|---|---|
| **$C_{11}$** | **1** | 1 | 1 | 1/3 |
| **$C_{12}$** | 1 | **1** | 1 | 1/3 |
| **$C_{13}$** | 1 | 1 | **1** | 1/3 |
| **$C_{14}$** | 3 | 3 | 3 | **1** |

| Criteria | $C_{11}$ | $C_{12}$ | $C_{13}$ | $C_{14}$ |
|---|---|---|---|---|
| **$C_{11}$** | **1** | 2 | 4 | 1 |
| **$C_{12}$** | 1/2 | **1** | 2 | 4 |
| **$C_{13}$** | 1/4 | ½ | **1** | 1/3 |
| **$C_{14}$** | 1 | 1/4 | 3 | **1** |

Table 6.4. Aggregated $2^{nd}$ Level Criteria Weights

| Criteria | Weight (priority) |
|---|---|
| **$C_{11}$** | 0.335 |
| **$C_{12}$** | 0.316 |
| **$C_{13}$** | 0.151 |
| **$C_{14}$** | 0.198 |

The same calculations are repeated for the remaining sub-criteria level by level, the details of which are omitted here. These calculations suggest that DM evaluations are sufficiently consistent, so that there is no need to recollect revised judgments. The normalized global priority weights and the rankings are shown in ***Table 6.5***.

Table 6.5. Calculated Weights of Environmental Criteria

| **Criteria** | **Sub-criteria** | **Priority within the Cluster** | **Overall Priority** |
|---|---|---|---|
| $C_{11}$: Pollutants (0,335) | $C_{111}$: Air emissions | 0.496 | 0.166 |
| | $C_{1111}$: Ambient air quality | 0.282 | 0.047 |
| | $C_{1112}$: Air pollutants and ozone protection | 0.295 | 0.049 |
| | $C_{1113}$: Climate change | 0.423 | 0.070 |
| | $C_{112}$: Effluents and waste | 0.398 | 0.133 |
| | $C_{1121}$: Water pollution and waste water quality | 0.192 | 0.025 |
| | $C_{1122}$: Effluent quantity | 0.165 | 0.022 |
| | $C_{1123}$: Solid waste | 0.224 | 0.030 |
| | $C_{1124}$: Hazardous waste | 0.258 | 0.034 |
| | $C_{1125}$: Management practices | 0.162 | 0.022 |
| | $C_{113}$: Other pollutants | 0.107 | 0.036 |
| | $C_{1131}$: Land use | 0.419 | 0.015 |
| | $C_{1132}$: Electromagnetic radiation and interference | 0.194 | 0.007 |
| | $C_{1133}$: Radioactivity | 0.163 | 0.006 |
| | $C_{1134}$: Noise emissions | 0.281 | 0.010 |
| $C_{12}$: Resource efficiency (0,316) | $C_{121}$: Water consumption | 0.244 | 0.077 |
| | $C_{1211}$: Total water usage | 0.568 | 0.044 |
| | $C_{1212}$: Water recycled and reused | 0.432 | 0.033 |
| | $C_{122}$: Energy use | 0.472 | 0.149 |
| | $C_{1221}$: Energy efficiency and intensity | 0.406 | 0.061 |
| | $C_{1222}$: Renewable energy | 0.428 | 0.064 |
| | $C_{1223}$: Non-renewable energy and fossil fuels | 0.166 | 0.025 |
| | $C_{123}$: Raw material use | 0.284 | 0.090 |
| | $C_{1231}$: Renewable raw materials | 0.319 | 0.029 |
| | $C_{1232}$: Non-renewable raw materials | 0.320 | 0.029 |
| | $C_{1233}$: Recycled and reused materials | 0.361 | 0.032 |
| $C_{13}$: Biodiversity and ecological impacts (0,151) | $C_{131}$: Ecosystem vulnerability | 0.298 | 0.045 |
| | $C_{1311}$: Land ecosystems | 0.530 | 0.024 |
| | $C_{1312}$: River ecosystems | 0.217 | 0.010 |
| | $C_{1313}$: Oceans, seas and coasts | 0.254 | 0.011 |
| | $C_{132}$: Critical habitats | 0.383 | 0.058 |
| | $C_{1321}$: Violation of animals' territory | 0.306 | 0.018 |
| | $C_{1322}$: Deforestation and vegetation cover | 0.318 | 0.018 |
| | $C_{1323}$: Species mortality | 0.166 | 0.010 |
| | $C_{1324}$: Extinction risk / vulnerable species | 0.210 | 0.012 |
| | $C_{133}$: Sustainable farming | 0.319 | 0.048 |
| | $C_{1331}$: Agricultural practices | 0.611 | 0.029 |
| | $C_{1332}$: Sustainable fishing and forestry | 0.389 | 0.019 |
| $C_{14}$: Environmental management (0,198) | $C_{141}$: Management systems and programs | 0.185 | 0.037 |
| | $C_{1411}$: Environmental Management Systems | 0.331 | 0.012 |
| | $C_{1412}$: Commitment to voluntary codes | 0.285 | 0.010 |
| | $C_{1413}$: Internal knowhow and capacity development | 0.384 | 0.014 |
| | $C_{142}$: Regulatory compliance | 0.307 | 0.061 |
| | $C_{1421}$: Legal environmental liabilities | 0.577 | 0.035 |
| | $C_{1422}$: Environmental risk management | 0.423 | 0.026 |
| | $C_{143}$: Environmental governance | 0.235 | 0.047 |
| | $C_{1431}$: Disclosed commitments and goals | 0.410 | 0.019 |
| | $C_{1432}$: Sustainability reporting and communication | 0.300 | 0.014 |
| | $C_{1433}$: Corporate identity and environmental transparency | 0.290 | 0.014 |
| | $C_{144}$: Supply chain management | 0.273 | 0.054 |
| | $C_{1441}$: Sustainable procurement | 0.272 | 0.015 |
| | $C_{1442}$: Green design and manufacturing | 0.298 | 0.016 |
| | $C_{1443}$: Green logistics and disposal | 0.430 | 0.023 |

These weights are *not* specific for the selected WtE projects and can therefore be applied to similar WtE project selection problems. The DMs did not eliminate any criteria, less important criteria are simply prioritized with lower global weights.

**<u>Stage 3:</u>** The proposed framework's 3rd stage is the evaluation and ranking of available alternatives. After consulting the DMs about their scores for each of the four projects assessed for every criterion, individual evaluations are merged into one single group decision with GDM first, and then VIKOR is applied to rank them. The aggregation of the evaluations is carried out by assigning specific weights to each of the experts. The set of DMs is defined as D = {$DM_1$, $DM_2$, . . ., $DM_k$}, where K = 5. The level of influence of $DM_k$ on the decision problem is defined as $\lambda_k$, with $\lambda_k \in [0,1]$ and $\sum_{k=1}^{K} \lambda_k = 1$. More experienced professionals will have a higher control on the outcome of this GDM practice. Considering DMs' backgrounds, their influence levels are assigned as: $\lambda_1$=0.25, $\lambda_2$=0.20, $\lambda_3$=0.20, $\lambda_4$=0.10, $\lambda_5$=0.25.

The priority scores for each of the selected WtE project alternatives are given in ***Table 6.6***, with which the best and worst values are found, as shown in ***Table 6.7.*** After these values are found, S, R and Q parameters are calculated next, the results of which are shown in ***Table 6.8***. These computations are implemented for $v$ = 0.5.

Table 6.6. Aggregated Criteria Evaluations for WtE Project Alternatives

| | $C_{1111}$ | $C_{1112}$ | $C_{1113}$ | $C_{1121}$ | $C_{1122}$ | $C_{1123}$ | $C_{1124}$ | $C_{1125}$ | $C_{1131}$ | $C_{1132}$ | $C_{1133}$ | $C_{1134}$ | $C_{1211}$ | $C_{1212}$ | $C_{1221}$ | $C_{1222}$ | $C_{1223}$ | $C_{1231}$ | $C_{1232}$ | $C_{1233}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **$A_1$** | 0.79 | 0.86 | 0.73 | 0.88 | 0.87 | 0.81 | 0.98 | 0.84 | 0.78 | 1.00 | 1.00 | 0.80 | 0.87 | 0.87 | 0.85 | 0.72 | 0.84 | 0.67 | 0.55 | 0.73 |
| **$A_2$** | 0.87 | 0.70 | 0.86 | 0.73 | 0.75 | 0.80 | 0.67 | 0.89 | 0.56 | 1.00 | 1.00 | 0.81 | 0.63 | 0.71 | 0.73 | 0.81 | 0.90 | 0.78 | 0.60 | 0.51 |
| **$A_3$** | 0.71 | 0.69 | 0.73 | 0.77 | 0.80 | 0.30 | 0.66 | 0.62 | 0.40 | 1.00 | 1.00 | 0.81 | 0.91 | 0.62 | 0.62 | 0.75 | 0.86 | 0.62 | 0.53 | 0.60 |
| **$A_4$** | 0.67 | 0.80 | 0.74 | 0.88 | 0.80 | 0.81 | 0.69 | 0.73 | 0.91 | 1.00 | 1.00 | 0.83 | 0.88 | 0.90 | 0.87 | 0.86 | 0.80 | 0.69 | 0.71 | 0.78 |

| | $C_{1311}$ | $C_{1312}$ | $C_{1313}$ | $C_{1321}$ | $C_{1322}$ | $C_{1323}$ | $C_{1324}$ | $C_{1331}$ | $C_{1332}$ | $C_{1411}$ | $C_{1412}$ | $C_{1413}$ | $C_{1421}$ | $C_{1422}$ | $C_{1431}$ | $C_{1432}$ | $C_{1433}$ | $C_{1441}$ | $C_{1442}$ | $C_{1443}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.91 | 0.98 | 0.93 | 0.95 | 0.88 | 0.98 | 0.75 | 0.76 | 0.90 | 0.90 | 0.74 | 0.93 | 0.67 | 0.80 | 0.84 | 0.85 | 0.88 | 0.94 | 0.83 | 0.84 |
| | 0.87 | 0.88 | 0.88 | 0.84 | 0.81 | 0.94 | 0.98 | 0.89 | 0.88 | 0.95 | 0.78 | 0.88 | 0.84 | 0.82 | 0.81 | 0.88 | 0.88 | 0.66 | 0.94 | 0.81 |
| | 0.54 | 0.72 | 0.87 | 0.72 | 0.71 | 0.84 | 0.98 | 0.67 | 0.78 | 0.98 | 0.91 | 0.78 | 0.86 | 0.64 | 0.73 | 0.81 | 0.88 | 0.79 | 0.91 | 0.81 |
| | 0.86 | 0.95 | 0.93 | 0.98 | 0.88 | 0.98 | 0.98 | 0.76 | 0.88 | 0.93 | 0.70 | 0.92 | 0.68 | 0.80 | 0.88 | 0.86 | 0.87 | 0.69 | 0.85 | 0.79 |

Table 6.7. Best ($f_i^*$) and Worst ($f_i^-$) Values of Evaluation Criteria

| | $C_{1111}$ | $C_{1112}$ | $C_{1113}$ | $C_{1121}$ | $C_{1122}$ | $C_{1123}$ | $C_{1124}$ | $C_{1125}$ | $C_{1131}$ | $C_{1132}$ | $C_{1133}$ | $C_{1134}$ | $C_{1211}$ | $C_{1212}$ | $C_{1221}$ | $C_{1222}$ | $C_{1223}$ | $C_{1231}$ | $C_{1232}$ | $C_{1233}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **$f_i^*$** | 0.87 | 0.86 | 0.86 | 0.88 | 0.87 | 0.81 | 0.98 | 0.89 | 0.91 | 1.00 | 1.00 | 0.83 | 0.91 | 0.90 | 0.87 | 0.86 | 0.90 | 0.78 | 0.71 | 0.78 |
| **$f_i^-$** | 0.67 | 0.69 | 0.73 | 0.73 | 0.75 | 0.30 | 0.66 | 0.62 | 0.40 | 1.00 | 1.00 | 0.80 | 0.63 | 0.62 | 0.62 | 0.72 | 0.80 | 0.62 | 0.53 | 0.51 |

| | $C_{1311}$ | $C_{1312}$ | $C_{1313}$ | $C_{1321}$ | $C_{1322}$ | $C_{1323}$ | $C_{1324}$ | $C_{1331}$ | $C_{1332}$ | $C_{1411}$ | $C_{1412}$ | $C_{1413}$ | $C_{1421}$ | $C_{1422}$ | $C_{1431}$ | $C_{1432}$ | $C_{1433}$ | $C_{1441}$ | $C_{1442}$ | $C_{1443}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.91 | 0.98 | 0.93 | 0.98 | 0.88 | 0.98 | 0.98 | 0.89 | 0.90 | 0.98 | 0.91 | 0.93 | 0.86 | 0.82 | 0.88 | 0.88 | 0.88 | 0.94 | 0.94 | 0.84 |
| | 0.54 | 0.72 | 0.87 | 0.72 | 0.71 | 0.84 | 0.75 | 0.67 | 0.78 | 0.90 | 0.70 | 0.78 | 0.67 | 0.64 | 0.73 | 0.81 | 0.87 | 0.66 | 0.83 | 0.79 |

Table 6.8. S, R and Q Values

| | **$S_j$** | **Rank** | **$R_j$** | **Rank** | **$Q_j$** | **Rank** |
|---|---|---|---|---|---|---|
| **$A_1$** | 0.35 | 2 | 0.07 | 3 | 0.53 | 3 |
| **$A_2$** | 0.39 | 3 | 0.05 | 1 | 0.07 | 1 |
| **$A_3$** | 0.74 | 4 | 0.07 | 3 | 1.00 | 4 |
| **$A_4$** | 0.33 | 1 | 0.07 | 2 | 0.44 | 2 |

The S, R and Q parameters are used for ranking the alternatives. For this, project scores are sorted in increasing order for their S, R and Q values, where the WtE that has the lowest Q value is identified as the best project. However, this is only true if the two conditions of VIKOR, 'acceptable advantage' and 'acceptable stability in decision making' conditions are met. If one or both of these conditions are unmet, VIKOR suggests a set of compromise solutions, instead of one single best alternative.

The results suggest that both conditions of 'acceptable advantage' and 'acceptable stability in decision making' are met for $A_2$. The difference of Q values between the first ($A_2$) and second ($A_4$) ranking alternatives is larger than DQ. Also, $A_2$ ranks the first in $R_j$. Thus, the most environmentally friendly WtE project alternative is the 'anaerobic digestion' ($A_2$) project. The lowest environmental performance is found for the 'landfill gas' project. The ranking list is shown in ***Table 6.9***;

Table 6.9. Final Environmental Ranking of WtE Projects

| | **Project** | **Rank** |
|---|---|---|
| **$A_1$** | Gasification | 3 |
| **$A_2$** | Anaerobic digestion | 1 |
| **$A_3$** | Landfill gas | 4 |
| **$A_4$** | Incineration | 2 |

## 6.4 Discussion

The case study confirms that the framework is a feasible option for distinguishing the most environmentally friendly WtE project from other alternatives. Similar to the previous case study, it is critical to comprehend how well the proposed framework functions. The strength of the proposed framework is tested by comparing the results to TOPSIS, the details of which are omitted here. The rankings found with TOPSIS are given in ***Table 6.10***. In contrast with the proposed framework, the ranking suggested by TOPSIS names $A_1$ (gasification) as the best WtE project. VIKOR's ranking agrees with TOPSIS for $A_3$ (landfill gas project having the last rank) and $A_4$ (incineration project being 2$^{nd}$ ranked). Apparently, TOPSIS and the proposed framework give different rankings for the 1$^{st}$ and 3$^{rd}$ ranks, but agree on the 2$^{nd}$ and 4$^{th}$ ranks. This comparison indicates that the landfill gas project shall not be prioritized. However, VIKOR suggests $A_2$ (anaerobic digestion) as the best option. This is an important contrast, which is discussed next.

Table 6.10. Comparison of Rankings with TOPSIS and VIKOR

| | TOPSIS score ($C_i^*$) | TOPSIS | VIKOR |
|---|---|---|---|
| **$A_1$** | 0.60 | 1 | 3 |
| **$A_2$** | 0.52 | 3 | 1 |
| **$A_3$** | 0.32 | 4 | 4 |
| **$A_4$** | 0.59 | 2 | 2 |

VIKOR provides a maximum "group utility" for the "majority" and a minimum of an individual regret for the "opponent". TOPSIS, in contrast, determines the ranks according to the shortest distance to the ideal solution and the longest distance from the negative-ideal solution. It ignores the comparative importance of these distances into account (Opricovic and Tzeng, 2004). VIKOR's methodological superiority provides clear benefits, where both conditions (C1 and C2) are satisfied in this case study. Thus, no compromise set is proposed. This suggests that $A_2$ is clearly the single best alternative in VIKOR, while the scores of TOPSIS for the first two ranks are very close to each other. To test the dependability of results, a sensitivity analysis is run by changing DMs' weights, the details of which are omitted here. It suggests that for different DM influence levels, the rank of $A_4$, the landfill gas project, is pretty the same for both TOPSIS and VIKOR, and the rank of $A_2$, anaerobic digestion project, is stable for VIKOR. In other words, VIKOR is quite strong in identifying the best and worst environmental performers, while TOPSIS is stable in only identifying the worst project. This analysis underscores the strength and benefits of the presented integrated AHP-VIKOR method. Thus, the proposed framework is able to successfully differentiate and make a decisive interpretation to WtE selection problems.

This chapter provided insights to the application of the proposed SPE framework for both researchers and local governments in designing better WtE projects and in deciding more easily on the most suitable project among different alternatives in terms of holistic environmental considerations. The method can also be extended to larger, smaller or more WtE projects.

# 7 THEORETICAL AND MANAGERIAL IMPLICATIONS

In this study, an MCDM-supported SPE framework is proposed. This framework consists of a conceptual SPE model that is integrated with AHP-VIKOR in a GDM environment. This framework presents a number of different practical and theoretical opportunities for both business managers and researchers working in this field. In terms of operations research applications, AHP-VIKOR under GDM is a well-known combined methodology to compare and select alternatives. The framework is particularly strong in its SPE model structure. In literature, there is no similar 4-level conceptual SPE model with 3 balanced dimensions and clearly sub-ordinated criteria with very MCDM-suitable numbers of sub-criteria. All criteria are designed to be evaluated numerically, so that they can be combined with other analytical techniques as well. This functionality is enhanced by its modularity; researchers can choose to only take out the social dimension, for instance, or any other component of the model and apply it separately. These features highlight the criteria-tree not only as a single-functional framework, but rather as a basis for further extension and adjustment for other fields of research. In this study, a number of research questions are posed and their answers are explored, as summarized in ***Table 7.1***.

Table 7.1. Analysis Results of Research Questions

| Issue | Difficulty | Possible measures |
|---|---|---|
| **Which 'sustainability performance' shall be evaluated?** | The scope and boundaries need to be well defined (country, supply chain, company, project, product etc.) not to disregard any significant impacts over the life time of the subject. | The ultimate goal of the SPE shall be well defined (e.g. benchmarking-indexing, decision-making, optimization etc.). |
| → Objective**: Decision-making support for businesses and projects** | | |
| **What needs to be measured to capture the performance?** | Previous literature and discussions indicate that certain economic, environmental and social impacts of any company, project, product etc. cannot be completely isolated from the other impacts. Inevitably, there will be interacting aspects, overlapping connotations, causal relations and changes over time, even if these sustainability criteria are clearly distinguished and well defined. | Assigning clear, easily understandable, standardized and well-defined sustainability criteria can facilitate its implementation in the industry. These criteria need to cover the wide extent of impacts as much as possible. Overlapping areas, interactions and relations among the criteria can be considered with different techniques. |

Table 7.1. Analysis Results of Research Questions (Cont'd)

| | | |
|---|---|---|
| → Method**: Extensive economic, environmental and social criteria and sub-criteria** | | |
| **How shall the criteria be determined?** | Every problem cannot be evaluated with the same criteria. Relationships and influence of criteria will also change. Standardization of criteria and their adaptation to specific circumstances are conflicting objectives. Another issue is who will decide on the criteria and their importance. | Hierarchical, level-by-level type criteria tree structures are well-known and intuitive. They can be expanded in each lower level to achieve high coverage of sustainability impacts. Some criteria levels can be fixed for standardization, while lower levels can be adjustable by adding and removing criteria on a case-by-case basis. Criteria structures and their adjustment shall be carried out with support from a group of experts, instead of only literature surveys or one single expert. |
| → Model**: Hierarchical criteria tree structure with upper fixed and lower adaptable levels** | | |
| **How shall the criteria be assessed?** | Each criterion can have different importance in the overall sustainability performance, depending on local priorities, time and industry, which shall be determined for the specific use. Once the weights (priorities) of these criteria and their interactions are determined, the subject's (e.g. company or project) sustainability performance needs to be evaluated by experts one by one for each criterion. | These two steps of first determining the importance of criteria and then scoring the subject (alternative) for its sustainability performance for each criterion shall be done with analytical (numerical) techniques. If more than one alternative is scored, they can be compared and ranked according to their sustainability performance. In case of decision-making, operations research tools can be handy. Subjectivity of many criteria can also be considered with these tools, such as MCDM techniques. GDM can improve the results. |
| → Technique**: MCDM techniques to weigh criteria and score alternative companies or projects** | | |
| **How shall the criteria assessments aggregated to reach a result?** | Knowing the importance of criteria and how well alternatives fare with respect to these criteria requires massive data collection. This large amount of valuable information needs to be processed and merged into results in a robust, dependable way not to lead to incorrect inferences. | For both weighing the criteria and scoring the alternatives' sustainability performance, different MCDM techniques can be used and combined in a GDM environment. If one certain industry is selected, the model can be adapted for that purpose specifically by determining the criteria weights. These weights can be used in the same industry for different uses. The alternatives' performance shall be determined anew for each decision-making problem. |
| → Framework (Model & Technique)**: An GDM-supported integrated MCDM method for ranking the best alternative project or company in a specific industry** | | |

In terms of theoretical and managerial implications, the framework is intended to guide its users in evaluating and benchmarking sustainability performance. This can be applied in various fields. This capability means that various types of potential users, such as investors, financiers (e.g. banks and international financial institutions), NGOs, academia and policy makers are able to:

- Use a standalone, standard tool for capturing the overall sustainability performance for a well-defined product, project, company, supply chain etc. without the need of additional models or techniques.
- Enjoy a complete SPE criteria model, the criteria of which encompass a very wide range of direct and indirect economic, environmental and social impacts.
- Better understand the kinds and concepts of the proposed sustainability aspects with the help of sub-criteria assigned to upper-level criteria and their definitions.
- Adjust the 3$^{rd}$ and 4$^{th}$ levels of the criteria tree, by adding new criteria, removing or renaming existing criteria. Also, re-definitions and introduction of new metrics and indicators for the 4$^{th}$ level criteria are possible, so that the SPE model acts as a platform for researchers to build upon.
- Perceive how conceptual models can be turned into solid SPE analytical frameworks by integrating numerical methods, such as operations research techniques. The techniques utilized are not extremely complicated to facilitate data gathering and processing.
- Facilitate the evaluation of subjective criteria (e.g. social aspects of sustainability) with the help of multiple experts through GDM. This subjectivity is a major challenge in SPE, which can be overcome by either using numerical analysis methods, or by simplifying the SPE problem into a descriptive verbal communication and public relations activity.
- Guide stakeholders about which data to collect for a thorough and successful SPE practice. These data support the function of the proposed framework and provide extensive information for business managers to take decisions in many different areas, as well as reporting their activities in a structured manner.
- Calculate both criteria-specific performance and the overall sustainability score for one or more entity, which can then be used for monitoring, reporting, comparison and benchmarking purposes by various players (e.g. NGOs, financial institutions, investors, governments, municipalities etc.).

- Make a balanced assessment of planned or ongoing (implemented) operations by taking all economic, environmental and social dimensions into account without largely disregarding any issue.
- Modify the SPE model with different analytical tools other than AHP and VIKOR to optimize it for specific needs, objectives and industries. Since each criterion has 2 to 5 sub-criteria, computational procedures are very suitable for many MCDM techniques.
- Use the SPE model completely, or partially, depending on the intended analysis depth, availability of time and experts, objective of the decision-making problem etc. For instance, the first 2 or 3 levels of the criteria-tree can separately be used without any methodological problems. The 4$^{th}$ level criteria would even support the experts in better understanding possible sustainability implications. Similarly, only one main branch of the model can be used. For instance, the social performance of a company can be captured by only using this branch with the help of 2, 3 or 4 layers of criteria, as desired.
- Convert the framework into a technical tool (e.g. software, handbook, questionnaire etc.) for sustainability reporting initiatives for industries, supply chains etc. All suppliers in a supply chain, for instance, can collect the same type of information and feed these data into a common system to eventually obtain their aggregate sustainability score, with or without minimum thresholds, improvement requirements etc.
- Develop the capacity of sustainability experts and companies to better deal with sustainability related challenges by gaining insight about which drivers cause what kind of impacts (e.g. with sensitivity analysis). Education and knowhow development can enhance operations' sustainability in the long term. These efforts can be strengthened by academia.
- Use the proposed framework as a sustainability index for well-defined environments, depending on the willingness of participants for disclosure. For instance, the ultimate VIKOR sustainability performance scores can be used as a 'corporate sustainability score' for stock exchanges, investment funds, development banks, policy makers, NGOs and researchers for inclusion/exclusion in green funds, stock exchange listings, lending decisions, interest rates, fees and penalties, incentive mechanisms, public relations, sustainability awards, green product labelling schemes etc.

These steps are educative. Continuously collected data and newly acquired knowledge can enhance the efficiency and value of business operations. This gradual knowhow-focused and data-intensive corporate improvement can lead to best practices, replicability effects and self-sustaining activities even if earlier-adopted sustainability actions are later discontinued, thanks to more capable human resources and internal voluntary/obligatory SPE teams and systems. This framework can add business value to sustainability accounting, monitoring and reporting activities.

This framework's strength lies in its ability to gather multiple inputs and generate one numerical output for each entity (e.g. company, energy project etc.). Thus, business managers are armed with a more uniform, less subjective and methodologically sound way of sustainability evaluation. These evaluations can be renewed periodically over time. Eventually, one single number can be attributed to economic, environmental and social performance each, and the overall sustainability as a whole. This is a convenient way for public relations in communicating simple messages to higher managements, as well as wide audiences.

Sustainability impacts differ considerably across industries and locations. The evaluation factors and their priorities will therefore have to be modified for different uses, but shall converge in the same region and industry. The framework's criteria can be reselected and re-evaluated to highlight the aggregated differences of perspectives of different stakeholder groups. These differences can be relatively easily captured with this framework as a strategic management tool.

A second managerial perspective is VIKOR's compromise function. The proposed method is not a simple additive aggregation tool. It proposes those alternatives that have the maximum sustainability performance at the beneficial criteria, and the minimum score at the cost criteria (e.g. those factors that work in the adverse direction) by considering the weights of these benefit and cost criteria. If the resulting utility values are very close to each other, then VIKOR offers a set of compromise solutions, in lieu of naming the highest score as the most sustainable. This aspect of VIKOR implies motivational opportunities for 'laggers' to improve their sustainability scores closer to the best performers in a competitive but constructive manner. If the framework gives a compromise set, then all those alternatives included in this set are proposed as best-performers. In other words, the selection of VIKOR is particularly suitable for the subjective and popular character of sustainability, as the sustainability impacts of concretely-defined options can be improved with protective measures.

Institutional, industrial and academic users of the framework can adjust the criteria and their weights according to their needs. If one or more criterion is undesired, or if the specific objective requires critical new factors to be evaluated, then the 3rd and 4th level criteria can be replaced as seen appropriate. Although its applicability is only tested and demonstrated in the energy project selection, principally there is no considerable barrier to extend it to other industries (e.g. product sustainability, supply chains, countries etc.). The usefulness of the framework also stems from its ability to use it partially. Therefore, the proposed framework can also be perceived as the collection of individual economic, environmental and social performance evaluation frameworks by their own.

This SPE framework can be used for the following functions:

- Forecasting the sustainability of different companies, project designs, products or supply chains in advance, as a decision-making support tool for choosing which one to realize, and perhaps to align business objectives with sustainability performance.
- Repeating the SPE evaluation periodically (e.g. annually) for a pre-defined portfolio of companies, projects etc. under operation. This can help its users to monitor their sustainability over years. Overall or criteria-specific performance can be linked to sustainability targets.
- Comparing different stakeholder approaches and perspectives towards sustainability performance by re-weighing and re-evaluating the same companies, projects etc. with different decision committees.

This chapter discussed the theoretical and managerial implications of the proposed framework.

# 8 CONCLUSION AND PERSPECTIVES

Sustainability has become a key concern for most of the world today. Air pollution, climate change, biodiversity and diminishing water resources have become ordinary concepts of daily life. Individuals, businesses and academia are increasingly aware of the unsustainable nature of today's way of production and consumption patterns and try to come up with concrete solutions and measures to protect economic welfare, social equity and ecosystems' carrying capacity. In the Anthropocene, the conventional business focus on economic profitability is over, while there is still no consensus how to balance environmental and social impacts.

As the management thinker Peter Drucker quotes, 'if you cannot measure it, you cannot manage it'. This also applies to sustainable development. A common definition does not exist on what the sustainability concept shall include, which information to collect in order to account for its different aspects, and whether and how to fuse these data to balance its different perspectives and come up with measures. In this study, it is proposed that this deficiency is partly attributable to the lack of adequate SPE frameworks and an effective solution is offered to fill this scientific and practical gap.

Economic, environmental and social dimensions of business activities are closely bound to each other. Today, from environmental permits to employment laws and accounting standards, there are various obligatory conditions to run a business. More than these mandatory requirements, there are countless voluntary actions that business choose to implement to strengthen their operations and their sustained continuity. The interactions and linkages among these activities are extremely difficult to model. These economic, environmental and social factors are to be satisfied simultaneously in almost every case, while how to do so remains the bigger mystery. These parameters are usually conflicting, meaning that there is mostly no one single solution that maximizes all the objectives at once.

Business operations consist of large numbers of everyday decisions; groups of managers assess many different options for a particular need and decide on a feasible option among available solution alternatives by considering conflicting factors. This is a demanding and complicated process. The poorly-defined concept of sustainability and what is should really cover adds to these complications, although many firms attempt to monitor, report and compare their overall sustainability performance with the help of different methods. The business world needs a standard and flexible SPE framework as a standalone tool to understand which aspects constitute their sustainability performance, how to distinguish the more important decision factors from minor criteria, and how to map the sustainability consequences of their activities.

In this study, a series of research questions are asked and their answers are sought. This search started with the topic of what is understood under SPE in terms of goal, scope and boundaries, then continued with which aspects shall be covered, and then how these aspects shall be transformed into criteria and their structure. Once this criteria structure is developed, the search moved on to how to determine the importance of these criteria in the overall problem, and also how to determine the alternatives' performance on each of these criteria. The last question was how to combine these criteria-specific alternative evaluations into meaningful conclusions.

This study presents a generic and industry-adaptable, multi-layered conceptual criteria-tree and combines it with two MCDM techniques, AHP and VIKOR in a GDM environment. This preference of MCDM methods enables its business and academic users to collect numerical input from multiple experts for each of the criterion's overall weight, as well as each alternative's performance score. In this setting, AHP is deployed with GDM to calculate the comparative and overall priorities of the decision criteria. Then, VIKOR is applied to judge available alternatives for each of their criteria and then select the one(s) with the highest combined sustainability score(s). GDM is particularly beneficial in overcoming the bias that one single decision maker brings to decision-making problems.

This framework has many potential uses and benefits. Its adaptable nature enables users to apply the SPE model as it is, or by adding and removing suitable criteria. Users can also apply the first 2 or 3 levels, or only one of its 3 main dimensions. This makes the proposed framework a general platform for many potential industrial and academic uses. The AHP and VIKOR techniques are able to adequately gather and process data for first identifying the criteria weights and then to calculate their sustainability performance in a relatively straight-forward and clearly-defined computational steps. The framework generates numeric outputs, which can be used for many different purposes by various stakeholders. This generic and novel approach can be effectively used for monitoring the current state and the progress of one or more companies, projects, products or supply chains in operation, or for projecting their sustainability impacts beforehand at the design phase. These comparisons can also be used for benchmarking, public disclosure, stock exchange listings, investment decisions, sustainability targeting, compliance with obligatory and voluntary programs etc. Therefore, the users and uses of the framework are multifold. The framework is tested in the energy industry as an application area. The results suggest that it is easily and effectively applicable, and for energy project selection it provides superior decision-making support.

This study is unique in multiple ways. The proposed SPE model is exceptionally original in its 4-level criteria structure that consists of 3 basic dimensions, distributed over 12 2$^{nd}$ level criteria, 37 3$^{rd}$ level criteria and 107 4$^{th}$ level criteria in total. It is an expert-validated model that is optimized for integrating with MCDM techniques with quantitative input. Even the lowest level of criteria can be extended by assigning them with additional metrics and indicators. It provides a wide thematic coverage in a very structured and hierarchical manner based on the three main dimensions of sustainability, which is a recognized and easily-understood way of perceiving sustainability. The added flexibility and adaptability of the model strengthens its scientific value, as it can be used by omitting lower levels or its main branches. There is no comparable conceptual SPE model in literature or business world that can comparably capture the sustainability performance with such generic and exhaustive coverage. The model is extended into an analytical framework by integrating well-defined MCDM and GDM methods, so that it can be applied individually without additional methods or criteria. Since the original criteria are balanced over the three dimensions of sustainability and in very suitable numbers for MCDM methods, it can also be modified with other analytical techniques. VIKOR's compromise set solution feature is particularly valuable in this setting, since sustainability is a subjective and qualitative practice, where similar performance scores shall be awarded in a compromise set approach. This analytical structure allows experts' inputs to be collected and processed in a straightforward manner. Two real case studies have demonstrated the applicability of the framework for different approaches. Another scientific contribution comes from its application area of energy projects. This distinction of energy generation technologies and concrete energy projects with similar scales is an innovative element of this framework. In other words, the framework is valuable because it offers a complete and directly applicable framework for both academics and businesses for energy project selection, as well as other uses, which is open to further development. The application provides a developing country perspective, where energy demand is rapidly expanding. Also, AHP and VIKOR have so far not been applied before to evaluate the environmental performance of WtE project alternatives. New criteria definitions can help actors to better understand sustainability concepts. Thus, the model, the framework structure and the case studies all present academic contributions.

This study is established on an in-depth literature review, intensive involvement of three different groups of sustainability experts for both model validation and case studies. Although the proposed framework offers the business world and academia considerable innovative options, it is, and cannot be the ultimate solution for accounting for sustainability for every need. Sustainability understanding also changes from expert to expert. The needs of businesses can also vary for different geographies, market settings and sectors. The proposed framework is based on crisp numbers. As a future research perspective, the model can be extended to the fuzzy environment, or modified with techniques other than AHP-VIKOR to gain other perspectives. Also, AHP assumes independent criteria, presenting another future research area. The extension and testing of this framework in industries other than energy can also demonstrate how useful it can be for different applications, offering researchers new opportunities. This study sets the foundation of a systematic, multi-disciplinary framework for investigating a research field that is not yet fully explored. This makes it a very promising contribution to decision-making processes both for scientific literature and businesses.

# 9 REFERENCES


Acquaye A, Feng K, Oppon E, Salhi S, Ibn-Mohammed T, Genovese A, and Hubacek K (2017) Measuring the environmental sustainability performance of global supply chains: A multi-regional input-output analysis for carbon, sulphur oxide and water footprints. *J Environ Manage* 187:571–585.

Aczél J, and Saaty TL (1983) Procedures for synthesizing ratio judgements. *J Math Psychol* 27:93–102.

Adams CA, and McNicholas P (2007) Making a difference: Sustainability reporting, accountability and organisational change. *Account Audit Account J* 20:382–402.

Aghajani Mir M, Taherei Ghazvinei P, Sulaiman NMN, Basri NEA, Saheri S, Mahmood NZ, Jahan A, Begum RA, and Aghamohammadi N (2016) Application of TOPSIS and VIKOR improved versions in a multi criteria decision analysis to develop an optimized municipal solid waste management model. *J Environ Manage* 166:109–115.

Ahi P, and Searcy C (2015) Assessing sustainability in the supply chain: A triple bottom line approach. *Appl Math Model* 2882–2896.

Akadiri PO, Olomolaiye PO, and Chinyio EA (2013) Multi-criteria evaluation model for the selection of sustainable materials for building projects. *Autom Constr* 30:113–125.

Allenby BR (1999) *Industrial ecology: policy framework and implementation*, Prentice Hall.

Allesch A, and Brunner PH (2014) Assessment methods for solid waste management: A literature review. *Waste Manag Res* 32:461–473.

Alves de Albuquerque G, Maciel P, Lima RMF, and Magnani F (2013) Strategic and Tactical Evaluation of Conflicting Environment and Business Goals in Green Supply Chains. *IEEE Trans Syst Man Cybern Syst* 43:1013–1027.

Amui LBL, Jabbour CJC, de Sousa Jabbour ABL, and Kannan D (2017) Sustainability as a dynamic organizational capability: a systematic review and a future agenda toward a sustainable transition. *J Clean Prod* 142, Part 1:308–322.

Andriantiatsaholiniaina LA, Kouikoglou VS, and Phillis YA (2004) Evaluating strategies for sustainable development: fuzzy logic reasoning and sensitivity analysis. *Ecol Econ* 48:149–172.

Artiach T, Lee D, Nelson D, and Walker J (2010) The determinants of corporate sustainability performance. *Account Finance* 50:31–51.

Atmaca E, and Basar HB (2012) Evaluation of power plants in Turkey using Analytic Network Process (ANP). *Energy* 44:555–563.

Awasthi A, Chauhan SS, and Goyal S (2010) A fuzzy multicriteria approach for evaluating environmental performance of suppliers. *Int J Prod Econ* 126:370–378.

Babcicky P (2013) Rethinking the Foundations of Sustainability Measurement: The Limitations of the Environmental Sustainability Index (ESI). *Soc Indic Res* 113:133–157.

Balat H (2010) Prospects of biofuels for a sustainable energy future: a critical assessment. *Energy Educ Sci Technol Part -Energy Sci Res* 24:85–111.

Barata J, Quelhas O, Costa H, Gutierrez R, de Jesus Lameira V, and Meiriño M (2014) Multi-Criteria Indicator for Sustainability Rating in Suppliers of the Oil and Gas Industries in Brazil. *Sustainability* 6:1107–1128.

Barnett J, Lambert S, and Fry I (2008) The Hazards of Indicators: Insights from the Environmental Vulnerability Index. *Ann Assoc Am Geogr* 98:102–119.

Bartelmus P (2010) Use and usefulness of sustainability economics. *Ecol Econ* 69:2053–2055.

Beccali M, Cellura M, and Mistretta M (2003) Decision-making in energy planning. Application of the Electre method at regional level for the diffusion of renewable energy technology. *Renew Energy* 28:2063–2087.

Begić F, and Afgan NH (2007) Sustainability assessment tool for the decision making in selection of energy system—Bosnian case. *Energy* 32:1979–1985.

Belgiorno V, De Feo G, Della Rocca C, and Napoli RMA (2003) Energy from gasification of solid wastes. *Waste Manag* 23:1–15.

Berardi U (2012) Sustainability Assessment in the Construction Sector: Rating Systems and Rated Buildings. *Sustain Dev* 20:411–424.

Bilbao-Terol A, Arenas-Parra M, and Cañal-Fernández V (2012) A fuzzy multi-objective approach for sustainable investments. *Expert Syst Appl* 39:10904–10915.

Böhringer C, and Jochem PEP (2007) Measuring the immeasurable — A survey of sustainability indices. *Ecol Econ* 63:1–8.

Boiral O, and Henri J-F (2015) Is Sustainability Performance Comparable? A Study of GRI Reports of Mining Organizations. *Bus Soc* 0007650315576134.

Bottani E, Gentilotti MC, and Rinaldi M (2017) A Fuzzy Logic-Based Tool for the Assessment of Corporate Sustainability: A Case Study in the Food Machinery Industry. *Sustainability* 9:583.

Bove R, and Lunghi P (2006) Electric power generation from landfill gas using traditional and innovative technologies. *Energy Convers Manag* 47:1391–1401.

Brandenburg M, Govindan K, Sarkis J, and Seuring S (2014) Quantitative models for sustainable supply chain management: Developments and directions. *Eur J Oper Res* 233:299–312.

Brown HS, de Jong M, and Levy DL (2009) Building institutions based on information disclosure: lessons from GRI's sustainability reporting. *J Clean Prod* 17:571–580.

Burton J, and Hubacek K (2007) Is small beautiful? A multicriteria assessment of small-scale energy technology applications in local governments. *Energy Policy* 35:6402–6412.

Büyüközkan G, and Berkol Ç (2011) Designing a sustainable supply chain using an integrated analytic network process and goal programming approach in quality function deployment. *Expert Syst Appl* 38:13731–13748.

Büyüközkan G, and Çifçi G (2012) A new incomplete preference relations based approach to quality function deployment. *Inf Sci* 206:30–41.

Büyüközkan G, and Çifçi G (2011a) A novel fuzzy multi-criteria decision framework for sustainable supplier selection with incomplete information. *Comput Ind* 62:164–174.

Büyüközkan G, and Çifçi G (2013) An integrated QFD framework with multiple formatted and incomplete preferences: A sustainable supply chain application. *Appl Soft Comput* 13:3931–3941.

Büyüközkan G, and Çifçi G (2011b) Evaluation of the green supply chain management practices: a fuzzy ANP approach. *Prod Plan Control* 23:405–418.

Büyüközkan G, and Görener A (2015) Evaluation of product development partners using an integrated AHP-VIKOR model. *Kybernetes* 44:220–237.

Büyüközkan G, and Güleryüz S (2014) A new GDM based AHP framework with linguistic interval fuzzy preference relations for renewable energy planning. *J Intell Fuzzy Syst* 27:3181–3195.

Büyüközkan G, and Güleryüz S (2016) An integrated DEMATEL-ANP approach for renewable energy resources selection in Turkey. *Int J Prod Econ* 182:435–448.

Büyüközkan G, and Karabulut Y (2017) Energy project performance evaluation with sustainability perspective. *Energy* 119:549–560.

Carlsson C, Ehrenberg D, Eklund P, Fedrizzi M, Gustafsson P, Lindholm P, Merkuryeva G, Riissanen T, and G.S. Ventre A (1992) Consensus in distributed soft environments. *Eur J Oper Res* 61:165–185.

Castellani V, and Sala S (2010) Sustainable performance index for tourism policy development. *Tour Manag* 31:871–880.

Cavallaro F, and Ciraolo L (2005) A multicriteria approach to evaluate wind energy plants on an Italian island. *Energy Policy* 33:235–244.

CDP (2014) Carbon Disclosure Project.

Chaaban FB, Mezher T, and Ouwayjan M (2004) Options for emissions reduction from power plants: an economic evaluation. *Int J Electr Power Energy Syst* 26:57–63.

Chardine-Baumann E, and Botta-Genoulaz V (2014) A framework for sustainable performance assessment of supply chain management practices. *Comput Ind Eng* 76:138–147.

Chatzimouratidis AI, and Pilavachi PA (2008) Multicriteria evaluation of power plants impact on the living standard using the analytic hierarchy process. *Energy Policy* 36:1074–1089.

Chatzimouratidis AI, and Pilavachi PA (2007) Objective and subjective evaluation of power plants and their non-radioactive emissions using the analytic hierarchy process. *Energy Policy* 35:4027–4038.

Chatzimouratidis AI, and Pilavachi PA (2009) Technological, economic and sustainability evaluation of power plants using the Analytic Hierarchy Process. *Energy Policy* 37:778–787.

Chee Tahir A, and Darton RC (2010) The Process Analysis Method of selecting indicators to quantify the sustainability performance of a business operation. *J Clean Prod* 18:1598–1607.

Cheng H, and Hu Y (2010) Municipal solid waste (MSW) as a renewable source of energy: Current and future practices in China. *Bioresour Technol* 101:3816–3824.

Cheng S, Chan CW, and Huang GH (2002) Using Multiple Criteria Decision Analysis for Supporting Decisions of Solid Waste Management. *J Environ Sci Health Part A* 37:975–990.

Cherchye L, and Kuosmanen T (2004) *Benchmarking sustainable development: A synthetic meta-index approach*, Research Paper, UNU-WIDER, United Nations University (UNU).

Chimeli AB, and Braden JB (2009) A capital scarcity theory of the environmental Kuznets curve. *Environ Dev Econ* 14:541.

Chuang S-P (2014) Assessing and improving the green performance using a compound approach. *Flex Serv Manuf J* 26:69–91.

Cobb C, Schuster D, Beloff B, and Tanzil D (2014) *Benchmarking Sustainability*.

Contreras F, Hanaki K, Aramaki T, and Connors S (2008) Application of analytical hierarchy process to analyze stakeholders preferences for municipal solid waste management plans, Boston, USA. *Resour Conserv Recycl* 52:979–991.

Costa R, and Menichini T (2013) A multidimensional approach for CSR assessment: The importance of the stakeholder perception. *Expert Syst Appl* 40:150–161.

Čuček L, Klemeš JJ, and Kravanja Z (2012) A Review of Footprint analysis tools for monitoring impacts on sustainability. *J Clean Prod* 34:9–20.

Dai C, Zhang X, Wang E, Liu Z, and Tang S (2012) Study on the Evaluation of Renewable Energy Technologies Based on the VIKOR Method. *Sci Decis Mak* 1:008.

Dai J, and Blackhurst J (2012) A four-phase AHP–QFD approach for supplier assessment: a sustainability perspective. *Int J Prod Res* 50:5474–5490.

de Almeida Guimarães V, and Leal Junior IC (2017) Performance assessment and evaluation method for passenger transportation: a step toward sustainability. *J Clean Prod* 142, Part 1:297–307.

Deloitte and Touche, and BCSD (1992) *Business strategy for sustainable development: Leadership and accountability for the '90s.*, DIANE Publishing Company.

Demirbas A (2011) Waste management, waste resource facilities and waste conversion processes. *Energy Convers Manag* 52:1280–1287.

Dias-Sardinha I, and Reijnders L (2001) Environmental performance evaluation and sustainability performance evaluation of organizations: an evolutionary framework. *Eco-Manag Audit* 8:71–79.

Ding GKC (2005) Developing a multicriteria approach for the measurement of sustainable performance. *Build Res Inf* 33:3–16.

Ding GKC (2008) Sustainable construction—The role of environmental assessment tools. *J Environ Manage* 86:451–464.

Dinh LTT, Guo Y, and Mannan MS (2009) Sustainability evaluation of biodiesel production using multicriteria decision-making. *Environ Prog Sustain Energy* 28:38–46.

DJSI Family Overview (2014).

Doukas H, Karakosta C, and Psarras J (2010) Computing with words to assess the sustainability of renewable energy options. *Expert Syst Appl* 37:5491–5497.

Duckstein L, and Opricovic S (1980) Multiobjective optimization in river basin development. *Water Resour Res* 16:14–20.

Düğenci M (2016) A new distance measure for interval valued intuitionistic fuzzy sets and its application to group decision making problems with incomplete weights information. *Appl Soft Comput* 41:120–134.

Epstein MJ, and Roy M-J (2001) Sustainability in Action: Identifying and Measuring the Key Performance Drivers. *Long Range Plann* 34:585–604.

Epstein MJ, and Wisner PS (2001) Using a Balanced Scorecard to Implement Sustainability. *Environ Qual Manag* 11:1–10.

Erol I, Cakar N, Erel D, and Sari R (2009) Sustainability in the Turkish retailing industry. *Sustain Dev* 17:49–67.

Erol I, Sencer S, and Sari R (2011) A new fuzzy multi-criteria framework for measuring sustainability performance of a supply chain. *Ecol Econ* 70:1088–1100.

Escrig-Olmedo E, Fernández-Izquierdo M-Á, Muñoz-Torres M-J, and Rivera-Lirio J-M (2015) Fuzzy TOPSIS for an Integrative Sustainability Performance Assessment: A Proposal for Wearing Apparel Industry, in *Scientific Methods for the Treatment of Uncertainty in Social Sciences* (Gil-Aluja J, Terceño-Gómez A, Ferrer-Comalat JC, Merigó-Lindahl JM, and Linares-Mustarós S eds) pp 31–39, Springer International Publishing.

Ferreira LMDF, and Silva C (2016) Integrating Sustainability Metrics in the Supply Chain Performance Measurement System, in *Multiple Helix Ecosystems for Sustainable Competitiveness* (Peris-Ortiz M, Ferreira JJ, Farinha L, and Fernandes NO eds) pp 113–132, Springer International Publishing.

Feyzioglu O, Ersoy MS, and Buyukozkan G (2008) Multi-criteria selection of alternatives for sustainable urban transportation, in *IEEE International Conference on Industrial Engineering and Engineering Management, 2008. IEEM 2008* pp 395–399.

Figge F, and Hahn T (2004) Sustainable Value Added—measuring corporate contributions to sustainability beyond eco-efficiency. *Ecol Econ* 48:173–187.

Fowler SJ, and Hope C (2007) A Critical Review of Sustainable Business Indices and their Impact. *J Bus Ethics* 76:243–252.

Frangopoulos CA, and Keramioti DE (2010) Multi-Criteria Evaluation of Energy Systems with Sustainability Considerations. *Entropy* 12:1006–1020.

Fuente A de la, Armengou J, Pons O, and Aguado A (2017) Multi-criteria decision-making model for assessing the sustainability index of wind-turbine support systems: application to a new precast concrete alternative. *J Civ Eng Manag* 23:194–203.

Gal T, Stewart T, and Hanne T (2013) *Multicriteria decision making: advances in MCDM models, algorithms, theory, and applications*, Springer Science & Business Media.

Garcia S, Cintra Y, Torres R de CSR, and Lima FG (2016) Corporate sustainability management: a proposed multi-criteria model to support balanced decision-making. *J Clean Prod* 136, Part A:181–196.

Garg RK, Agrawal VP, and Gupta VK (2007) Coding, evaluation and selection of thermal power plants – A MADM approach. *Int J Electr Power Energy Syst* 29:657–668.

Gasparatos A, El-Haram M, and Horner M (2008) A critical review of reductionist approaches for assessing the progress towards sustainability. *Environ Impact Assess Rev* 28:286–311.

Gatti L, and Seele P (2013) Evidence for the prevalence of the sustainability concept in European corporate responsibility reporting. *Sustain Sci* 9:89–102.

Ghadimi P, Azadnia AH, Mohd Yusof N, and Mat Saman MZ (2012) A weighted fuzzy approach for product sustainability assessment: a case study in automotive industry. *J Clean Prod* 33:10–21.

Ghadimi P, Dargi A, and Heavey C (2017) Sustainable supplier performance scoring using audition check-list based fuzzy inference system: A case application in automotive spare part industry. *Comput Ind Eng* 105:12–27.

Gjølberg M (2009) Measuring the immeasurable?: Constructing an index of CSR practices and CSR performance in 20 countries. *Scand J Manag* 25:10–22.

Global Reporting Initiative (2013) *Global Reporting Initiative (GRI) 4 - Reporting Principles and Standard Disclosures*, Amsterdam.

Goldberg E (2002) *Aggregated Environmental Indices: Review of Aggregation Methodologies in Use*, OECD, Paris, France.

Govindan K, Khodaverdi R, and Jafarian A (2013) A fuzzy multi criteria approach for measuring sustainability performance of a supplier based on triple bottom line approach. *J Clean Prod* 47:345–354.

Goyal P, Rahman Z, and Kazmi AA (2013) Corporate sustainability performance and firm performance research: Literature review and future research agenda. *Manag Decis* 51:361–379.

Griggs D, Stafford-Smith M, Gaffney O, Rockström J, Öhman MC, Shyamsundar P, Steffen W, Glaser G, Kanie N, and Noble I (2013) Sustainable development goals for people and planet. *Nature* 495:305–307.

Grossman GM, and Krueger AB (1995) Economic Growth and the Environment. *Q J Econ* 110:353–377.

GS Foundation (2012) Gold Standard.

Guillez A (2009) BASF: Eco-Efficiency and SEE-Balance for sustainable developments.

Gunasekaran A, Irani Z, and Papadopoulos T (2014) Modelling and analysis of sustainable operations management: certain investigations for research and applications. *J Oper Res Soc* 65:806–823.

Hansen EG, and Schaltegger S (2016) The Sustainability Balanced Scorecard: A Systematic Review of Architectures. *J Bus Ethics* 133:193–221.

Haralambopoulos DA, and Polatidis H (2003) Renewable energy projects: structuring a multi-criteria group decision-making framework. *Renew Energy* 28:961–973.

Hendriksen B, Weimer J, and McKenzie M (2016) Approaches to quantify value from business to society: Case studies of KPMG's true value methodology. *Sustain Account Manag Policy J* 7:474–493.

Heravi G, Fathi M, and Faeghi S (n.d.) Evaluation of sustainability indicators of industrial buildings focused on petrochemical projects. *J Clean Prod*, doi: 10.1016/j.jclepro.2015.06.133.

Herrera F, Herrera-Viedma E, and Verdegay JL (1995) A sequential selection process in group decision making with a linguistic assessment approach. *Inf Sci* 85:223–239.

Herva M, and Roca E (2013) Review of combined approaches and multi-criteria analysis for corporate environmental evaluation. *J Clean Prod* 39:355–371.

Hsu C-W, Lee W-H, and Chao W-C (2013) Materiality analysis model in sustainability reporting: a case study at Lite-On Technology Corporation. *J Clean Prod* 57:142–151.

Hsueh S-L, and Yan M-R (2013) A Multimethodology Contractor Assessment Model for Facilitating Green Innovation: The View of Energy and Environmental Protection. *Sci World J* 2013:e624340.

Hu AH, Chen L-T, Hsu C-W, and Ao J-G (2011) An Evaluation Framework for Scoring Corporate Sustainability Reports in Taiwan. *Environ Eng Sci* 28:843–858.

Hubbard G (2009) Measuring organizational performance: beyond the triple bottom line. *Bus Strategy Environ* 18:177–191.

Hung M-L, Ma H, and Yang W-F (2007) A novel sustainable decision making model for municipal solid waste management. *Waste Manag* 27:209–219.

Hutchins MJ, and Sutherland JW (2008) An exploration of measures of social sustainability and their application to supply chain decisions. *J Clean Prod* 16:1688–1698.

IChemE (2002) *The Sustainability Metrics*, The Institution of Chemical Engineers, Rugby.

Ingwersen W, Cabezas H, Weisbrod AV, Eason T, Demeke B, Ma X, Hawkins TR, Lee S-J, Bare JC, and Ceja M (2014) Integrated Metrics for Improving the Life Cycle Approach to Assessing Product System. *Sustainability* 6:1386–1413.

Iniyan S, and Sumathy K (2000) An optimal renewable energy model for various end-uses. *Energy* 25:563–575.

International Energy Agency (ed) (2015) *World energy outlook 2016*, OECD, Paris.

*International Labour Standards* (2014) , ILO.

Invest in Turkey (2016) Energy and Renewables.

*Investing in Renewable Energy: The GEF Experience* (2009) , Global Environmental Facility.

Jawahar N, Pandian GS, Gunasekaran A, and Subramanian N (2015) An Optimization Model for Sustainability Program. *Ann Oper Res* 1–37.

Jayal AD, Badurdeen F, Dillon Jr. OW, and Jawahir IS (2010) Sustainable manufacturing: Modeling and optimization challenges at the product, process and system levels. *CIRP J Manuf Sci Technol* 2:144–152.

Jerry Ho W-R, Tsai C-L, Tzeng G-H, and Fang S-K (2011) Combined DEMATEL technique with a novel MCDM model for exploring portfolio selection based on CAPM. *Expert Syst Appl* 38:16–25.

Jüttner U, and Maklan S (2013) Supply chain resilience in the global financial crisis: an empirical study. *Supply Chain Manag Int J*, doi: 10.1108/13598541111139062.

Kabak M, and Dağdeviren M (2014) Prioritization of renewable energy sources for Turkey by using a hybrid MCDM methodology. *Energy Convers Manag* 79:25–33.

Kahraman C, and Kaya İ (2010) A fuzzy multicriteria methodology for selection among energy alternatives. *Expert Syst Appl* 37:6270–6281.

Kahraman C, Kaya İ, and Cebi S (2009) A comparative analysis for multiattribute selection among renewable energy alternatives using fuzzy axiomatic design and fuzzy analytic hierarchy process. *Energy* 34:1603–1616.

Kajikawa Y, Inoue T, and Goh TN (2011) Analysis of building environment assessment frameworks and their implications for sustainability indicators. *Sustain Sci* 6:233–246.

Kamali M, and Hewage K (2017) Development of performance criteria for sustainability evaluation of modular versus conventional construction methods. *J Clean Prod* 142, Part 4:3592–3606.

Karger CR, and Hennings W (2009) Sustainability evaluation of decentralized electricity generation. *Renew Sustain Energy Rev* 13:583–593.

Karmperis AC, Aravossis K, Tatsiopoulos IP, and Sotirchos A (2013) Decision support models for solid waste management: Review and game-theoretic approaches. *Waste Manag* 33:1290–1301.

Kaya T, and Kahraman C (2011) Multicriteria decision making in energy planning using a modified fuzzy TOPSIS methodology. *Expert Syst Appl* 38:6577–6585.

Kaya T, and Kahraman C (2010) Multicriteria renewable energy planning using an integrated fuzzy VIKOR & AHP methodology: The case of Istanbul. *Energy* 35:2517–2527.

Keijzers G (2002) The transition to the sustainable enterprise. *J Clean Prod* 10:349–359.

Khan S, and Faisal MN (2008) An analytic network process model for municipal solid waste disposal options. *Waste Manag* 28:1500–1508.

Kim DB, Shin S-J, Shao G, and Brodsky A (2015) A decision-guidance framework for sustainability performance analysis of manufacturing processes. *Int J Adv Manuf Technol* 78:1455–1471.

Koellner T, Weber O, Fenchel M, and Scholz R (2005) Principles for sustainability rating of investment funds. *Bus Strategy Environ* 14:54–70.

Kolak Oİ, Akin D, Birbil SI, Feyzioglu O, and Noyan N (2011) Multicriteria sustainability evaluation of transport networks for selected European countries, in *Proceedings of the World Congress on Engineering 2011* p.

Kolak OI, and Feyzioglu O (2016) Sustainability Performance Evaluation of Transportation Networks Using MCDM Analysis, IAENG, International Association of Engineers, Hong Kong.

Köne AÇ, and Büke T (2007) An Analytical Network Process (ANP) evaluation of alternative fuels for electricity generation in Turkey. *Energy Policy* 35:5220–5228.

Kowalski K, Stagl S, Madlener R, and Omann I (2009) Sustainable energy futures: Methodological challenges in combining scenarios and participatory multi-criteria analysis. *Eur J Oper Res* 197:1063–1074.

Krajnc D, and Glavič P (2005) How to compare companies on relevant dimensions of sustainability. *Ecol Econ* 55:551–563.

Krukanont P, and Tezuka T (2007) Implications of capacity expansion under uncertainty and value of information: The near-term energy planning of Japan. *Energy* 32:1809–1824.

Kühnen M, and Hahn R (2015) Social Indicators in Corporate Sustainability Performance Measurement. *Acad Manag Proc* 2015:12108.

Kumar A, Sah B, Singh AR, Deng Y, He X, Kumar P, and Bansal RC (2017) A review of multi criteria decision making (MCDM) towards sustainable renewable energy development. *Renew Sustain Energy Rev* 69:596–609.

Kylili A, Fokaides PA, and Lopez Jimenez PA (2016) Key Performance Indicators (KPIs) approach in buildings renovation for the sustainability of the built environment: A review. *Renew Sustain Energy Rev* 56:906–915.

Labuschagne C, Brent AC, and Van Erck RP (2005) Assessing the sustainability performances of industries. *J Clean Prod* 13:373–385.

Lee AHI, Chen HH, and Kang H-Y (2009) Multi-criteria decision making on strategic selection of wind farms. *Renew Energy* 34:120–126.

Lee K-H, and Farzipoor Saen R (2012) Measuring corporate sustainability management: A data envelopment analysis approach. *Int J Prod Econ* 140:219–226.

Li T, Zhang H, Yuan C, Liu Z, and Fan C (2012) A PCA-based method for construction of composite sustainability indicators. *Int J Life Cycle Assess* 17:593–603.

Liao H, Xu Z, and Zeng X-J (2015) Hesitant Fuzzy Linguistic VIKOR Method and Its Application in Qualitative Multiple Criteria Decision Making. *IEEE Trans Fuzzy Syst* 23:1343–1355.

Liberatore MJ, and Nydick RL (1997) Group Decision Making in Higher Education Using the Analytic Hierarchy Process. *Res High Educ* 38:593–614.

Liu G (2014) Development of a general sustainability indicator for renewable energy systems: A review. *Renew Sustain Energy Rev* 31:611–621.

Liu G, Rasul MG, Amanullah MTO, and Khan MMK (2011) Sustainability Indicator of Renewable Energy System Based on Fuzzy Multi-Criteria Decision Making Methods. *Adv Mater Res* 361–363:1263–1273.

Liu H-C, Wu J, and Li P (2013) Assessment of health-care waste disposal methods using a VIKOR-based fuzzy multi-criteria decision making method. *Waste Manag* 33:2744–2751.

Løken E (2007) Use of multicriteria decision analysis methods for energy planning problems. *Renew Sustain Energy Rev* 11:1584–1595.

Lu LY, Wu C, and Kuo T-C (2007) Environmental principles applicable to green supplier evaluation by using multi-objective decision analysis. *Int J Prod Res* 45:4317–4331.

Maas K, Schaltegger S, and Crutzen N (2016) Integrating corporate sustainability assessment, management accounting, control, and reporting. *J Clean Prod* 136, Part A:237–248.

Maltz E, Bi HH, and Bateman M (2016) Benchmarking sustainability performance: the next step in building sustainable business models. *J Public Aff* n/a-n/a.

Manzini F, Islas J, and Macías P (2011) Model for evaluating the environmental sustainability of energy projects. *Technol Forecast Soc Change* 78:931–944.

Marshall JD, and Toffel MW (2005) Framing the Elusive Concept of Sustainability: A Sustainability Hierarchy. *Environ Sci Technol* 39:673–682.

Mayer AL (2008) Strengths and weaknesses of common sustainability indices for multidimensional systems. *Environ Int* 34:277–291.

McElroy MW, Jorna RJ, and van Engelen J (2008) Sustainability quotients and the social footprint. *Corp Soc Responsib Environ Manag* 15:223–234.

Medel-González F, García-Ávila LF, Salomon VAP, Marx-Gómez J, Hernández CT, Medel-González F, García-Ávila LF, Salomon VAP, Marx-Gómez J, and Hernández CT (2016) Sustainability performance measurement with Analytic Network Process and balanced scorecard: Cuban practical case. *Production* 26:527–539.

MFA (2016) Turkey's Energy Profile and Strategy.

Miller P, de Barros AG, Kattan L, and Wirasinghe SC (2016) Analyzing the sustainability performance of public transit. *Transp Res Part Transp Environ* 44:177–198.

Ministry of Energy and Natural Resources (n.d.).

Moldan B, Janoušková S, and Hák T (2012) How to understand and measure environmental sustainability: Indicators and targets. *Ecol Indic* 17:4–13.

Morhardt JE (2010) Corporate social responsibility and sustainability reporting on the Internet. *Bus Strategy Environ* 19:436–452.

Morioka SN, and de Carvalho MM (2016) A systematic literature review towards a conceptual framework for integrating sustainability performance into business. *J Clean Prod*, doi: 10.1016/j.jclepro.2016.01.104.

Murino T, Romano E, and Santillo LC (2011) Supply chain performance sustainability through resilience function, in *Proceedings of the Winter Simulation Conference* pp 1605–1616, Winter Simulation Conference.

Nardo M, Saisana M, Saltelli A, Tarantola S, Hoffman A, and Giovannini E (2005) *Handbook on Constructing Composite Indicators: Methodology and User Guide*, OECD.

Ness B, Urbel-Piirsalu E, Anderberg S, and Olsson L (2007) Categorising tools for sustainability assessment. *Ecol Econ* 60:498–508.

New Zealand Business Council for Sustainable Development (2003) *Business Guide to a Sustainable Supply Chain*.

Nigim K, Munier N, and Green J (2004) Pre-feasibility MCDM tools to aid communities in prioritizing local viable renewable energy sources. *Renew Energy* 29:1775–1791.

Nikolaou IE, Evangelinos KI, and Allan S (2013) A reverse logistics social responsibility evaluation framework based on the triple bottom line approach. *J Clean Prod* 56:173–184.

Nixon JD, Dey PK, Davies PA, Sagi S, and Berry RF (2014) Supply chain optimisation of pyrolysis plant deployment using goal programming. *Energy* 68:262–271.

Nixon JD, Dey PK, Ghosh SK, and Davies PA (2013) Evaluation of options for energy recovery from municipal solid waste in India using the hierarchical analytical network process. *Energy* 59:215–223.

Norese MF (2006) ELECTRE III as a support for participatory decision-making on the localisation of waste-treatment plants. *Land Use Policy* 23:76–85.

Nunes B, Alamino RC, Shaw D, and Bennett D (2016) Modelling sustainability performance to achieve absolute reductions in socio-ecological systems. *J Clean Prod* 132:32–44.

O'Connell D, Raison J, Hatfield-Dodds S, Braid A, Cowie A, Littleboy A, Wiedmann T, and Clark M (2013) *Designing for Action: Principles of Effective Sustainability Measurement*, World Economic Forum.

Onar SC, Oztaysi B, Otay İ, and Kahraman C (2015) Multi-expert wind energy technology selection using interval-valued intuitionistic fuzzy sets. *Energy* 90, Part 1:274–285.

Onat NC, Gumus S, Kucukvar M, and Tatari O (2016) Application of the TOPSIS and intuitionistic fuzzy set approaches for ranking the life cycle sustainability performance of alternative vehicle technologies. *Sustain Prod Consum* 6:12–25.

Önüt S, Tuzkaya UR, and Saadet N (2008) Multiple criteria evaluation of current energy resources for Turkish manufacturing industry. *Energy Convers Manag* 49:1480–1492.

Opricovic S (1998) Multi-criteria Optimization of Civil Engineering Systems, Faculty of Civil Engineering, Belgrade. *Table II Perform Matrix*.

Opricovic S, and Tzeng G-H (2004) Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS. *Eur J Oper Res* 156:445–455.

Opricovic S, and Tzeng G-H (2007) Extended VIKOR method in comparison with outranking methods. *Eur J Oper Res* 178:514–529.

Pan T-C, and Kao J-J (2009) Inter-generational equity index for assessing environmental sustainability: An example on global warming. *Ecol Indic* 9:725–731.

Paquette R J (n.d.) The Supply Chain Response to Environmental Pressures.

Parra-López C, Calatrava-Requena J, and de-Haro-Giménez T (2008) A systemic comparative assessment of the multifunctional performance of alternative olive systems in Spain within an AHP-extended framework. *Ecol Econ* 64:820–834.

Pask F, Lake P, Yang A, Tokos H, and Sadhukhan J (2017) Sustainability indicators for industrial ovens and assessment using Fuzzy set theory and Monte Carlo simulation. *J Clean Prod* 140, Part 3:1217–1225.

Perrini F, and Tencati A (2006) Sustainability and stakeholder management: the need for new corporate performance evaluation and reporting systems. *Bus Strategy Environ* 15:296–308.

Phillis YA, and Andriantiatsaholiniaina LA (2001) Sustainability: an ill-defined concept and its assessment using fuzzy logic. *Ecol Econ* 37:435–456.

Phillis YA, Kouikoglou VS, and Manousiouthakis V (2010) A Review of Sustainability Assessment Models as System of Systems. *IEEE Syst J* 4:15–25.

Pietersen K (2006) Multiple criteria decision analysis (MCDA): A tool to support sustainable management of groundwater resources in South Africa. *Water SA* 32:119–128.

Pilavachi PA, Stephanidis SD, Pappas VA, and Afgan NH (2009) Multi-criteria evaluation of hydrogen and natural gas fuelled power plant technologies. *Appl Therm Eng* 29:2228–2234.

Pinar M, Cruciani C, Giove S, and Sostero M (2014) Constructing the FEEM sustainability index: A Choquet integral application. *Ecol Indic* 39:189–202.

Pires A, Chang N-B, and Martinho G (2011) An AHP-based fuzzy interval TOPSIS assessment for sustainable expansion of the solid waste management system in Setúbal Peninsula, Portugal. *Resour Conserv Recycl* 56:7–21.

Pohekar SD, and Ramachandran M (2004) Application of multi-criteria decision making to sustainable energy planning—A review. *Renew Sustain Energy Rev* 8:365–381.

Polatidis H, and Haralambopoulos D (2004) Local Renewable Energy Planning: A Participatory Multi-Criteria Approach. *Energy Sources* 26:1253–1264.

Polatidis H, Haralambopoulos DA, Munda G, and Vreeker R (2006) Selecting an appropriate multi-criteria decision analysis technique for renewable energy planning. *Energy Sources Part B* 1:181–193.

Pons O, and de la Fuente A (2013) Integrated sustainability assessment method applied to structural concrete columns. *Constr Build Mater* 49:882–893.

Pope J, Annandale D, and Morrison-Saunders A (2004) Conceptualising sustainability assessment. *Environ Impact Assess Rev* 24:595–616.

Poveda CA, and Elbarkouky MMG (2016) Hybrid process-criterion benchmarking methodology framework to support sustainability performance assessment and reporting. *Int J Sustain Dev World Ecol* 23:278–291.

Rajak S, and Vinodh S (2015) Application of fuzzy logic for social sustainability performance evaluation: a case study of an Indian automotive component manufacturing organization. *J Clean Prod* 108:1184–1192.

Raut R, Cheikhrouhou N, and Kharat M (2017) Sustainability in The Banking Industry: A Strategic Multi-Criterion Analysis. *Bus Strategy Environ* 26:550–568.

Ren J, Manzardo A, Toniolo S, and Scipioni A (2013) Sustainability of hydrogen supply chain. Part I: Identification of critical criteria and cause–effect analysis for enhancing the sustainability using DEMATEL. *Int J Hydrog Energy* 38:14159–14171.

*Renewable Energy & Environmental Technologies* (2013).

Rivera JM, Muñoz MJ, and Moneva JM (2017) Revisiting the Relationship Between Corporate Stakeholder Commitment and Social and Financial Performance. *Sustain Dev* n/a-n/a.

*ROBECOSAM's Corporate Sustainability Assessment Methodology* (2014) , Robecosam.

Rodger JA, and George JA (2017) Triple bottom line accounting for optimizing natural gas sustainability: A statistical linear programming fuzzy ILOWA optimized sustainment model approach to reducing supply chain global cybersecurity vulnerability through information and communications technology. *J Clean Prod* 142, Part 4:1931–1949.

Rodrigues VP, Pigosso DCA, and McAloone TC (2016) Process-related key performance indicators for measuring sustainability performance of ecodesign implementation into product development. *J Clean Prod* 139:416–428.

Rojas-Zerpa JC, and Yusta JM (2015) Application of multicriteria decision methods for electric supply planning in rural and remote areas. *Renew Sustain Energy Rev* 52:557–571.

Roundtable for Product Social Metrics (2016) *Handbook for Product Social Impact Assessment*.

Rowley HV, Peters GM, Lundie S, and Moore SJ (2012) Aggregating sustainability indicators: Beyond the weighted sum. *J Environ Manage* 111:24–33.

Saaty TL (1980) The analytic hierarchy process: planning, priority setting, resources allocation. *McGraw-Hill*.

Sabbas T, Polettini A, Pomi R, Astrup T, Hjelmar O, Mostbauer P, Cappai G, Magel G, Salhofer S, Speiser C, Heuss-Assbichler S, Klein R, and Lechner P (2003) Management of municipal solid waste incineration residues. *Waste Manag* 23:61–88.

San Cristóbal JR (2011) Multi-criteria decision-making in the selection of a renewable energy project in spain: The Vikor method. *Renew Energy* 36:498–502.

Schmidt W-P (2006) Life Cycle Tools within Ford of Europe's Product Sustainability Index. Case Study Ford S-MAX & Ford Galaxy (8 pp). *Int J Life Cycle Assess* 11:315–322.

Schneider A, and Meins E (2012) Two Dimensions of Corporate Sustainability Assessment: Towards a Comprehensive Framework. *Bus Strategy Environ* 21:211–222.

Schöggl J-P, Baumgartner RJ, and Hofer D (2017) Improving sustainability performance in early phases of product design: A checklist for sustainable product development tested in the automotive industry. *J Clean Prod* 140, Part 3:1602–1617.

Schöggl J-P, Fritz MMC, and Baumgartner RJ (2016) Toward supply chain-wide sustainability assessment: a conceptual framework and an aggregation method to assess supply chain performance. *J Clean Prod* 131:822–835.

Searcy C (2012) Corporate Sustainability Performance Measurement Systems: A Review and Research Agenda. *J Bus Ethics* 107:239–253.

Searcy C (2014) Measuring Enterprise Sustainability. *Bus Strategy Environ* n/a-n/a.

Searcy C (2011) Updating corporate sustainability performance measurement systems. *Meas Bus Excell* 15:44–56.

Shaun M. Powell (2011) The nexus between ethical corporate marketing, ethical corporate identity and corporate social responsibility. *Eur J Mark* 45:1365–1379.

Shekdar AV (2009) Sustainable solid waste management: An integrated approach for Asian countries. *Waste Manag* 29:1438–1448.

Shen L, Li Hao J, Tam VW, and Yao H (2007) A checklist for assessing sustainability performance of construction projects. *J Civ Eng Manag* 13:273–281.

Siddique R, Khatib J, and Kaur I (2008) Use of recycled plastic in concrete: A review. *Waste Manag* 28:1835–1852.

Sikdar SK, Sengupta D, and Mukherjee R (2017a) Statistical Algorithms for Sustainability Measurement and Decision Making, in *Measuring Progress Towards Sustainability* pp 153–184, Springer International Publishing.

Sikdar SK, Sengupta D, and Mukherjee R (2017b) Sustainability Measurement for Technology and Business Systems: Use of Currently Available Tools for Quantification, in *Measuring Progress Towards Sustainability* pp 93–127, Springer International Publishing.

Singh AK, and Vinodh S (2017) Modeling and performance evaluation of agility coupled with sustainability for business planning. *J Manag Dev* 36:109–128.

Singh RK, Murty HR, Gupta SK, and Dikshit AK (2012) An overview of sustainability assessment methodologies. *Ecol Indic* 15:281–299.

Singh RK, Murty HR, Gupta SK, and Dikshit AK (2007) Development of composite sustainability performance index for steel industry. *Ecol Indic* 7:565–588.

Singh RP, Tyagi VV, Allen T, Ibrahim MH, and Kothari R (2011) An overview for exploring the possibilities of energy generation from municipal solid waste (MSW) in Indian scenario. *Renew Sustain Energy Rev* 15:4797–4808.

Soltani A, Hewage K, Reza B, and Sadiq R (2015) Multiple stakeholders in multi-criteria decision-making in the context of Municipal Solid Waste Management: A review. *Waste Manag* 35:318–328.

Spangenberg JH, Pfahl S, and Deller K (2002) Towards indicators for institutional sustainability: lessons from an analysis of Agenda 21. *Ecol Indic* 2:61–77.

*Stakeholder Engagement Standard (exposure draft)* (2005) , AccountAbility.

Streimikiene D, Balezentis T, Krisciukaitienė I, and Balezentis A (2012) Prioritizing sustainable electricity production technologies: MCDM approach. *Renew Sustain Energy Rev* 16:3302–3311.

Su J-P, Chiueh P-T, Hung M-L, and Ma H-W (2007) Analyzing policy impact potential for municipal solid waste management decision-making: A case study of Taiwan. *Resour Conserv Recycl* 51:418–434.

Suganthi L, and Williams A (2000) Renewable energy in India — a modelling study for 2020–2021. *Energy Policy* 28:1095–1109.

Székely F, and Knirsch M (2005) Responsible Leadership and Corporate Social Responsibility:: Metrics for Sustainable Performance. *Eur Manag J* 23:628–647.

Tan Y, Ochoa JJ, Langston C, and Shen L (2015) An empirical study on the relationship between sustainability performance and business competitiveness of international construction contractors. *J Clean Prod* 93:273–278.

Tokos H, Pintarič ZN, and Krajnc D (2012) An integrated sustainability performance assessment and benchmarking of breweries. *Clean Technol Environ Policy* 14:173–193.

Topcu YI, and Ulengin F (2004) Energy for the future: An integrated decision aid for the case of Turkey. *Energy* 29:137–154.

Traverso M, Asdrubali F, Francia A, and Finkbeiner M (2012) Towards life cycle sustainability assessment: an implementation to photovoltaic modules. *Int J Life Cycle Assess* 17:1068–1079.

Tsai W-H, and Chou W-C (2009) Selecting management systems for sustainable development in SMEs: A novel hybrid model based on DEMATEL, ANP, and ZOGP. *Expert Syst Appl* 36:1444–1458.

Tseng M-L (2009) Application of ANP and DEMATEL to evaluate the decision-making of municipal solid waste management in Metro Manila. *Environ Monit Assess* 156:181.

Tsoutsos T, Drandaki M, Frantzeskaki N, Iosifidis E, and Kiosses I (2009) Sustainable energy planning by using multi-criteria analysis application in the island of Crete. *Energy Policy* 37:1587–1600.

Tuzkaya G (2013) An intuitionistic fuzzy Choquet integral operator based methodology for environmental criteria integrated supplier evaluation process. *Int J Environ Sci Technol* 10:423–432.

Tzeng G-H, Lin C-W, and Opricovic S (2005) Multi-criteria analysis of alternative-fuel buses for public transportation. *Energy Policy* 33:1373–1383.

Uğurlu S, and Kahraman C (2011) Fuzzy multicriteria risk assessment for hazardous waste management: The case of Istanbul. *J Risk Anal Crisis Response* 1:29–41.

Ugwu OO, and Haupt TC (2007) Key performance indicators and assessment methods for infrastructure sustainability—a South African construction industry perspective. *Build Environ* 42:665–680.

Ugwu OO, Kumaraswamy MM, Wong A, and Ng ST (2006) Sustainability appraisal in infrastructure projects (SUSAIP): Part 1. Development of indicators and computational methods. *Autom Constr* 15:239–251.

UNCSD (2007) *Indicators of Sustainable Development: Guidelines and Methodologies; 3rd Edition*, Department of Economic and Social Affairs of the United Nations Secretariat, New York.

UNFCC (2016) Investors Urge G20 Leaders to Swiftly Ratify Paris Agreement.

United Nations (ed) (2007) *Indicators of sustainable development: guidelines and methodologies*, 3rd ed, United Nations, New York.

Van de Kerk G, and Manuel AR (2008) A comprehensive index for a sustainable society: The SSI — the Sustainable Society Index. *Ecol Econ* 66:228–242.

van der Voet H, van der Heijden GWAM, Kruisselbrink JW, Tromp S-O, Rijgersberg H, van Bussel LGJ, van Asselt ED, and van der Fels-Klerx HJ (Ine) (2014) A decision support tool for assessing scenario acceptability using a hierarchy of indicators with compensabilities and importance weights. *Ecol Indic* 43:306–314.

Vego G, Kučar-Dragičević S, and Koprivanac N (2008) Application of multi-criteria decision-making on strategic municipal solid waste management in Dalmatia, Croatia. *Waste Manag* 28:2192–2201.

Vera I, and Langlois L (2007) Energy indicators for sustainable development. *Energy* 32:875–882.

Vinodh S, and Girubha RJ (2012a) PROMETHEE based sustainable concept selection. *Appl Math Model* 36:5301–5308.

Vinodh S, and Girubha RJ (2012b) Sustainable concept selection using ELECTRE. *Clean Technol Environ Policy* 14:651–656.

Vinodh S, Kamala V, and Shama MS (2013) Compromise ranking approach for sustainable concept selection in an Indian modular switches manufacturing organization. *Int J Adv Manuf Technol* 64:1709–1714.

Waheed B, Khan F, and Veitch B (2009) Linkage-Based Frameworks for Sustainability Assessment: Making a Case for Driving Force-Pressure-State-Exposure-Effect-Action (DPSEEA) Frameworks. *Sustainability* 1:441–463.

Wang J-J, Jing Y-Y, Zhang C-F, and Zhao J-H (2009) Review on multi-criteria decision analysis aid in sustainable energy decision-making. *Renew Sustain Energy Rev* 13:2263–2278.

Wang L, and Lin L (2007) A methodological framework for the triple bottom line accounting and management of industry enterprises. *Int J Prod Res* 45:1063–1088.

Watson B (2016) Have we reached the tipping point for investing in renewable energy?

WCED (1987) *Our Common Future*, World Commission on Environment and Development (WCED), Oxford University Press.

Weber O, Scholz RW, and Michalik G (2010) Incorporating sustainability criteria into credit risk management. *Bus Strategy Environ* 19:39–50.

Wibowo S, and Grandhi S (2016) Evaluating the sustainability performance of thermal power enterprises, in *2016 IEEE 11th Conference on Industrial Electronics and Applications (ICIEA)* pp 1754–1759.

Wilson J, Tyedmers P, and Pelot R (2007) Contrasting and comparing sustainable development indicator metrics. *Ecol Indic* 7:299–314.

Wolfslehner B, Brüchert F, Fischbach J, Rammer W, Becker G, Lindner M, and Lexer MJ (2012) Exploratory multi-criteria analysis in sustainability impact assessment of forest-wood chains: the example of a regional case study in Baden–Württemberg. *Eur J For Res* 131:47–56.

World Bank (2016) Energy & Mining, World Bank.

World Bank (2017) Energy Overview.

Yakovleva N (2007) Measuring the Sustainability of the Food Supply Chain: A Case Study of the UK. *J Environ Policy Plan* 9:75–100.

Yao H, Shen L, Tan Y, and Hao J (2011) Simulating the impacts of policy scenarios on the sustainability performance of infrastructure projects. *Autom Constr* 20:1060–1069.

Zadeh LA (1965) Fuzzy sets. *Inf Control* 8:338–353.

Zencey E (2014) Economists Who Say the Planet Has Infinite Resources Are Today's Flat Earth Society. *YES Mag*.

Zhang L, Zhou P, Newton S, Fang J, Zhou D, and Zhang L (2015) Evaluating clean energy alternatives for Jiangsu, China: An improved multi-criteria decision making method. *Energy* 90, Part 1:953–964.

Zhao H, and Li N (2016) Performance Evaluation for Sustainability of Strong Smart Grid by Using Stochastic AHP and Fuzzy TOPSIS Methods. *Sustainability* 8:129.

Zhou L, Tokos H, Krajnc D, and Yang Y (2012) Sustainability performance evaluation in industry by composite sustainability index. *Clean Technol Environ Policy* 14:789–803.

Zhou P, and Ang BW (2008) Indicators for Assessing Sustainability Performance, in *Handbook of Performability Engineering* (Misra PKB ed) pp 905–918, Springer London.

Zhou P, Ang BW, and Poh KL (2006) Comparing aggregating methods for constructing the composite environmental index: An objective measure. *Ecol Econ* 59:305–311.

Ziegler A, Schröder M, and Rennings K (2007) The effect of environmental and social performance on the stock performance of european corporations. *Environ Resour Econ* 37:661–680.

Ziolkowska JR (2014) Optimizing biofuels production in an uncertain decision environment: Conventional vs. advanced technologies. *Appl Energy* 114:366–376.

Zolfani SH, and Saparauskas J (2014) New Application of SWARA Method in Prioritizing Sustainability Assessment Indicators of Energy System. *Eng Econ* 24.

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After his master's degree, he worked for various international consulting and engineering companies in Turkey in the fields of energy, finance and environment. In parallel to his professional carrier, he started with his doctoral study in 2012 at Galatasaray University, Graduate School of Social Sciences, Ph.D. Program in Business Administration. He currently assumes technical and managerial roles in an international sustainability management consultancy and gives speeches at various events. His thematic experience is focused on environmental protection, corporate health and safety, climate change, renewable energy and sustainable cities.

List of publications:

Journal Articles

- Büyüközkan, Gülçin, and Karabulut, Yağmur. "Energy project performance evaluation with sustainability perspective." Energy 119 (2017): 549-560.

Conference Papers

- Karabulut, Yağmur and Büyüközkan, Gülçin (2012). Product Life Cycle Management for Sustainable Supply Chain: A Literature Survey. 10th International Logistics & Supply Chain Congress.
- Büyüközkan, Gülçin, and Karabulut, Yağmur (2013). Linking Product Design with Supply Chain for Product Life Cycle: A Sustainability Framework Approach. 11th International Logistics & Supply Chain Congress.
- Firmalar için Sürdürülebilirlik Performans Değerlendirme Model Önerimi". Gülçin Büyüközkan, Yağmur Karabulut. YAEM 2015, 35. Yöneylem Araştırması ve Endüstri Mühendisliği Kongresi, ODTÜ, Eylül 2015.

Other

- Columnist ("Karbon Yönetimi") at the industrial periodical "Lojistik Dergisi", writing on carbon management in logistics (2012 – ongoing).

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