

**POLITECNICO DI MILANO**  
Scuola di Ingegneria dei Sistemi



**POLO TERRITORIALE DI COMO**

**Master of Science in  
Management, Economics and Industrial Engineering**

**Rapid Sustainability Assessment Methodology  
With Focus on Energy Efficient Manufacturing**

**Supervisor: Prof. Marco Taisch  
Assistant Supervisor: Gokan May  
Bojan Stahl**

**Master Graduation Thesis by: Vahid Sadr  
Student Id. number :754870**

**December 2012**

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# Acknowledgements

I would like to express my deep gratitude to my supervisors, Prof. Marco Taisch, Gokan May and Bojan Stahl for their professional guidance and valuable support from initial to the final step that made me able to write this master thesis. without their help and guidance I wouldn't be able to understand the subject deeply.

I would like to express my very great appreciation to my family who always supported me in all the levels of my life and understanding me during these years of education.

Thanks to all my friends who helped me by supporting and sharing their ideas with me.

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# Abstract in English

This thesis intends to investigate the current tools and frameworks for sustainability development assessments in industrial sectors and tries to find out the gaps between the theory and practice toward sustainability assessments.

As sustainability is gaining more and more attention, companies are trying to implement different types of assessments to find out how sustainable they are. this assessments enables companies to not only become more competitive but also it improves their compatibility with customer expectations. the reason for this claim is that with improvements in the knowledge of customers toward production processes and economic and environmental sustainability, their expectations have been changed. they look for products that are more environmental friendly and more green. they care more about energy and energy usage so in order to satisfy these changes companies also are in need to move toward sustainability.

Considering the importance of sustainability assessment in industrial sectors the state of art in this field have been analyzed in order to find the gaps and also the potentials of more improvement in assessment tools, methods or frameworks. so it has been recognized that there is lack of a Rapid Sustainable Assessment tool in this area in that sense that almost all the methods and frameworks which exist for this purpose, are in need for deep evaluations that not only they are time consuming, but also they mainly focus on one of the pillars of sustainability more than other pillars. in other words there is lack of a comprehensive tool or framework to assess sustainability developments in appropriate time.



By Analyzing the state of art it has been recognized that also energy efficiency plays an important role toward sustainability improvements because while it includes environmental issues at the same time it can improve economic sustainability and finally above all, concept of energy efficient manufacturing is completely aligned with existing definitions for sustainability. because while it tries to satisfy the needs of current generation it tries to use the resources in a better way for future.

At the end a framework with a set of indicators have been designed toward sustainability assessment in which the focus and the insist of this framework is on energy efficient manufacturing.

In order to gather real data from industry and comparing the result with the scholar and theory in order to find the gaps an on-line survey has been provided and has been sent to over 200 companies that 16 answers from important companies consisting of large medium and small size have been collected and analyzing the answers led to improving the introduced framework for sustainability assessment.

# Abstract in Italian

Questa tesi si propone di investigare sugli attuali strumenti e piattaforme utilizzati per le valutazioni di sostenibilit di sviluppo nei settori industriali e cercare di scoprire le discrepanze tra la teoria e la pratica nei confronti delle valutazioni di sostenibilit.

Poich la sostenibilit sta guadagnando sempre pi attenzione, le aziende stanno cercando di attuare diversi tipi di valutazioni per scoprire quanto siano sostenibili. Questa valutazione consente alle aziende non solo di diventare pi competitive, ma anche di migliorare la compatibilit con le aspettative dei clienti. La ragione di questa affermazione che con il miglioramento della conoscenza dei clienti verso i processi di produzione e la sostenibilit economica e ambientale, le loro aspettative sono state modificate. Loro cercano prodotti che rispettano l'ambiente e che siano ecologici. Si preoccupano di pi del risparmio energetico e dell'uso razionale dell'energia, quindi al fine di soddisfare questi cambiamenti, le aziende si trovano nella condizione di doversi muovere verso la sostenibilit.

Considerando l'importanza della valutazione della sostenibilit nei settori industriali, lo stato dell'arte in questo campo stato analizzato al fine di trovare le lacune e anche le potenzialit di maggiori miglioramenti sugli strumenti di valutazione, sui metodi o sui framework. Pertanto stato riconosciuto che in questo settore vi la mancanza di uno strumento di rapida valutazione sostenibile, nel senso che quasi tutti i metodi e le strutture esistenti a questo scopo, hanno bisogno di valutazioni profonde che non solo sono dispendiose in termini di tempo, ma anche si concentrano, principalmente, su uno dei pilastri della sostenibilit pi di altri pilastri. In altre parole vi la

manca di uno strumento completo o di una piattaforma per valutare gli sviluppi della sostenibilit in un tempo appropriato.

Analizzando lo stato dell'arte stato riconosciuto che anche l'efficienza energetica svolge un ruolo importante verso il miglioramento della sostenibilit, perch, mentre include problematiche ambientali, al tempo stesso pu migliorare la sostenibilit economica e infine, pi di tutto, il concetto di produzione energetica efficiente perfettamente in linea con le definizioni esistenti per la sostenibilit perch mentre cerca di soddisfare le esigenze della generazione attuale, cerca di utilizzare le risorse nel modo migliore per il futuro.

Alla fine un framework con una serie di indicatori stato progettato per la valutazione della sostenibilit, nel quale l'attenzione stata rivolta al risparmio energetico nel settore manifatturiero.

Al fine di raccogliere i dati reali dall'industria e per confrontare il risultato con lo studio e la teoria, per individuare le lacune stato realizzato un questionario on-line ed stato inviato a pi di 200 aziende, da cui 16 risposte di importanti aziende di grandi, medie e piccole dimensioni sono state raccolte e l'analisi delle risposte ha portato a migliorare il framework introdotto per la valutazione della sostenibilit.

# Chapter 1

## Literature Review

### 1.1 Definition of Sustainability and Sustainability Indicators

In recent years, sustainable development is becoming more important for policy makers in industrial sectors. Famous definition of sustainable manufacturing by itself shows the reason for this claim. It defines sustainable development as an improvement that satisfies the needs of present generation without compromising the possibility of future generation to reach their own needs [33].

Associations such as The World Business Council on Sustainable Development [8], the Global Reporting Initiatives [11] and development of standards [7], have been started the basis for sustainability reporting.

As of today there have been remarkable efforts to investigating and establishing methods, frameworks and techniques toward sustainability assessment. for instance i can mention to [17] that they collected and created a standardized set of sustainability indicators for enterprises and companies to consider all the main aspects of sustainability.

The necessity of the information analysis in order to make efficient decisions highlights the importance of assessment tools for decision makers.

There are large number of assessment tools to carry out sustainability assessment. As each tool according to its characteristics provides different information and analysis, therefore it is able to fulfill a specific purpose. Thus choosing the proper tool becomes a critical decision to be made. for example some tools may be appropriate for making short term decisions while another tool is better for or long term decisions and some can fulfill requirements for issues related to costs and benefits or other aspects of sustainable development.

For making more clear description of sustainability assessment and what exactly the term assessment refers to in this master thesis, I would like to describe different types of assessment by referring to a report which is published from an OECD workshop on *Sustainability Assessment Methodologies* which was held in Amsterdam, the Netherlands (2008). OECD sustainability studies, roughly divided assessment tools in three types which are Analytical tools and methods, Participative tools and methods and the more managerial "assessment frameworks" [25].

Analytical tools try to bring sustainability assessments into communications for instance analytical tools like sustainable national income or genuine savings or even it is possible to categorize integrated assessment models which enable the user to track and explain the behavior of dynamic balances between periods.

Participative tools are one of the key tools in integrated assessments and they are based on sharing data, knowledges, views and ideas of different participants such as researchers (not scientists), policy makers, social organizations etc. Assessment frameworks are used to investigate different aspects of sustainability and try to find the linkage between different aspects hence it enables to find out the possible ways for implementing an integrated assessment.

As it is investigated by many scholars, integrated assessment approaches obey a generic set of steps consisting of four phases, that below we are going to shortly describe these phases [25]:

- 1) **Phase I- Problem Analysis:** in this phase the purpose is to get a deeper understanding of the problem in hand and try to frame it.
- 2) **Phase II- Finding options:** using the the knowledge gained from the previous phase, this phase tries to find all the possible solutions that may solve the problem.
- 3) **Phase III- Analysis:** this phase intend to investigate options in detail to find the best possible solutions as options for implementation.
- 4) **Phase IV- Follow up:** the purpose of this phase is to learn by reflecting on the whole process and then monitoring and evaluating the chosen and executed option.

Quick assessments and consequently simple policy processes, as well as long term and complicated processes follow these four generic steps.

OECD sustainability development has published a table which summarizes the theoretical framework used for selection of specific tool [25].

Among what has been explained till now I would like to highlight the importance of the analytical tools and approaches and the reason for this claim is that analytical tools can enable one to consider also the environmental and social aspects of sustainability while they were originally made considering economic aspects of sustainability. This extension has been both in theoretical terms and in practice [24].

	Phase I Problem Analysis	Phase II Finding Options	Phase III Analysis	Phase IV Follow-up
Participatory tools	Problem framing (mobilizing and integrating knowledge and values)	Supporting scenario building	Providing the context for and improve robustness of MCA, CBA and CEA	Evaluating the assessment process
Scenario tools	Providing he future perspective to future framing	Visioning features, finding options and setting options	Providing references for the application of analytical tools	-
Multi-criteria analysis tools (MCA)	-	Definition of criteria	Comparing different alternatives	-
Cost-benefit analysis (CBA) and Cost-effective analysis (CEA)	Providing the analytical basis for problem framing	Supporting objective settings	Full analytical characterization of options to enable comparison	Ex-post assessments
Accounting tools				
Model tools				

Figure 1.1: The Role of Tools in Sustainability Assessment Adopted from OECD (2004)

When we talk about sustainability we in-fact discuss about three main pillars of sustainability. As these pillars are the very basic concepts of sustainability and it they are well-known concepts so I will avoid to repeat obvious concepts. I briefly mention them in the upcoming paragraph.

A complete sustainability problem will be defined, considering it's three main pillars of sustainability. these three pillars are consist of Social aspects, Economic aspects and Environmental aspects. if one of these pillars is weak the system as a whole is not sustainable. here in the below picture a popular method to show these three pillars is illustrated.

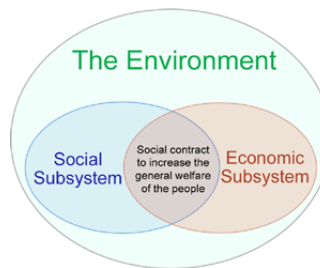


Figure 1.2: The Three Pillars of Sustainability Assessment (Adams, 2006)

The OECD works on social aspects of sustainable development which means analyzing the links between environmental and social changes and balancing the progress between other dimensions of sustainability. considering discussions which exist till now around sustainability and sustainable development, environmental aspect has been discussed more.

In other words if we look at the history of sustainability discussions we will find environmental aspect as the most discussed subject. (Measuring Sustainable Development, OECD, 2004). but recently social aspects also became under investigation and they are gaining more attention both at international and domestic level [24].

According to researches and workshops held by OECD, right now improving the statistical frameworks is one of the critical issues because the current statistical frameworks are not capable of giving an integrated view of different aspects of sustainability development [24].

As there is lack of integration between three dimensions of sustainable development and it causes difficulties in making trade-off among alternative policies through various sets of indicators so we can claim that one of the most important existing gaps for sustainability development is an integrated analytical framework which can bridge the gap between three dimensions in terms of integration [24].

When Brundtland commission introduced its famous definition of sustainability as it is mentioned above also this challenge raised between policy makers that how to measure sustainability development, how to find out how sustainable we are etc. because this definition would remain just as a theory unless proper performance indicators be introduced to the area.

As Brundtland suggested this idea so it tried to gather some performance indicators to enable sustainability measurements which below I highlighted some of the principle approaches done by Brundtland.

**UN system of Environmental and Economic Accounts:** a framework for environmental accounting



**Genuine Saving:** World Bank, change in total wealth, accounting for resource depletion and environmental damages;

**Genuine progress indicator:** Redefining progress and index of sustainable economic welfare UK and other countries. An adjust GDP figure, reflecting welfare losses from environmental and social factors;

**Ecological Footprint:** Redefining progress, WWF and others. a measure of productive land and sea area required to produce renewable resources and sequester carbon emissions.

**Living Planet Index** WWF, An assessment of the population of animals species in forest. fresh water and marine environments.

**Environmental Sustainability Index** World Economic Forum, An aggregate index spanning 22 major factors that contribute to environmental sustainability.

**Environmental Pressure Indices** Netherlands EU, A set of aggregate indices for specific environmental pressures such as acidification or emissions of greenhouse gases.

**Resource Flows** World Resources Institute, Total material flows underpinning economic processes.

Adopted from *Measuring Sustainability* (OECD, 2004)

The conclusion that I can draw on the basis of mentioned indicators, suggested by Brundtland, is that it is clear that the ability of these indicators are limited for measuring the progresses toward sustainability and the reason for this limitation is lack of proper integrated framework to be able to collect and connect all the gathered information in all the aspects of sustainability. How ever still these indicators look essential for analyzing the progress of sustainability in economic aspect.

The mutual reliance between environmental, social and production-consumption subsystems makes sustainability as a characteristic of the system. The social subsystem

can not sustainable if the environmental subsystem is not sustainable. ( it is necessary to mention that according to (Hueting, 2003) in this case the opposite situation is not true for long term).[24]

It is discussed that in order to develop a "social-economic-environmental" system as a system to be claimed sustainable, the development should not threat the existence of the system itself nor the characteristics and its components. So it means that the variables and the characteristics should be developed constant or increasingly [24].

According to what has been explained it can be claimed that indicators and composite indicators are useful tools for policy makers to share the information in country level in all fields of economy, environment, society and technological development. Indicators are able to summarize large amount of data efficiently hence it will be more effective to use short and useful data in making decisions or analyzing the level of improvement.

I would like to mention to what (Meadow, 1998) believed about indicators which is " indicators arise from values and it means we measure what is important for us and they create value for us because we care about what we measure." [20]

## 1.2 A state of the art on sustainable development approaches and frameworks

Warhurst (2002) believes that we can measure sustainability development through a two step approach. In the first step the progress of sustainability development will be measured by the help of Sustainability Development Indicators (SDIs) in a number of selective individual fields and in the second step we will find out the overall progress toward sustainable development by assessing these individual considering their relation together [32]. Following this idea i would like to add that Lancker and Nijkamp (2000) believe that an indicator has nothing to do with sustainability improvement measurement unless there is a reference threshold for it [18]. This idea brings the discussion to another level of argument about indicators. This idea is directly talking about benchmarking the indicators and their assessment so we will need a set of indicators as a standard or reference which till this moment this has been one of the arguments between scholars to establish a set of comprehensive indicators which covers all the aspects of sustainability plus it enables to make comparisons in both domestic and international levels. Here I am going to summarize some of the existing approaches which are popular and most used by different institutes and policy makers which are working on sustainability improvement measurements. These examples can prove lack of a comprehensive framework for sustainability improvement measurements.

Pressure-State-Response is one the frameworks which is being used as a base for several frameworks designed by researchers and organizations. The PSR framework is developed by OECD (1998). pressure indicators explain how environment is being influenced by the the pressure of human activities and the way they use natural resources. Figure 1.3 shows the main PSR framework.[23]

It is proved in practice that defined indicators of PSR framework are not universal set of frameworks hence defining complementary indicators need to be defined to satisfy the needs of users. OECD has developed sector related indicators for energy, transport and agriculture[23]. It is clear that this framework maybe be a good tool

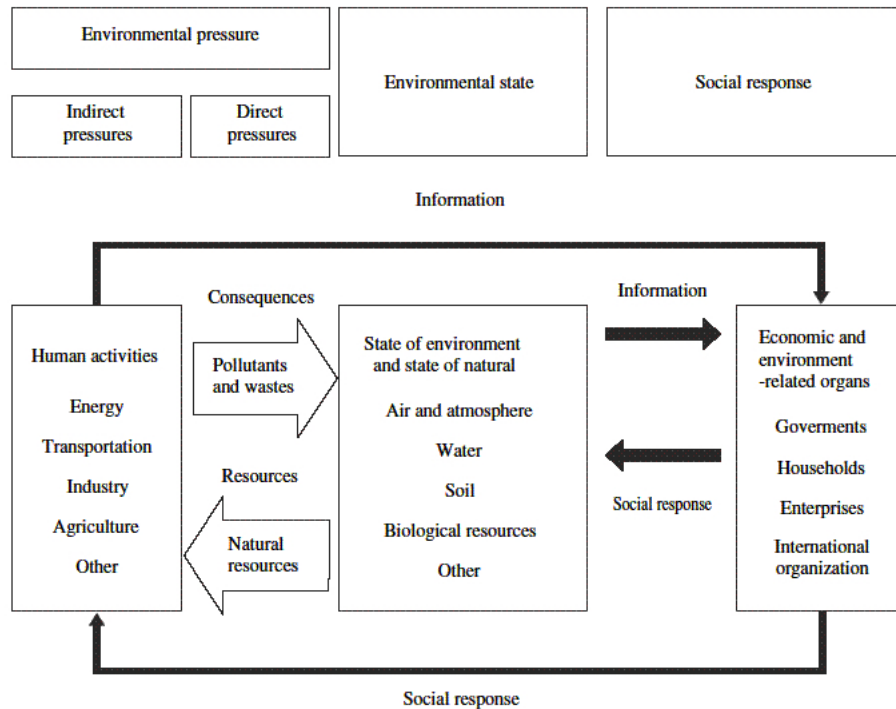


Figure 1.3: The pressure-state-response framework OECD (1998)

for describing environmental aspects however it may be less useful in describing the social and economical aspects of sustainability improvement.

European Environmental Agency (EEA) and European Statistical Office (Eurostat 1977) suggested a modified version of PSR framework. the framework tries to cover all the three aspects of sustainability development in terms of driving forces and impacts. Figure 1.4 shows the DPSIR framework.[6]

As it is clear in the Figure 1.4 the framework is useful in identifying different cause and effect relationships. the DPSIR framework is useful to describe the relationship between origins and consequences of environmental problems but in order to understand it's dynamics it is useful also to find out the links between DPSIR elements. Kristensen (2004)

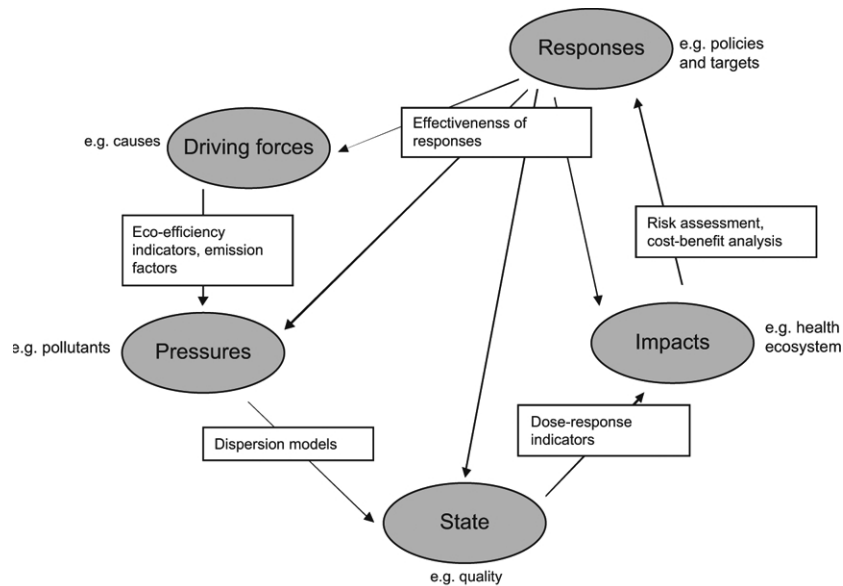


Figure 1.4: The DPSIR framework for reporting on environmental issues Eurostat (1977)

Lundin, (2003) believes that there are two different approaches which can be used in order to create a framework and it's indicators. these two typical approaches can be defined as:

**Top-Down Approach:** in this approach experts and researchers develop the framework and then they set the appropriate Sustainability Indicators (SIs) for the framework. the mentioned framework in Figure 1.4 and Figure 1.3 are examples of Top-down approach.

**Bottom-up Approach:** this approach is based on corporation and synergy. participants and stakeholders try to share ideas and develop a framework and it's required indicators. examples of this approach can be [29]:

- Sustainable Seattle
- Bellagio Principles
- PICABUE

as the details of these examples don't cover the purposes of these thesis it suffices just to name them.

In 1992 Holmberg and Karlsson challenged the lack of physical relation between society and nature hence they developed the concept of Socio-Ecological Indicators (SEIs) [14].

By recognizing the gaps between different aspects of sustainability, complementary frameworks were introduced by researchers, scholars, organizations and institutes. In order to evaluate both environmental and social components of sustainable development two components attracted attention. First the one which is named eco-system well being and second is human-well being that both of them have to be improved for reaching sustainable development.[31]

A five level framework named LCSP framework was introduced in order to organize the existing indicators and help to develop new indicators. The framework suggests to start from easy and simple performance indicators to measure sustainability developments and move toward complex ones. The LCSP framework mainly focus on environmental, safety and health aspects of sustainable development, [30]. here in the Figure ?? the five steps of the framework are presented.

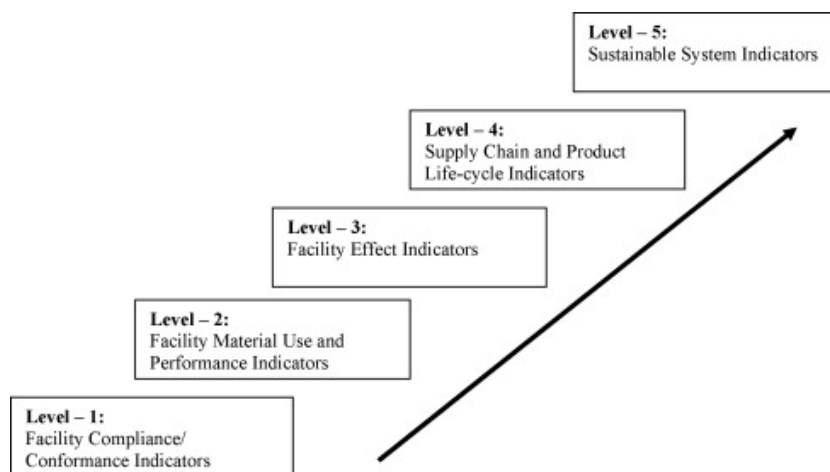


Figure 1.5: Five Step LCSP Framework adopted from [26]

One of the popular and famous frameworks toward sustainability development is founded at 1997 by non-profit organizations named Environmentally Responsible Economies (CERES) and the Tellus Institute in Boston.

In early 1990s a framework was pioneered for environmental reporting and after implementing more developments on this framework it came up with the framework of Global Reporting Initiative.

GRI came with the motive of "do more than environment" hence the scope of the framework was broadened to cover social, economic and governance issues. GRI's guidance became a Sustainability Reporting Framework, with Reporting Guidelines at its heart, (GRI official website, 2012).

GRI uses a hierarchical framework covering all the aspects of sustainability including social, economical and environmental aspects. in Figure 1.6 you can see the GRI framework and it's focal points.

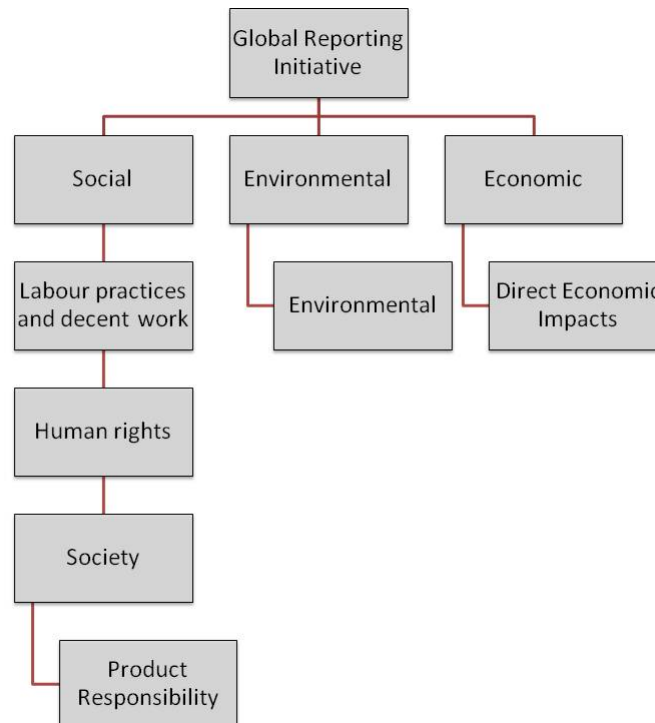


Figure 1.6: GRI Framework adopted from GRI official website

A set of required indicators were published by The United Nations Commission on Sustainable Development (CSD) as an indicator framework which enables the evaluation of governmental progress toward sustainability. it is made by 38 sub-themes and 15 main themes covering four aspects toward sustainability. Figure 1.7 represents these indicators.



Indicators of Sustainable Development			
	Theme	Sub-theme	Indicator
S O C I A L	Equity	Poverty	Percentage of Population Living below Poverty Line
			Gini Index of Income Inequality
			Unemployment Rate
		Gender Equality	Ratio of Average Female to Wage to Male Wage
		Nutritional Status	Nutritional Status of Children
	Health	Mortality	Mortality Rate Under 5 Years Old
			Life Expectancy at Birth
		Sanitation	Percent of Population with Adequate Sewage Disposal Facilities
		Drinking Water	Population with Access to safe Drinking Water
		Healthcare Delivery	Percent of Population with Access to Primary Health Care Facilities
	Immunization Against Infectious Childhood Diseases		
	Contraceptive Prevalence Rate		
	Education	Education Level	Children Reaching Grade 5 of Primary Education
Literacy		Adult Secondary Education Achievement Level Adult Literacy Rate	
Housing	Living Conditions	Floor Area per Person	
Security	Crime	Number of Recorded Crimes per 100.000 Population	
Population	Population Change	Population Growth Rate	
		Population of Urban Formal and Informal Settlements	
E N V I R O N M E N T A L	Atmosphere	Climate Change	Emissions of Greenhouse Gases
		Ozone Layer Depletion	Consumption of Ozone Depleting Substances
		Air Quality	Ambient Concentration of Air Pollutants in Urban Areas
	Land	Agriculture	Arable and Permanent Crop Land Area
			Use of Fertilizers Use of Agricultural Pesticides
		Forests	Forest Area as a Percent of Land Area Wood Harvesting Intensity
		Desertification	Land Affected by Desertification
		Urbanization	Area of Urban Formal and Informal Settlements
	Oceans, Seas and Coasts	Coastal Zone	Algae Concentration in Coastal Waters Percent of Total Population Living in Coastal Areas
		Fisheries	Annual Catch by Major Species
	Fresh Water	Water Quantity	Annual Withdrawal of Ground and Surface Water as a Percent of Total Available Water
		Water Quality	BOD in Water Bodies Concentration of Faecal Coliform in Freshwater
	Biodiversity	Ecosystem	Area of Selected Key Ecosystems
Protected Area as a % of Total Area			
	Species	Abundance of Selected Key Species	
E C C O	Economic Structure	Economic Performance	GDO per Capita Investment Share in GDP
		Trade	Balance of Trade in Goods and Services
		Financial Status	Debt to GNP Ratio
			Total ODA Given or Received as a Percent of GNP
N O M I C	Consumption and Production Patterns	Material Consumption	Intensity of Material Use
		Energy Use	Annual Energy Consumption per Capita
		Waste Generation and Management	Share of Consumption of Renewable Energy Resources
			Intensity of Energy Use
			Generation of Industrial and Municipal Solid Waste
			Generation of Hazardous Waste Management of Radioactive Waste
		Waste Recycling and Reuse	
Transportation	Distance per Capita by Mode of Transport		
I S T I T U T I O N A L	Institutional Framework	Strategic Implementation of SD	National Sustainable Development Strategy
		International Cooperation	Implementation of Ratified Global Agreements
		Information Access	Number of Internet Subscribers per 1000 Inhabitants
	Institutional Capacity	Communication Infrastructure	Main Telephone Lines per 1000 Inhabitants
		Science and Technology	Expenditure on Research and Development as a Percent of GDP
		Disaster Preparedness and Response	Economic and Human Loss Due to Natural Disasters

Figure 1.7: The United Nations Commission Sustainability Indicators UNCS (2012)

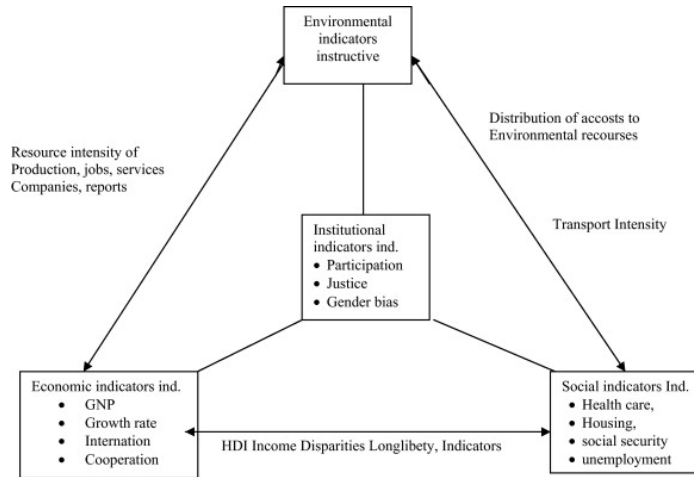


Figure 1.8: The Wuppertal Sustainable Development Indicator Framework Adopted from Rajesh Kumar e al (2008)

The Wuppertal Institute also developed a framework of indicators for sustainable developments in four aspects as it was published by CSD plus considering the existed relationship between the aspects and indicators which you can see it in Figure 1.8

## 1.3 An Introduction to Sustainability Assessment Tools

In this section the intention is to gather existing tools for sustainability development assessment. the main effort in this section is to categorize the existing tools according to their practice area and give a brief description of each tool.

So far, the existing articles and papers done by scholars are a prove on this fact that classifying sustainability tools can be done considering large amount of factors and dimensions.(Baumann and Cowell, 1999; Moberg, 1999; Wrisberg et al., 2002; Finnveden et al., 2003; Finnveden and Moberg, 2005; Kates et al., 2005).

considering what is suggested by reviewing the researches it has been tried to categorize existing tools according to their focus on sustainable pillars and practicality.

on Figure 1.9 a schematic diagram shows some existing tools according to our selection criteria which is explained.

### 1.3.1 Indicators and Indices

Indicators and indices assemble the first part of sustainability assessment tools. Main characteristics of indicator are being efficient and easy to use. Mainly they are quantitative indicators how ever qualitative indicators also are very applicable. Indicators are able to represent economic, social and environmental aspects of sustainability in defined criteria. By aggregating indicators considering a common aspect between them, we will reach and index.

Harger and Meyer (1996), stated that indicators should be as simple as possible while at the same time they should be able to be specific or comprehensive depending to the objective of usage. indicators and indices should allow to identification of trends through time horizons. [12]

Constant measurements of indicators and indices will enable us to track the changes by extracting the trends and also use short-term and long-term prediction toward the behavior of variable under measurement.

There are large number of indicators and indices in different criteria that next section

is assigned to the identification of some important and popular indicators.

### 1.3.2 Product-based assessment tools

The second category is concentrated on the connection and relation between production and consumption flows of materials.

In agreement with (Anderberg et al., 2000), they have similarities to flow indicators in the first category (which will be explained on next section) [1]. The difference is that in this category tools intent to evaluate various flows between products and consumptions.

These tools are trying to find out the impacts of using resourcing to satisfying the require demands on environment. these evaluations can be performed through evaluation of production line and their impact on sustainability aspects or through products life cycle assessment from the moment they are intended to produce till their burial. Although life cycle costing assessment includes also economic aspects but these tools mainly are focused on environmental dimensions.

#### life Cycle Assessment

The most famous tool in the category of product-based assessment tools is life Cycle Assessment (LCA) tool. This tool is among the oldest and well-developed tools for sustainability assessments. LCA is a very powerful tool in evaluating the environmental impacts of a product during its life cycle. It is considered as a comprehensive tool for assessing environmental impacts because it analyzes actual and potential impacts that a product may has on the environment during raw material acquisition, production process, use, and disposal of the product [19].

The International Standards Organization (ISO) has published protocol and principles for LCA that have been further interpreted and developed by many (Ciambrone, 1997; Hauschild and Wenzel, 2000; Ross and Evans, 2002; Jolliet et al., 2004).

Results coming from LCS feeds decision makers with useful information for making decisions for eco-design systems, process optimizations, production system improvements, energy management etc.

### **Life Cycle Costing**

Life Cycle Cost analysis is an economic method which considers all the costs in general. This method calculates all the possible costs related to a product, activity or a process over its life time, [9]. The main goal of life cycle cost analyze is to choose the best option among a series of alternatives to choose the lowest long-term cost option. This method is mainly focused on economic dimension than environmental.

### **Material Flow Analysis**

In order to give a definition of Material Flow Analysis (MFA) I would like to quote the definition which is given by Brunner and Rechberger which is a clear and comprehensive definition.

MFA is defined as systematic accounting of the flows and stocks of materials within a system defined in space and time. It connects the sources, the pathways, and the intermediate and final sinks of a material. Because of the law of conservation of matter, the results of an MFA can be controlled by a simple material balance comparing all inputs, stocks, and outputs of a process, (Brunner and Rechberger, 2004).

The Wuppertal Institute for climate, environment and energy in germany, designed the so called model, Material Intensity Per Service unit (MIPS) which quantifies the material intensity of a product or service by summing up the total material input which is moved or extracted to produce the product or provide the service. This model considers the lifecycle perspective at the beginning of the production process. Substance Flow Analysis (SFA) investigates the inflows and outflows of substance through it's life cycle steps hence it can track the sources of environmental impacts and consequently manage the impacts by taking proper actions.

SFA is capable of using in product life cycle analysis but usually it is being used in industry analysis.

### **Life Cycle Energy Analysis**

Life cycle energy analysis measures the required energy to produce a product or providing a service. [13]

energy measurements includes measurements of both direct energy and indirect energy. Indirect energy can be defined as the energy which is used for producing inputs. Life cycle energy analysis intend to evaluate energy in different levels of manufacturing a product as well as Life cycle-based Exergy and Emergy Analysis which have the same purpose.

Emergy analysis usually is appropriate for evaluating production processes of a single product [15] or the whole industries. [5]

Exergy analysis evaluate energy systems like heating etc. [22] [3]

### 1.3.3 Integrated Assessment

The third category includes Integrated Assessment tools. These tools help decision makers in decisions regarding to a policy or projects in specific regions.

As it is mentioned by (Barry Nass e al, 2007), Project related tools are used for local scale assessments, whereas the policy related focus on local to global scale assessments. [2]

Integrated assessment are usually based on forecasts than actual results. Many of these tools are based on integration of society and environment dimensions. Integrated assessment tools are useful tools for understanding complex problems, [10]

#### Conceptual modeling

Conceptual Modeling are useful qualitative tools which can help to simplify complex situations. With the help of flowcharts, diagrams, and charts it is possible to visualize the problem and find out the flows, their relationships, points of weakness and strength. By applying conceptual modeling we can start the initial part of computer modelings and as a result achieve precise solutions.

#### System Dymanics

Although systems dynamics tools have similarities with conceptual modelings in terms of simplifying complex problems to understand them better, but there are significant differences between them. In system dynamics computer models of complex situations are built and then they will be examined over time to study the behavior of model over time,[4].

#### Multi-criteria Analysis

Multi-criteria Analysis (MCA) is one the most useful and practical tools in helping decision making processes when we have a complex situation which is necessary to



choose between alternatives that are competing together. Above all, this tool is a very useful in sustainability assessments where we are in need to analyze complex and inter-connected alternatives in environmental, social and economic dimensions. This method can be used in both qualitative and quantitative analysis.

### **Risk Analysis and Uncertainty Analysis**

One of the best definitions of risk has been given by (Rotmans, 1990), which is: "Risk can be defined as a possibility of damage or loss that may happen because of an event or series of events". [27]

Risk analysis tries to find out these possible damages by identifying the risks and their probability of happening and help decision makers to take proper actions in order to diminish them or make appropriate mitigation actions.

As risk and uncertainty have tight relation together they are inseparable with each other.

it is possible to name several types of uncertainty while two important types of uncertainty especially in sustainability discussions are stochastic uncertainty refers to natural variability of the system and fundamental uncertainty which is inability to predict because of lack of deep knowledge from the system [16].

### **Vulnerability Analysis**

First it is needed to give a definition of vulnerability. Vulnerability is the level in which a system or subsystem or different parts of a system are likely to be harmed because of being in danger or under pressure or stress.

Vulnerability Analysis intend to find out the level of sensitiveness and resistant of the system toward changes and how capable are to cope with these changes [28].

If vulnerability analysis proves that the system is vulnerable, then risk analysis will be executed.

Vulnerability analysis has been implemented as a useful tool in climate change studies, (Kelly 2000; Nixon et al, 2003; O'Brien et al, 2004).

### **Cost Benefit Analysis**

Cost Benefit Analysis (CBA), has been used for the first time in early of twenty century in order to help decision makers to make trade-off between the costs and benefits of the proposed investments by weighting the costs against the expected benefits, (Johansson, 1996). In the area of sustainability this tool can be used in order to make the trade-offs for example, between the environmental benefits of an alternative comparing to its social costs, [35].

The remarkable point in CBA as it is mentioned also by (Moberg, 1999) is that using monetary units for expressing the expected benefits and similar issues can sometimes be a problem [21].

### **Impact Assessment**

Impact assessment has been increasingly used for helping policy makers and legislations toward sustainability. This method has been increased for improving regulations in terms of effectiveness and efficiency. ( European Commission 2005, 2011).

In general Impact assessment is a forecast based method which tries to evaluate the potential impacts of projects, policies, in different stages by considering the definition of problem, definition of solution, their integrity and hence their impact on each other and then suggesting mitigation actions toward these impacts and effects. So in conclusion it is possible to state that this tool intends to help policy makers in order to have a more clear vision toward their suggested policy for the existing problem by showing the impacts of both solution and problem on each other. (Renda 2006; Wilkinson 2006).

To show how powerful and effective is this tool, some examples of its application are mentioned here:

Environmental Impact Assessment (EIA) has been proved to be an effective impact assessment since 1960s to evaluate and assess the effects of large projects on environment and trying to reduce negative impacts, (Sadler, 1999).

In 1985 the European Union Commission made EIA compulsory for the projects which are likely to have effects on environment. (EU Commission, 1985).

In 1990s it was discussed by EU to implement EIA not only to projects but also for plans and programs and it was the start of suggesting SEA process to achieve this goal. SEA is a series of steps to evaluate and identify the impacts of specific plans and programs before their implementation, (Clyton and Sadler, 2004).

One of the weaknesses of impact assessment methods was their low flexibility toward different areas and their specific focus on specific policy area, all these became reasons that it is continuously tried specially by EU commission to improve or develop more integrated methods. For instance development of Sustainability Impact Assessment (SIA), as an integrated tool which considers all the aspects of sustainability is one the results of these efforts. SIA tool was used in early 2003 for the first time, and it's application is increasing. [34]

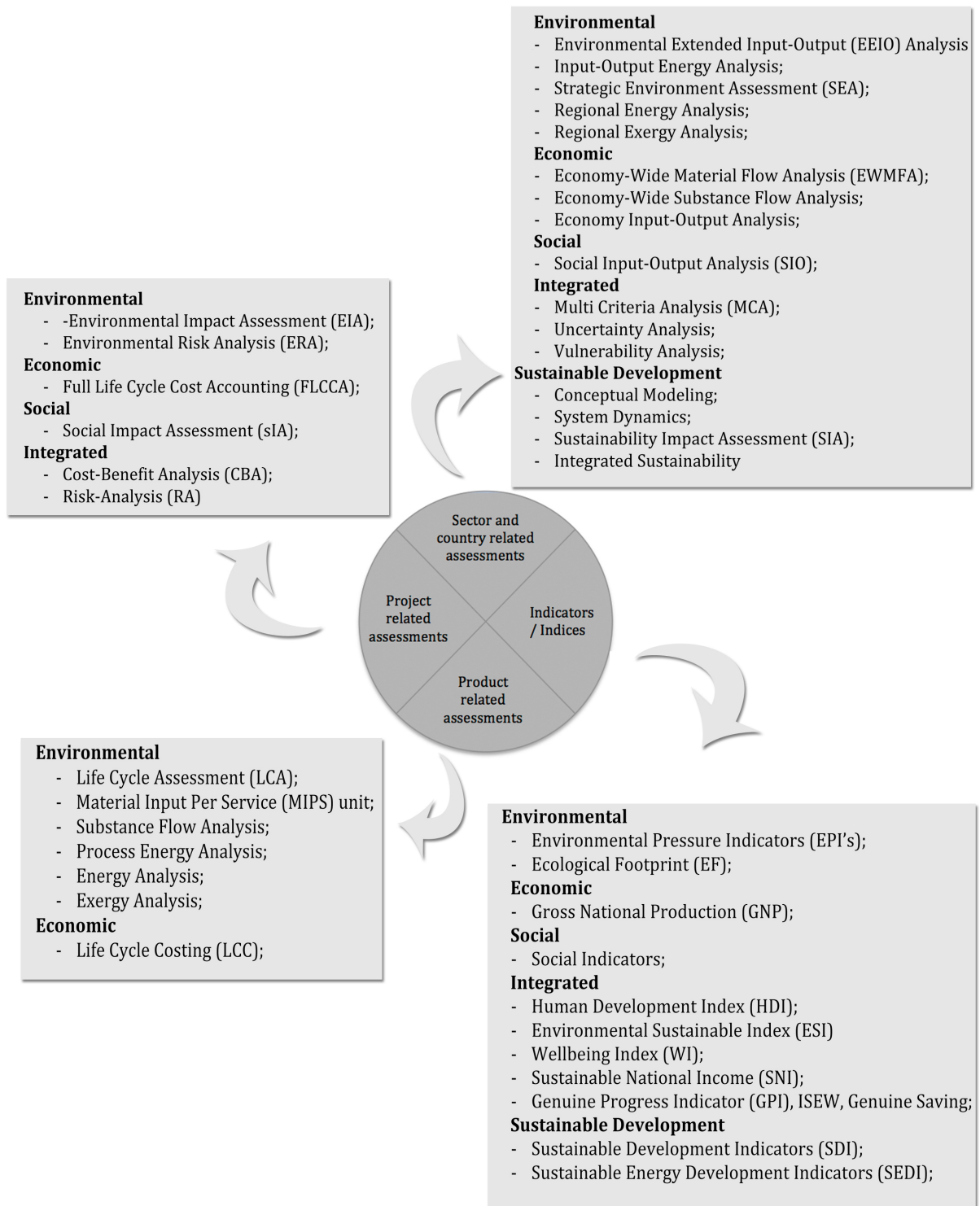


Figure 1.9: Sustainability Assessment Tools

## 1.4 A review on Sustainability Indicators (SIs) as a key tool in Sustainability Assessments

As it is explained in the previous chapters also, it is clear that indicators and indices are playing a key role in sustainability development assessments. following the explained reason, a chapter has been assigned specifically to sustainability indicators to be able to investigate more details about this important assessment tools.

Investigating sustainability methodologies will lead us to two main streams of sustainability assessment methodologies. One of these streams is based on economic approaches while the second one is related to physical indicators.

according to [26], economic approaches include the GDP, resource accountings, development modelings and investigating points of strength and weakness of each. Economic approaches are considered as a part of sustainable development of economy. on the other hand, the other approach is working with physical indicators and frameworks to assess sustainability developments. this approach is more wanted by scientists and researchers.

The main reason that raised sustainability discussions, is the scarcity of resources so efficient allocation of sources became a challengeable topic and one of the primary goals of Neo-classical models.

Neo-classical models are based on Neo-classical economy theory which is concentrated on prices, outputs and income distribution in market which they depend on demand and supply. The theory tries to find the optimum point for the functionality of the consumption and supply.

Sustainability models which are around this idea intend to keep the equilibrium between consumption and supply by finding substitutions for capital and keep it at the same level while reducing the use of non-renewable sources and technology use.

Charles Perrings in his book "Economics of Ecological Resources" mentioned that Hicks-Lindahl explain the definition of sustainable income as reaching the greatest level of possible benefits from defined set of assets, without compromising the flow of future benefits and establishing policies to keep this flow by making choices between

current consumption and current investment hence between current consumption and future consumption. (Solow, 1987).

Economic models represent a special sub-class of the quantitative models. In fact, this area has been extremely active in academia. Generating models, representing various economic concepts, ranging from Neo-classical, evolutionary, ecological economics to Neo-Ricardian (Faucheux et al, 1996)

As it is mentioned by (R.K. Singh et al, 2009), talking about natural capitals some economists focus on conventional capital theory, which argues about replacing natural resources with other capital forms, while some scholars try to investigate the resource exhaust by using the decreased values of natural capitals from diminished values of products, produced by using these resources.

Based on what is explained till now and also what can be concluded from the existing states of the art, it is possible to claim that sustainable economic improvements are turning around the idea of reducing the use of scarce sources by increasing the man-made capital. (OECD 2001) however the so called substitutions are dependent to availability of two main and primitive hypothesis of the Neo-classical paradigm (Spangenberg, 2005).

As there is no perfect approach, there are some weaknesses integrated with this approach too.

One of these weaknesses is that in order to be able to use the capital approach in the perfect possible way we need to measure all the capital stocks. This can be a constraint because sometimes it is not possible to figure out all the ways that a capital is involved and as a consequence not being able to define its value. Moreover we need to find out a measurement unit to express the value of our measurements that in capital approaches it is clear that the interest is toward the use of monetary units while in some cases it is not easy to translate the measurements in monetary values.

Another limitation that I would like to add is that not for all countries it is possible to develop substitution of resources because this idea is hand to hand with technological developments more over sometimes measuring the values of all capital stocks need

also technology and specialties which may in some cases be out of their access and/or ability in both terms of financial and human resource and this makes the approach less practical.

As it is mentioned in a review of sustainability measurements by joint work of UN-ECE/OECD/Eurostat (2008) one of the important limitation of capital approach is that finding the level of sustainability among capital types is one of the constraint. Some capitals are considered as critical ones while some other can be easily replaced by man-made capitals so it doesn't seem to be right to accumulate all the values together regardless of critical or non-critical capital stocks.

Considering what is explained will lead us to this conclusion that executing capital approach and framework will not survive using only monetary indicators, however monetary indicators are essential.

### 1.4.1 A review on process of defining indices

When we go through the literature to find out about indices and indicators, a large amount of definitions, frameworks and methods to implement them will appear which makes it a complicated issue.

Gallopín (1997) presented an extensive review of all definitions and indicators. He notes that indicator is a "statistical measure", "Parameter", "variable", "a proxy for measuring" and "a subindex".

His focus is on considering an indicator as a variable mainly because of the definition of a variable.

United Nations Glossary of Classification Terms, defines variable as a characteristic of a unit being observed that may assume more than one of a set of values to which a numerical measure or a category from a classification can be assigned (e.g. income, age, weight, etc., and occupation, industry, disease, etc.

Based on the given definition, each variable will lead to a value which explains the measured attribute and the value can be different depending on the purpose of measurement and required data.

According to what is explained Gallopín believes that indicators are variables and data are real measurements or observations.

In order to construct indicators, at the first step it is needed to define the bottom line and features of the components of our indicator that can be reached through existing theories, analyzing methods, experience or benchmarking.

using empirical analysis requires the implementation of bivariate and multivariate statistical techniques.

In bivariate analyze the goal is to find the correlation between pairs of variables hence finding the level in which the pairs are associated together. While in multivariate analyze we concern about finding the correlation structure of variables within groups.

The main objective of these analytical and statistical techniques is to investigate latent variables beneath our data and also to translate them to meaningful data which can be used for analyzing and selection processes. more over they enable us to epitomize the data and increase the reliability of data.



After analyzing the the gathered data using analytical methods and selecting required indicators according to the purpose of implementing measurements it is time to scale the composite indicators. In statistical point of view there are four possible ways to arrive to this aim. In the upcoming paragraph these methods will be discussed.

According to a review of sustainability development assessment by (Rajesh Kumar Singh e al, 2009), the first possible option is to skip scaling because the variables are scaled. The second option which is more practical for composite indicators is to implement standard scoring method like z-scoring to t-value table. In this method we adjust the raw data for example in z-scoring method it will be : e.g.  $z = [(\text{actual score} - \text{mean}) / \text{standard deviation}]$ . The third possible method we can use is to use ordinal response scale. The last option for scaling will be use of linear scaling method. Ebert and Welsch (2004) presented a guideline for scaling which is applicable to variables. Although the approach is not practical in all real situations but it shows the least methodological requirements that each meaningful sustainability development index should meet. In Figure 1.10 you can see these general aggregation rules.

	Non-comparability	Full comparability
Interval scale	Dictatorial ordering	Arithmetic mean
Ratio scale	Geometric mean	Any homothetic function

Figure 1.10: Aggregation rules for variables by Ebert and Welsch

After the aggregation of indices it is time to validate them which is possible through item analysis or external validation. During the whole construction process it should be noted to keep the indicators as simple as possible.

validation need to be done to enhance the quality of final estimations.

## 1.4.2 An Overview of Sustainability Indicators

### Non-integrated indicators

One of the main objectives of European Communities (Eurostat), is to develop a set of comprehensive and comparable indicators which enable all the European countries and regions to measure and compare the sustainability levels and trends. pursuing this this goal, sets of Non-integrated indicators have been defines till present which one of these sets is Environmental Pressure (EPIs) established by statistical office the european community. The EPI set consists of 60 indicators, six in each of the ten policy fields under the Fifth Environmental Action Program.(Lammers and Gilbert, 1999),(European Commission and Eurostat, 1999, 2001).

As another example it is useful to mention also to 58 national indicators used by the United Nations Commission on Sustainable Development (UNCSD).

### Flow-based Indicators

Measuring resource flows and other physical flows are always critical for sustainability measurements. These measurements can be the input for Material Flow Analysis (MFA). Flow indicators act as enablers for these measurements. For example energy analysis is based on measuring all energy flows in an economy. Flow indicators are considered as Non-integrated indicators as they are only concentrated on physical flows than environmental aspect.

### Integrated Indicators and Indices

As far there have been large number of efforts to develop different dimension indicators to a unique indicator or index due to existence of numerous number of indicators and indices which each of them is focused in a specific aspect or diminution of sustainability related issues.

Hanley e al, 1999 provided a detailed list of many of these indicators concluding their

assessment results.

Sustainable National Income is one of these indexes that it tries to go beyond the borders of specifically focused economic aspects, and involve social dimensions in sustainability assessments too. This indice was developed for Netherlands firstly, (Huetting e al, 1993).

This indice struggles to define well-being by integrating sustainable resource employments into national income accounting.

Gerlagh e al, (2002), describes the application of this index as a tool to make a comparison between national income which is intended to be sustainable and conventional national income accounting implementations so the difference between these two amounts will show the dependency of the country to the natural resources usage that exceeds sustainable utilizations.

The Index of Sustainable Economic Welfare (ISEW) (Daly and Cobb, 1989), and the Genuine Progress Indicator (GPI), are two indicators which have been created in mid-1990s, (Cobb et al., 1995), with the intention of integrating social, economic and environmental dimensions to build a comprehensive tools which are intimately near to each other and their purpose is to define welfare determinants in more extended level.

Evaluating sustainability in national level can be done through anther option named Adjusted Net Savings, also called Genuine Savings (Hamilton et al., 1997). The tool is mainly focused on economic and environmental aspects while along with them, it tries to consider also other components like educational aspects. The advantage of this tool is its direct signal toward sustainability developments for example a positive value is interpreted as a positive trend toward sustainability and vice-versa.

In 2002, in Johannesburg in a meeting for world sustainability development, an indicator named Well-being Index has been introduce that it includes two other indexes the Human Well-being Index (HWI) and Ecosystem Well-being Index (EWI)

that they can be represented as a summary of sixty variable indicators, (Prescott-Allen, 2001).

The Environmental Sustainability Index (ESI) is developed to measure overall progress toward environmental sustainability (Centre for International Earth Science Information Network, 2002).

It consists of 68 indicators of five different categories: the state of environmental systems (air, water, soil, ecosystems, etc.), reducing stresses on environmental systems, reducing human vulnerability to environmental change, social and institutional capacity to cope with environmental challenges, and the ability to comply with international standards and agreements (Centre for International Earth Science Information Network, 2002).

The goal of this indicator is mainly supporting environmental decisions by enabling comparisons between countries.

The first Human Development Report introduced a new way of measuring development by combining indicators of life expectancy, educational attainment and income into a composite human development index, the HDI. The breakthrough for the HDI was the creation of a single statistic which was to serve as a frame of reference for both social and economic development. The HDI sets a minimum and a maximum for each dimension, called goalposts, and then shows where each country stands in relation to these goalposts, expressed as a value between 0 and 1, (UNDP, 2012). in Figure 1.11 the framework developed by United Nation Develop Program (UNDP) shows the components of this index.

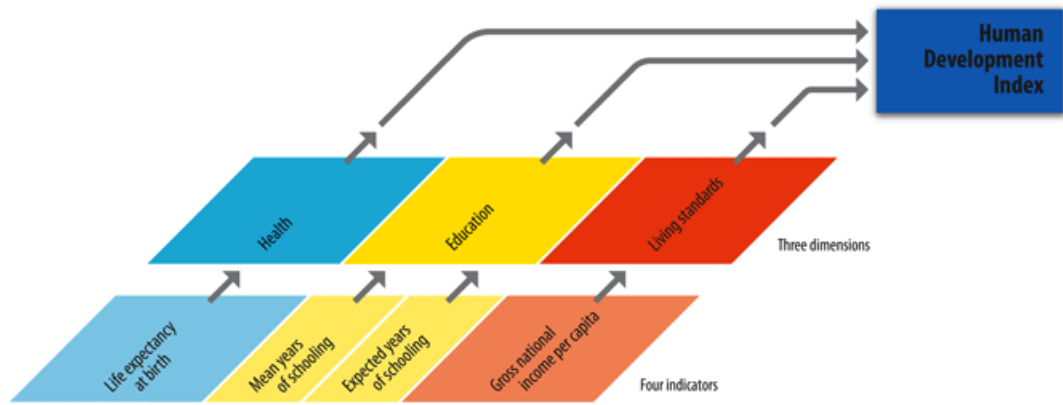


Figure 1.11: Components of Human Development Index adopted from UNDP

## Chapter 2

# Gap Analysis Toward Sustainability Assessments Tools

In the first chapter different tools and methods which are currently in use for sustainability development assessments have been discussed.

In this chapter the goal is to define the scopes of this master thesis toward sustainability assessment tools.

As it is mentioned in the literature review sustainability is an extended subject which involves governments, resources, people etc. so it is clear that there exist large number of tools, methods, frameworks and processes toward sustainability measurements and as a result each of them have some points of strength and some weaknesses respecting to the purpose of measurements and where they applied.

One of the aims of this thesis is to gather an state of the art of what has been done till present time. So it can be considered as a brief and summarized data base on current tools and methods for sustainability assessment, which this goal has been reached on the chapter under the name of Literature Review.

As sustainability tools and methods have very large application in different sectors and areas hence the main goal of this thesis is to discuss about the effectiveness and existing gaps of sustainability assessment tools which are applicable in industrial sectors and then suggesting a solution in order to improve sustainability development assessments in industrial sectors.

Industrial sectors are one of the main users of resources to satisfy the needs of society by their productions through manufacturing processes, hence the subject of sustainability in industrial sector is a critical issue which is the discussion of all the societies and organizations that are working on sustainability issues.

In the first chapter popular sustainability development assessment tools have been discussed and the application of each was briefly described.

From what is discussed there are number of existing gaps that they have the potential of being future research topics toward sustainability development. Reducing the existing gaps will improve sustainability to a new era. The existing gaps are mainly related to sustainability development assessments and their applications.

One of the existing gaps between scholars and practices, is that sustainability assessments are significantly time consuming to be implemented.

there are variety of reasons for this issue which I believe the most important one can be lack of a set of comprehensive indicators for sustainability development assessment. availability of such a comprehensive indicators can enable assessment tools to consider all pillars of the sustainability in the measurements and consequently reducing the need for executing different tools for measuring sustainability considering different aspects and then complementary tools, frameworks or methods to aggregate and compile the results of all measurements so it is possible to announce a unique set of conclusions to support decision makers regarding to sustainability decisions.

The second gap which worth to mention, is that the existing tools, methods and processes of sustainability development assessments are mostly specific ones which they focus on spacial criteria, sector or sustainability aspect. this can be a problem in different sectors or criteria because it may require time to find out about the most proper tool which serves the best for the intended purpose of sustainability measurements and evaluations.

although there have been efforts for finding proper solutions to bridge this gap but still this issue has not been eliminated completely.

another reason in this issue is the level of complexity of decisions vary from simple ones to very complex ones depending on how big a project or a company is and also how many variables are involved in assessments so the necessity of using different types of frameworks or tools can be an extra weight for making the assessments more complex.

A common element which is remarkable between these two important gaps is that they both are reasons to make the process of assessments and measurements as a time consuming process. consequently it is possible to extract a third important gap by investigating these two gaps. this third gap can be interpreted as lack of a tool, framework or a method which is able to assess sustainability developments in the minimum possible time. in the other words there is lack of a rapid assessment tool (RAT).

The lack of this tool is tangible and can be convinced considering some important reasons that they are conclusion of what was investigated in the literature review. sustainability assessment tools should be able to be implemented in all the industrial sectors to be efficient so they should be able to justify the costs and motivations of implementation even in small and medium enterprises and this is one of the most important reasons that the need for and Rapid Assessment Tool is being felt. Another reason which can prove the urgent of such a tool is that there is this gap between scholar and practice in terms of sustainability development assessments and measurements. the idea in researches and scholars is insisting in continuous measurements and analysis while because of the reasons such as complexity of assessments in most of the cases, the need for experts or consultants, costs of assessments, lack of knowledge toward sustainability assessments etc. implementing this idea is more complex than what it seems or even sometimes for small companies it is not justifiable to implement these measurements. so this has been changed to an obstacle toward sustainability assessments in small and medium enterprises.

Aggregating all that have been debated in this chapter and what has been discussed in the previous chapter, it can be concluded that one of the main gaps between what researches and scholars believe that it should be and what is being done in



practice and reality, that still exist is the lack of a comprehensive framework toward sustainability development assessments which can be implemented in all the industrial sectors as a rapid assessment tool. existence of such a framework can measure sustainability developments from a holistic view and this can be the characteristic of such a tool which makes it possible to be implemented in a acceptable time period.

As a result the main purpose and focus of this thesis is to answer to the following question :

*How to implement a Rapid Sustainability Assessment in small and medium enterprises?*

In the next chapters it has been try to suggest a possible solution for this question and the stages toward this process will be explained step by step.

# Chapter 3

## Research methodology

In this chapter the methodology which is followed toward satisfying the research question and purpose of thesis is defined.

The purpose of literature review is to build a body of knowledge of the topic which is under investigation and this goal will be reached following a consecutive set of steps which can be defined as identification, analyzing, evaluating and interpreting them to required knowledge. The main goal of literature review, which is a requirement for each dissertation or thesis can be state as a part to make a review of what has been done about a specific subject and how it is possible to link different studies together. this can be done by:

- Collecting all the studies related to the subject by using keywords and summarizing them.
- Ordering the summarized studies according to their level of relevance and finding the relations between them, points of strength and weaknesses and recognizing the gaps by investigating the most recent developments in the subject.
- Evaluating the built knowledge and trying to put it in a conceptual framework to be easily understood and be able also to identify the future research potentials.

It has been tried to follow a structure similar to what is explained above in this

master thesis as methodology of thesis. So mainly its methodology is consist of four main steps as following:

- Material Collection : gathering required data considering limitations.
- Material Classification: grouping materials according to their concentration on aspics of subject under investigation.
- Descriptive Analysis: qualitative assessment of material.
- Material Evaluation: analyzing and interpreting grouped material.

In the following sections the methodology steps have been explained with more details to make them more clear.

### 3.1 Material Collection:

in this phase the objective is to collect all the related material including papers, articles, books etc. to gather knowledge about the topic under investigation. This phase has been primarily started by web searching and gathering all the related information by the keyword **Sustainability Assessment**. All the used sources are available in the bibliography of these thesis. After this primary search all the required keywords have been defined, they led to the next phase of information gathering which was using the major databases that are available on-line such as, Wiley ([www.wiley.com](http://www.wiley.com)), Emerald ([www.emeraldinsight.com](http://www.emeraldinsight.com)), Elsevier ([www.sciencedirect.com](http://www.sciencedirect.com)) that the focus was mainly on Elsevier database.

#### 3.1.1 Constraints Toward Data Gathering:

I: it is needed to mention that all the papers and articles that have been analyzed are from *peer-review* scientific journals that are published in english and are used more frequent by other researchers, scientist etc. and consequently have been cited more.

II: One the limitations of toward data collecting data was the barrier of language that obliged to exclude some of related sources because they are not available in english version.

III: this thesis includes only papers that they discuss about sustainability assessment and related keywords such as sustainability assessment tools, frameworks etc.

IV: this thesis includes papers between 1995 and 2011.

## **3.2 Material Classification:**

After gathering required material including papers, articles, books, reports etc. it was essential to categorize each of them according to the concept and focused point in order to be able to find out the linkage between concepts and moreover categorizing the concepts facilitated the act of using each paper or article etc at the right place. as a result it was needed to study the papers and articles and related chapters of the books and other materials in order to find out the concepts and points of strength and weakness so it was possible to categorize them. the first classification of material under investigation has been shown in [Figure 3.1](#)

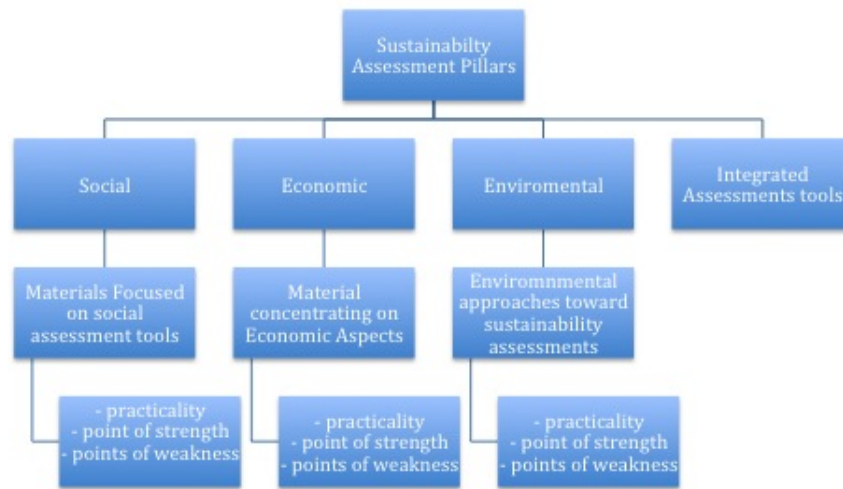


Figure 3.1: Study Material Classification

### 3.3 Descriptive Analysis:

As the objective of this thesis was clear in some levels so the main criteria on which the study intended to focus was known hence all the materials could be categorized in the main criteria. in qualitative analysis this approach is named deductive approach. in deductive approach classification is done before reading materials and sources as it is done also in this thesis. in the first step of descriptive analysis materials are being classified deductively.

In the second step groups of study have been identify inductively from the material concepts for example grouping assessment methods considering sustainability pillars. Microsoft Office Excel has been used as an effective tool for categorizing the material and highlighting the focus point of each material.

### 3.4 Evaluation Phase:

In this step again the study and investigation of all the gathered material started however the intention in this step is to evaluate them and trying to father information and facts and analyze them. this step leads to fonduing the patterns, states of art, concepts, ideas and then recognizing the gaps between what researches and scholars suggest to be and what is happening in reality. this will enable us to find out solutions for bridging this gaps or assessing the current solutions and try to improve them to make them practical or improve them to their next level.

Below in the Figure 3.1 there is a schematic figure which shows explained steps according to the layers in which they are dependent to each other and also the amount of effort they need comparing to each other.

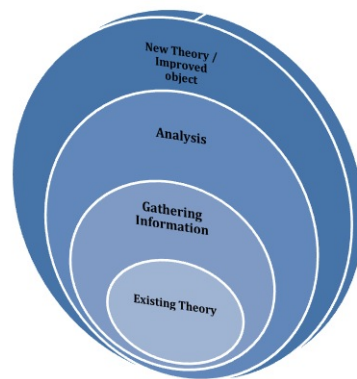


Figure 3.2: Reaserch Methodology of the thesis

To achieve the objective of this thesis the need for gathering data from a source out of the academic sources such as papers, articles, books, workshops etc. was critical because this thesis intends to develop a new solution for the existing gap which is explained in the previous chapter, hence some of the required data are not available in the academic sources so an online survey has been designed and carried out to gather the information from companies to find out at which practical stage they currently are and cover the information gap for the objective of the thesis.

So an on-line questionnaire has been designed and sent to over 200 companies, of which only 16 company replied to this survey. the details of this questionnaire including the purpose for each question, steps of designing questions and the analysis of answers will be explain in the next chapter.

In the Figure 3.3 the main steps of research methodology of this thesis has been schematically shown.

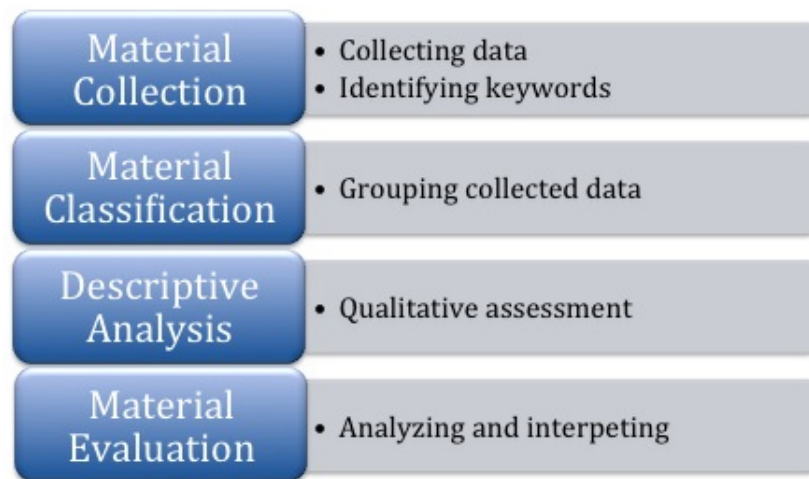


Figure 3.3: Research Methodology Steps

# Chapter 4

## Rapid Sustainability Assessment Tool (RSAT)

After gathering all the articles and required material, they have been classified regarding to their main concept and their focus subject. In order to be able to analyze and evaluate the extracted data it is easier to show them as a framework so by making them more visual the concept will be more tangible and it will be easier to evaluate them.

### 4.1 knowledge architecture

In order to reach the aim of this thesis considering what is explained above following steps have been followed to construct the body of knowledge:

1. Data gathering: Collecting the related material from all the available resources.
2. Data preparation: Purifying data by removing unrelated data comparing to the subject under investigation
3. Data assessment: Evaluating data in order to interpret them or making them ready for being interpreted in order to reach the objective.



In the Figure 4.1 these three steps simply are shown.

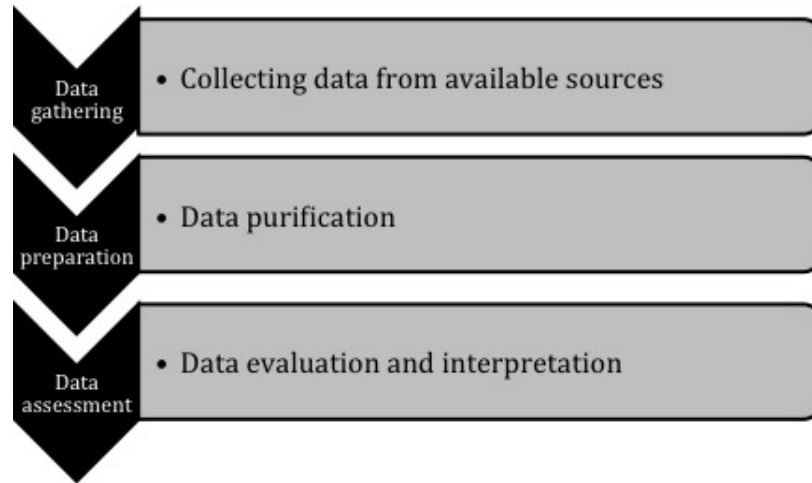


Figure 4.1: Data architecture phases

### 4.1.1 Data gathering

At the first step a web-based search has been executed by using the keyword sustainability assessment. the result was a large amount of articles, papers, academic researches, university and institution websites, workshops etc. all related to the sustainability and sustainability assessments.

As this topic is taken into consideration in variety of fields such as Environmental science, Social Science, Engineering fields such as Industrial engineering and management fields etc. so the variety of materials are quite high so it was required to identify more keywords and repeat the search again in order to filter the results considering more specific keywords hence another search has been implemented in order to collect more specific results which they are more applicable and more aligned with the purposes of this thesis.

This step has been updated several times in order to purify the collected data by executing more filters on each update so data was continuously updated after each collecting stage.

Although the searches for gathering data was repeating for several times, other methods such as brainstorming has been used also for the purpose of reducing the variance of data collection and using other points of view as well.

After selecting the related material according to the steps which are explained above, the collected set of knowledge was ready to start the academic research of this master thesis. as it a was explained before also this thesis has been concentrated on the papers which are published between 1995 and 2011 in international journals in fields of environmental, manufacturing, industrial engineering and similar topics. As the purpose was to find out the latest developments related to the topic under investigation and identifying the gaps it seemed that papers, books, conference reports and journals out of this time interval can be eliminated.

### 4.1.2 Data preparation

A Microsoft Excel spread sheet has been provided in order to make a selection among the gathered material to categorize them and also prioritize them according to their relevance and applicability to the subject under investigation. the categories were identified by signs AAA, AA and A in which papers that are placed in the first category are those that are completely aligned with the objective of this thesis while the second category is less relevant and finally the third category are those that can be useful to clear some concepts during the literate review phase.

this purpose has been reached by reviewing the selected materials again and summarizing the abstracts and taking notes in order to make comparisons in order to find the relation between them.

the reason that this step is named data preparation is because durning several reviews the collected data became more and more relevant by eliminating those materials that their core concept were not relevant or they could be used only for describing some simple concepts so by going more deep in the subject they were not useful any more. In the Figure 4.2 it is tried to visualize these steps that they are described above to

make them more tangible.

### 4.1.3 Data assessment

After categorizing materials according to their core concept and the level in which they are more concentrated on the objective of this thesis, the analysis of the materials has been started. all the material from the first category were studied carefully to extract the existing facts about the subject under investigation and trying to find out the relation between the concepts in the theory and compare them with the current developments which are in practice in industrial sectors.

extracting the existed facts enables the researcher to compare the concept of what it should be and what it currently is and this leads to identifying the gaps.

Identification of gaps will guide to finding solutions to bridge the gaps and hence improving the subject to more advanced level.

not only these steps guide to developing solutions to bridge the gaps but also it can be a complementary work to improve the solutions that are already suggested but still are not complete so it is possible to improve them.

this thesis followed all the explained phases and steps in order to identify the existing gaps between scholars and practice and consequently suggesting a possible solution in order to bridge this gap.

following this objective by analyzing the current state of art toward the subject it has been recognized that there is an important gap which seems

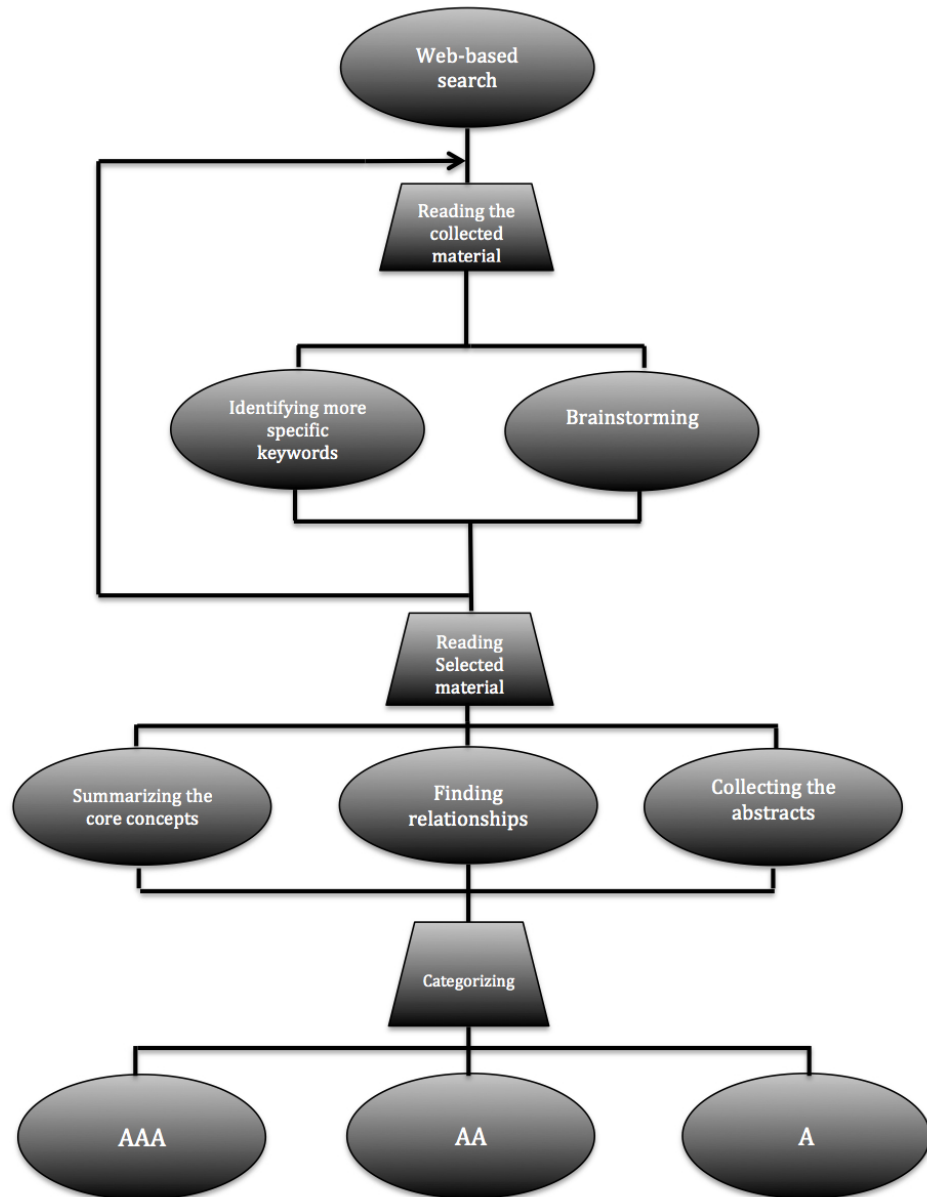


Figure 4.2: Steps Toward Idea Development

that it hasn't absorb so much attention and as a result not many researches can be found in the area. so it has been tried to gather all the possible informations from scholars to find out the linkage between them and develop this new idea and suggest it as a solution to bridge this gap. in the next section the goal is to discuss in detail about this issue.

## 4.2 Idea development

As it is discussed in the chapter literature review not only the effort was to discuss about the main concepts of sustainability and sustainability assessment, but also one of the main goals of this chapter was to identify, distinguish and explain the most popular and applicable tools which are currently being used toward sustainability assessments.

Analyzing the literature and state of art introduce a large number of existing tools, frameworks, evaluation methods, key performance indicators etc. toward sustainability development assessments. considering this fact implementing a sustainability assessment in an industrial sector will be in need for a pre-assessment phase in which it is required to gather a team consist of specialists to choose the best method or framework which can be used for the intended purpose. In order to achieve the most accurate result this selection should be according to the area on which the industrial sector is operating and characteristics and specifications of that industrial area which are different sector to sector and they can be sometimes very complicated considering also the size of the company.

so this pre-phase can itself change to a project in a big company or sector and the first impact will be the implementation time of the assessment which will be a cause for making the project to a time consuming project.

Another important aspect that can be interpreted from what is analyzed through the state of art is that existed methods, frameworks, tools etc. each of them is mainly focused on a specific dimension of sustainability development and this is a reason for

this claim that the lack of a comprehensive tool to consider all the aspects of sustainability at the same time and evaluating the improvement and effects of each aligned with the other one is remarkably being felt.

Developing a comprehensive framework which can be used as a rapid tool to evaluate the level of sustainability and sustainability development in an industrial sector was the first idea for bridging this gap.

as in big industries usually there are assigned departments for sustainability and environmental assessments and evaluations, and also usually there are designed frameworks and pre-defined procedures for sustainability development evaluations and assessments, so they are considered out of the scope of this thesis and the suggested solution is mainly focused on small and medium sized enterprises (SMEs).

The general idea is to develop a framework which it's main purpose is to assess sustainability and it's main features are:

- It includes the key aspects of sustainability assessment.
- It is less time consuming comparing to other frameworks or methods and in other words a rapid assessment framework.
- It is applicable in all industrial sectors.
- It is less complicated comparing to existed frameworks.
- It looks at the sustainability assessment in a holistic view.

These are the most important characteristics of the framework in which this thesis is trying to develop as a solution for rapid sustainability assessment.

By analyzing the state of art a basic framework was developed in order to find out different layers which are integrated and involved directly or indirectly in sustainability assessments. Figure 4.3 shows this framework.

Evaluating deeply, the collected material by considering all the three pillars that they have been explained previously and also concentrating on sustainability assessment as a core concept all have been led to identify this basic framework. it is necessary to mention that integrating the results of this evaluation with conclusions gained from brainstorming with couple of researches in sustainability area also helped to develop the basic framework.

Development of this basic framework was to visualize different layers in order to make them more tangible. it is the conclusion of reviewing existing scholars and discovering the main and common layers that exist in an industrial sector and are mainly involve in sustainability assessments and sustainability developments. in fact by studying all the materials and states of art about the core subject of sustainability assessments and comparing what has been done and what is suggested, some common parameters have been recognized. the relation between these parameters shows that they don't act just as simple parameters but also where ever sustainability assessment is being discussed directly or indirectly they are involved. the key role that they are playing in sustainability assessments changes their role to enablers for sustainability so by finding the exact relationships between them and also sustainability assessments it is possible to develop a general framework which looks at sustainability as a holistic view and by developing suitable key performance indicators for each of these enablers

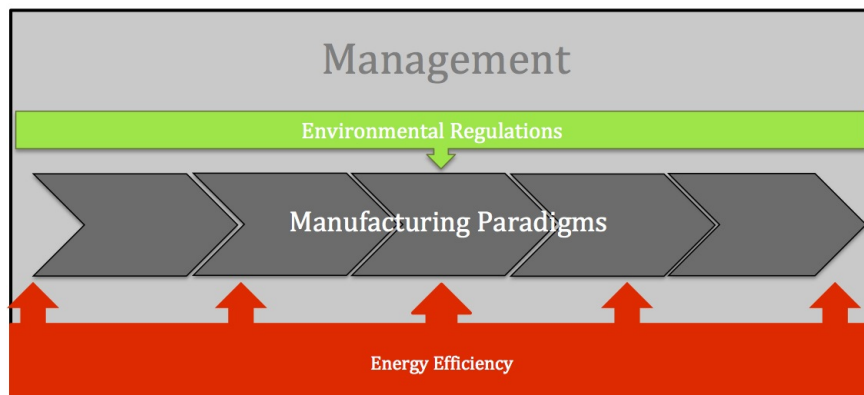


Figure 4.3: Basic Framework

it is possible to use it for sustainability development assessments.

Four main layers in this basic framework are presented that after analyzing the current states of art these layers have been found as common parameters in industrial sectors. after reviewing them more in detail and brain storming the relation between these for parameters or better to say enablers have been recognized as it is shown in the Figure 4.3 these four parameters are:

- Management
- Environmental regulations
- Manufacturing paradigms
- Energy efficiency

### 4.2.1 Management

Management is the main bed for all the other parameters. everything at the first level will be dependent on the policies which are defined by the management from short decisions to long term strategies all will effect the sustainability related decisions hence the management will act as a core on which it influences all the decisions and hence a continues control on all parameters and roles. considering such a important effect of management it is decided to define role of management as a bed for other parameters that they all lay down on it.

Concluding from what is explained above, it is possible to consider strategic approaches which are directly dependent on management decisions and the enterprise policy which is defined by management, can be the first enabler of sustainability development assessments it is a common factor between all industrial sectors.

The importance of management and strategic decisions toward sustainability is an inevitable factor specially when is in a context with other parameters and enablers. for example a decision which is made by management toward implementing a new



policy in the company regarding to economic aspects of company which is decided to redesign the manufacturing processes due to reduction in raw material usage by improving the old processes to new ones using new technology. such a decision will definitely influence the level of the sustainability in the company. this is a very basic and simple example to show that the impacts of policies and decisions defined by management on sustainability developments are inevitable.

### 4.2.2 Manufacturing Paradigms

Manufacturing paradigms are the heart of each enterprise. companies operate according to the defined processes. each activity is consist of a single process or set of processes.

This layer of the framework is concentrated on the assessment of how enterprises define and organize their manufacturing processes.

Manufacturing paradigms have been improved time by time. lean production has been introduced to manufacturing processes in order to increase the benefits as the concept of quality management was added to manufacturing paradigms in order to increase the customer satisfaction.

Presently integrating concepts such as green and sustainable manufacturing with manufacturing paradigms are under investigation and this is a reason to consider manufacturing paradigms as the second enabler toward sustainability development assessments.

In fact manufacturing processes are the main field for implementing assessments because mainly manufacturing process of a company are representative of the companies activities and efficiency and effectiveness so other enablers also are directly or indirectly dependent on manufacturing paradigms.

As a matter of fact today's challenge is how to integrate sustainability with existing paradigms in order to satisfy requirements for a sustainable manufacturing. a reason for this claim is that, in the modern manufacturing era the customer behavior

has been also changed and they became more conscious about the manufacturing processes and this has been changed customer behavior.

This has been made customers to start thinking about economic sustainability hence their expectations toward the products they use also has been changed. as a result in order to be aligned with customers and their expectations it seems critical to integrate sustainability requirements with manufacturing paradigms.

Concluding from all have been explained it can be said that not only manufacturing paradigms will act as an enabler for sustainability development assessments but also integrating sustainability requirements in order to develop a sustainable manufacturing or production system will be a competitive advantage in the new manufacturing era.

The U.S. department of commerce has published a comprehensive strategy review of manufacturing challenges in U.S. that this paper has discussed the evolution of manufacturing paradigms and systems and how more green they became by time. after reviewing this paper a diagram has been designed in order to illustrate and summarize this issue and make it more tangible. Figure 4.4 shows how manufacturing systems moved toward sustainability by time.

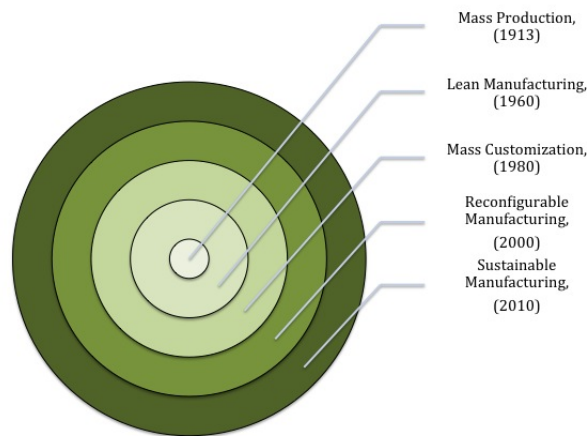


Figure 4.4: Evolution of manufacturing systems toward sustainable manufacturing

### 4.2.3 Environmental Regulations

Environmental regulations are considered not only as an ethical issue between human being and the environment that human being is living in but also later they changed to a competitive advantage for industrial sectors to be more environmental friendly. Governments understood that we are responsible toward the environment that we are living in hence in order to reduce the harmful impacts of industrial sectors different regulations have been defined to be obeyed in order to reduce the harmful impacts of industrial activities on environment we are living in.

This issue is more complex than what it seems because different operations have different impacts on environment and in a company depending on company size the number of operations are from hundreds to thousands and defining regulations for each is a complex process. different organizations and institutions including governmental or private ones are continuously working on these regulations in different sectors and different operations and this has been improved as the the manufacturing process intended to become more green by time because of variety of reasons such as responsibility toward our environment, customer behavior changes, competitive advantages etc.

In the current era of industry and manufacturing customers are more aware of issues around them and goods and their production processes are not excluded from this fact so their behavior and expectations toward the products they use has been changed for example their tendency toward environmental friendly products has been improved. considering this fact plus referring to the famous definition of sustainability given by Brundtland Commission, the importance of environmental regulations and the motive for development and improvement of those regulations is obvious. hence industrial sectors also will consider this fact by trying to become more green. as a result developing a sustainable manufacturing is an important step toward green production and green and environmental friendly production means being responsible toward the environmental we are living in plus considering the future needs of next generations which in general all these mean sustainability. from what is explained

it is clear that the concept of sustainability and environmental friendly production are tightly hand to hand in a way that existence of one is not applicable without the other one.

From what is explained it is clear that companies are trying to implement environmental regulations in order to adjust themselves with the new era of product and manufacturing processes hence they are trying to move toward sustainability. in fact it is possible to claim the first step toward sustainability to be taken by industrial sectors is execution of environmental regulations which are also considered as an competitive advantage to show how green and as a result how sustainable they are.

According to all has been explained environmental regulations has been introduced as an enabler toward sustainability assessment in industrial sectors. it is described above that not only some of these regulations are mandatory and an obligation for industrial sectors but also some others are considered as competitive advantage according to the ability and potential of the enterprises in implementing these regulations. as a result it is clear that this parameter is a common factor between industrial sectors and hence it can be introduced as an enabler toward sustainability development assessments especially when the assessments are being implemented in a holistic point of view.

#### **4.2.4 Energy Efficiency**

In this section energy efficiency will be discussed as the main enabler of sustainability development assessments in an industrial sector.

As it was discussed in previous chapter the purpose of this thesis is to develop a solution for a rapid assessment of sustainability which can be applicable in industrial sectors and mainly in small and medium sectors (SMEs). but it is needed to mention that along with this purpose this thesis will focus on energy efficiency as one of the dimensions of the developed framework, more because energy efficiency (EE) has

been recently understood as an important key role and enabler toward sustainability and still there are lack of attention toward this important enabler and it is missing in many of the frameworks and methods in sustainability assessments.

As it was illustrated in the Figure 4.4 manufacturing is moving toward green and sustainable manufacturing comparing to the last couple of decades. the focus of manufacturing approaches have been changed from pure cost to quality, productivity and delivery performances. significant environmental and economic impacts which is associated with energy consumption causes energy efficiency to gain a remarkable attention in both theory and practice.

As it was mentioned previously the focus of the thesis is more on energy efficiency as a diminution of the developed framework. As a result this thesis intends to put more stress on this aspect by giving more in detail knowledge about it.

In the new era of manufacturing reasons such as scarcity of resources, strict legislations, awareness of customers and competitive advantages made industrials to think about better and more efficient use of resources. these reasons along with economic considerations due to raises in energy price made energy efficiency as a remarkable bold topic between both industrial sectors and academic scholars.

Concerns such as global warming and scarcity of resources have been reasons for developing strict regulations in industrial sectors and putting pressure on policy makers in industry because large amount of energy is being supplied from carbon based sources and this has been increased more than 25% during last 20 years (IEA, 2008). International strategies and policies such as Europe 2020 have been made the first key concept toward energy efficiency and energy efficient manufacturing.

Enterprises have been feeling the necessity of evaluation and assessments of their systems, processes and methods in order to find out how energy efficient they are and they can be, considering global and industrial obligations to do so.

After recognizing how beneficial is to control and assess energy consumption in an industrial sector the importance of energy efficiency and energy efficient manufacturing

became clear for manufacturing companies hence improvements in energy management and its integration with manufacturing systems is being remarkable.

Due to mentioned reasons it is needed that companies paying more attention to effective use of energy and resources along with traditional performances in order to be able to compete with other in their area of activity. consequently putting more effort on in-depth analysis of energy and resource performance within they manufacturing processes is an urgent that should be taken in action.

### 4.3 Framework Development

Beside all the given knowledge which is mentioned above to illustrate the importance of energy efficiency, there is another key concept which makes energy efficiency a critical and key concept which should be under investigation for improvements. the reason that converts energy discussions to a critical issue is that energy is considered as one of the key factors for sustainability development because not only it's environmental impacts, but also it's social and economic impacts are significant and as these are exactly the main pillars toward sustainability development hence the key role of energy efficiency toward sustainability development is clear. thus energy efficiency becomes a core issue for policy-makers and industries and society.

Recognizing the key role of energy efficiency made scholars to start investigating the potentials of energy efficiency and developing methods, frameworks, tools etc. toward sustainability developments. although the topic is significantly under investigation in both academy and industry but still lack of holistic frameworks toward integration of sustainability developments and energy efficiency exist. reviewing the state of art in the respected area is a prove for this claim that is also explained in the chapter related to literature review.

A basic framework has been introduced at the beginning of this chapter. this basic framework has been concluded from an in detail review of current states of art and each part of this framework has been explained with reasoning that why they are

introduced as enablers for sustainability assessment. as it was mentioned also because of the special focus of this thesis on energy efficiency as the most important enabler in the framework and on-line survey has been executed in order to gather real data from industrial sectors in which the development of the survey will be explain in the next section. So by gathering all the required data and after analyzing them deeply and also integrating them with the basic framework which was mentioned previously, a path has been made that led to develop the below framework as a framework which has a comprehensive and holistic view toward sustainability development assessment and can be considered as a Rapid Sustainability Assessment Tool.

This frame work has a comprehensive and holistic view toward sustainability assessment which is comprise of four components:

- Strategic Approach
- Manufacturing Paradigms
- Environmental Regulations
- Energy Efficiency

The importance and effectiveness of each enabler is explained in this current chapter to illustrate that at the first step how they can act as enablers and secondly to illustrate the importance of each. after developing the basic framework and the data which is gathered from the on-line survey, by analyzing all the data and a deep review of the characteristics of each enabler with the purpose of gaining a deep knowledge toward them a new frame work has been designed in which considers the inter connection of these enablers toward the framework and also it shows how they are connected with each other.

Figure 4.5 shows the main pillars of the developed framework for sustainability development assessments which is named Rapid Sustainability Assessment Tool.

This framework is completely a new framework for sustainability development assessments and the novelty of this framework is because of following characteristics:

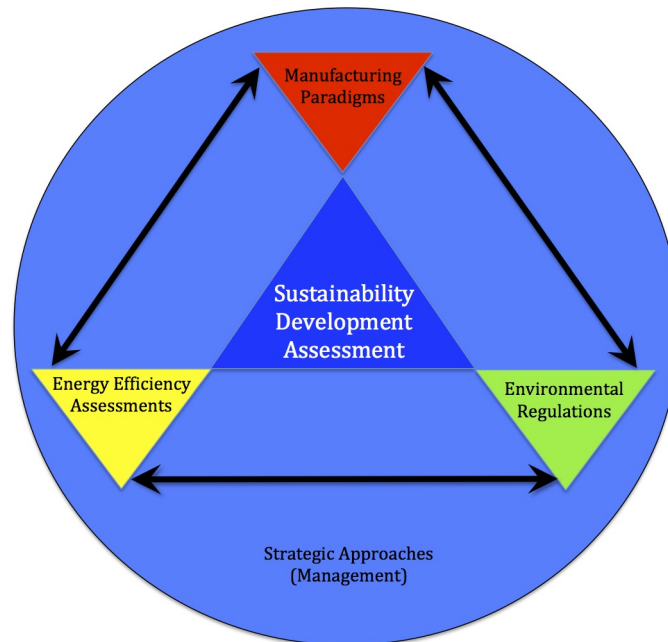


Figure 4.5: Main Pillars of Rapid Sustainability Assessment Tool (RSAT)

- It includes the key aspects of sustainability assessment.
- It is less time consuming comparing to other frameworks or methods.
- It is applicable in all industrial sectors.
- It is less complicated comparing to existed frameworks
- It looks at the sustainability assessment in a holistic view

As it is clear from these characteristics this framework includes the common parameters which exist in almost all the industrial sectors so it is applicable in all the industrial sectors and mainly small and medium enterprises (SMEs) and the reason is that usually large companies have their own trends and methods for sustainability and energy assessments while in small and medium companies reasons such as lack of budget, lack of speciality or experts, etc. have been changed to obstacles toward sustainability assessments. however this frame work has this power to show the simplicity of sustainability assessments because it uses the very common enablers which



exist on each industrial sector more over it highlights the role of energy efficiency assessments and measurements as a key enabler toward sustainability and sustainability assessments.

Another advantage of this framework is that it can enable industrial sectors to become comparable in terms of sustainability developments and assessments. the reason for this claim is that industrial sectors in the same area use the same set of environmental regulations or similar to each other and as they operate in the same criteria usually they use similar manufacturing paradigm systems by adding energy efficiency assessments they will be able to be compared in terms of sustainability developments with a good estimation.

As a matter of fact the heavy weight of this framework is being held by energy efficiency assessments. introducing energy efficiency assessments in this frameworks will show how important is this enabler and more attention is needed for this component. in fact integrating energy efficiency with manufacturing systems will enable industrial sectors to continuously move toward sustainability development and sustainability assessments.

As far there are limited number of scholars and academic works in which discuss about energy efficiency and integration of energy efficiency with manufacturing systems and this proves that this topic is a very new one which is gaining attention in both academia and industry very fast. due to this limitation it was needed to gather required data from real industry word.

As a matter of fact this survey have been designed to answer to the research question of: **How to assess energy efficiency developments in an industrial sector?**

Hence, this study intends to establish a basis for the companies and academia to have a holistic understanding on energy efficient practices as a first step on the way to integrate energy efficiency in manufacturing. In this context, we identify the main

objectives as below:

- Understand how and what companies are doing currently to integrate energy efficiency in their manufacturing.
- Determine the priorities of companies and stimuli for energy efficient manufacturing.
- Understand the level of consideration given to integration of energy efficiency in manufacturing on the industry side.
- Develop insight into the use of ICT and other supporting tools/methodologies for improving energy efficiency.
- Identify the gap between the theory and the practice.

The expected practical implications are insights and suggestions to practitioners in order to foster energy efficient manufacturing, aligned with the strong commitment from different actors in Europe (academia, industry and policy makers) to head towards sustainable development. Since the study will highlight the gap between academia and industry serving as a reality check between what is being developed in theory and what is implemented in the real business context and thus help to identify future research directions in the area, academics in operations management and energy related research fields will benefit from the findings as well.

The idea of rapid sustainability assessment tool has been inspired from a paper which is published in the May 2002 Harvard Business Review about Rapid Plant Assessment by Dr. Goodson, Professor at the University of Michigan Business School teaching operations management.

He explains that when he was heading up the automotive seating operation at Hoover Universal once he was very influenced by a report from a group of visitors coming from the Japanese competitor. They asked for permission to visit the plant and it has been agreed on the condition that they reciprocate and as it was believed they will learn from this tour the tour took less than an hour in one of the best plants

and visitors didn't take any note during this brief tour. at the end when reading the report of the Japanese group everybody was shocked by the level of details that they explained the plant.

This shows that having a framework which is comprise of suitable indicators can enable a trained and knowledgable person or in other words a trained eye to assess a plant in less than a day and this is what currently is missing in sustainability development assessments.

Figure 4.5 represents the main pillars for sustainability development assessment and their relation to gather. here in this part the components of each pillar will be discussed. key performance indicators (KPIs) are always useful tools for assessments and evaluations. among the existing KPIs some of them have more effect in assessments depending on the purpose of assessment. According to this fact it is possible to develop a framework based on the indicators that influence sustainability assessment more so by using them we can have almost a precise estimation of sustainability developments in a short period of time.

In the Figure 4.5 the main pillars of rapid sustainability assessment have been illustrated. now in the Figure 4.6 the components of each pillar will be shown and each of them will be discussed to make it clear how they will lead to the implementation of a rapid sustainability assessment.

As it is clear in the Figure 4.6 the components of the main pillars have been defined. these indicators have been chosen according to to their influence on sustainability plus their common features between small and medium size enterprises. in the next parts each of these components will be discussed to show how the are able to assess sustainability development in an industrial sector.



Figure 4.6: Components of Rapid Sustainability Assessment

### 4.3.1 Environment

The first pillar is environmental dimension. this aspect can be considered as minimum requirement for evaluating sustainability. environmental regulations considering different aspects such as Environmental management standards (ISO 14001), Energy Management Standard (ISO 50001) etc. are sometimes considered as competitive advantage and some also are obligatory for some industrial sectors. there are large number of these regulations that some times the costs of keeping and implementing them are not convincible. but still this dimension is one of the main pillars of sustainability and can be considered as a minimum requirement for sustainability developments. in other words it is the necessary condition but not sufficient.

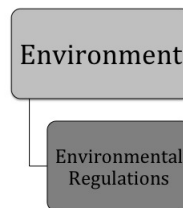


Figure 4.7: Environmental dimension

### 4.3.2 Manufacturing Paradigms

Manufacturing Paradigms are the main bed for executing the sustainability practices. the main effort is to try to integrate methods, tools and similar processes with manufacturing processes to move them toward more sustainable production.

the main components in this pillar can be summarized as:

- production processes
- technology
- quality

These three sub categories can lead to evaluation of the production system and how sustainable it is or how sustainable it can be. production processes, is the main subcategory since in a company each activity is being done by a set of processes. integrating sustainability practices with processes has been always the first goal of sustainability development.

The subcategory of technology will evaluate how the sector is operating according to the latest improvements and how the sector is applying the existing technologies toward sustainability. does the sector changes the production technology according to new improvements to become more sustainable? this sub category intends to answer to these questions then it will be possible to find out how important sustainability is in this sector and how integrated are sustainability developments with manufacturing processes.

In the subcategory quality intends to find out about risk management and suggestion channels which exist in the sector. finding the potentials in order to integrate sustainability practices mentioned practices of quality in the production processes can be a big step toward sustainability so this subcategory intends to find out this possibility.

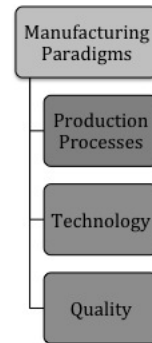


Figure 4.8: Manufacturing Paradigms dimension

### 4.3.3 Energy Efficient Manufacturing

As it is mentioned before the focus of this framework is on energy efficiency. Integrating energy efficiency practices with manufacturing systems is a big step toward sustainability.

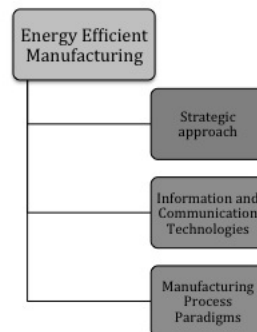


Figure 4.9: Energy Efficient Manufacturing

**Strategic approach:** The main issue here is the alignment of energy efficiency in manufacturing with corporate goals. Commitment of top management is a crucial part for implementation of any kind of measures in the industry and establishes the base for strategic focus. The concepts under scrutiny regarding the strategic focus of the companies are e.g. policies and standardization; strategic decisions (e.g. buy-sell, demand management, location decisions, etc.); technology selection, development and deployment; Investments on research and development and innovation; and

eventually voluntary initiatives (e.g. CSR, etc.).

Information and Communication Technologies: ICT has the potential to play a very significant role in improving energy efficiency in manufacturing and its share and importance has been growing during recent years. Hence, ICT as a supporting tool and an enabler for achieving energy efficiency in manufacturing needs a further consideration. Thus, ICT dimension of the framework will be the main focus of the study. ICT provides support through following dimensions:

- ProductionITSystems(e.g.ERP,MES,SCADA,etc.)
- Support on manufacturing processes (e.g. CAD, CAM, etc.)
- Internet of Things and Future Enterprise Systems
- Intelligent sensors and control systems, etc.

Manufacturing Process Paradigms: This part of the framework is aimed at assessing how companies organize their manufacturing processes in such a way that energy efficiency is effectively integrated in manufacturing. To manufacture any product, some set of processes should be followed and types of processes depend on the type of products as well as companies considerations of different aspects and related decisions in manufacturing. Manufacturing technologies (e.g. development of technologies and materials), manufacturing process management (MPM), process design and optimization, switching energy modes of machines (i.e. on, off, stand-by, etc.) and scheduling are examples to paradigms to be considered.

#### 4.3.4 Management

As a matter of fact management as it is also shown in the Figure 4.5 and also in the basic framework, is the main bed that other pillars are laid on it. the reason is that directly or indirectly all the approaches in the company is under influence of management decisions and actions.

in the subcategory of strategic decisions mainly the purpose is to find out how aligned

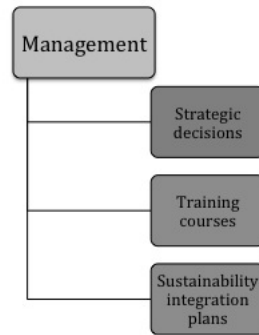


Figure 4.10: Management Dimension

are sustainability development plans with corporate aims and approaches. commitment of top management is the first step toward implementing sustainability development plans and measurements in the company.

subcategory of training courses follows the fact that how well-known is sustainability culture in the company and between employees. does the management board consider training courses for middle level managers, low level managers and employees to adjust the culture of continuous sustainability improvements? this is a critical question that shows how knowledgeable are different levels of employees toward sustainability developments and how is the culture of sustainability in the company.

sustainability integration plans is a subcategory that directly investigates the plans that management is executing in the company or plans to execute toward sustainability developments.

## 4.4 Survey Development

As it is described before, it is defined in the objectives of this thesis to integrate energy efficiency in the framework which intends to bridge the existing gap toward sustainability development assessment. To reach this objective gathering data from real industrial world was an important necessity specially that the number of papers and scholars which discuss specifically about energy efficiency and sustainability assessments are very limit and this made the idea of this thesis as a novel and new idea.



To pursue the explained objective, an explorative research has been done by designing an on-line survey with the purpose of assessing manufacturing companies and gathering some data from industrial sectors.

Survey method is mainly implemented in the study to assess the energy efficiency related practices in the industry with the purpose of obtaining an insight using the framework developed. base on the research objectives a questionnaire of 10 comprehensive questions has been developed to assess the companies. This survey was composed of questions about company characteristics, energy efficient strategies and applications of the company, supporting tools and relevant manufacturing processes. the main components of the questionnaire are based according to the latest framework developed by (Gokan May, 2011) for evaluating energy efficiency in industrial sectors and mainly small and medium enterprises (SMEs).

Questionnaire is consequently designed according to main components of the named framework. this framework is based on four enablers for energy efficient manufacturing and questions are based on these four enablers. Since intentional or unintentional bias could occur in the answers to many questions as some companies are willing to see/show themselves more energy efficient than what they really are, alternating objective and subjective questions have been asked to test reliability and the validity of the responds. The questionnaire have been modified several times in order to make some questions easier to understand, some questions have been eliminated because of being very technical or academic and some other questions have been added in order to assure that all the required information will be collected..

After all the revisions the final version of the questionnaire became ready and it has been uploaded on the internet using the Survey Monkey website which is an on-line survey developer. then the link of the survey has been sent to the companies which is the below link:

*<http://www.surveymonkey.com/s/Y59Y36C>*. The survey response collection process

began by sending the questionnaire by email to all the contacts collected and re-sending if not replied. There had been 2 reminders by e-mail to the non-respondents followed by a phone call where possible.

Questionnaire was sent to a combination of large companies and SMEs. Sample firms were selected from manufacturing companies operating in Europe in mechanical, electric and automotive sectors. Although the questionnaire was proposed to over 300 companies, we got the responds from and analyzed 16 companies which are subject to many EU legislations. The respondents were all relatively large companies. This survey includes questions about company characteristics, energy efficient strategies and applications of the company, supporting tools and relevant manufacturing processes.

The main objectives of this thesis can be defined as:

- To attain a better understanding of current practices of companies toward energy efficiency
- For theory building and fact finding and testing
- Identifying existing gaps between theory and practice

#### **4.4.1 Analysis of the survey questions and answers**

In this section it has been tried to analyze the answers which have been collected by the on-line questionnaire. the survey was consist of 10 comprehensive questions with the aim of recognizing sustainable strategies of the companies and the role of energy efficiency assessments in the companies.

The first question of the survey was dedicated to the characteristics of the company and industrial sector that they operate. mainly the respondents were from Non-energy intensive sectors (e.g. electrical, mechanical, automotive and semi-conductor industries).

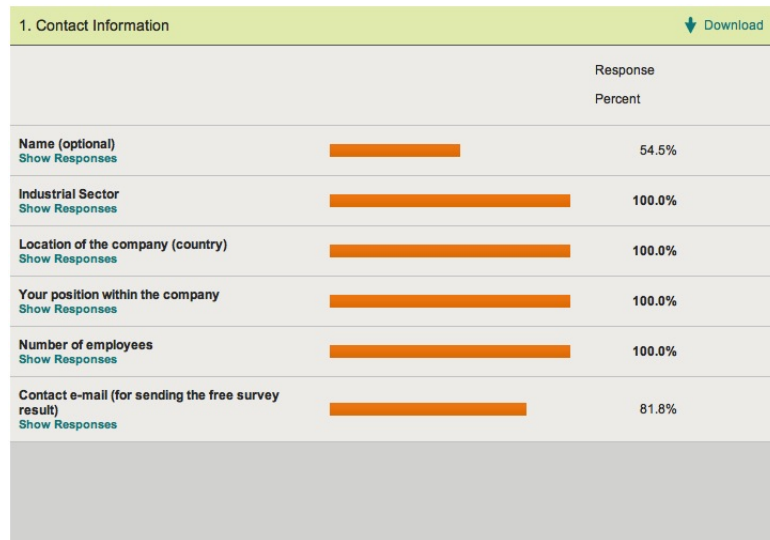


Figure 4.11: Question 1

The second question has been asked with the intention of recognizing that at the first step how energy intensive are the companies and secondly to highlight the fact that energy efficient manufacturing can enable companies to significantly reduce their costs in other words to highlight the economic aspects of energy efficient manufacturing.

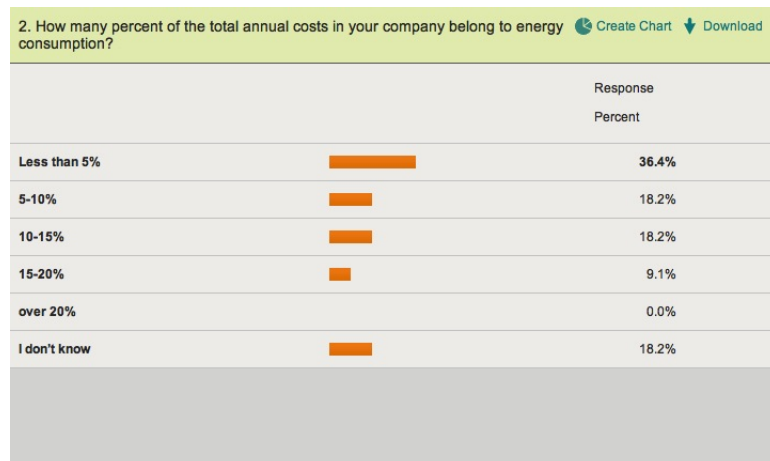


Figure 4.12: Question 2

The third question follows the purpose of recognizing which method is more applicable in industrial sector so it can be compared with the enablers of the framework to find out how practical they are in the industrial sectors. This question has the potential of finding the gaps also between the theory and practice. Each alternative in this question represents different aspects of energy efficiency assessments; hence in this way it is possible to understand the weight of each aspect also. As it is clear by the answers, assessing energy efficiency is becoming more popular than, for example, regulations concerning this issue. One of the reasons can be the complexity of the large number of existing regulations which makes companies have more tendency toward energy monitoring, specially in the new manufacturing era that the economical benefits of energy monitoring are more significant than costs of implementing regulations.

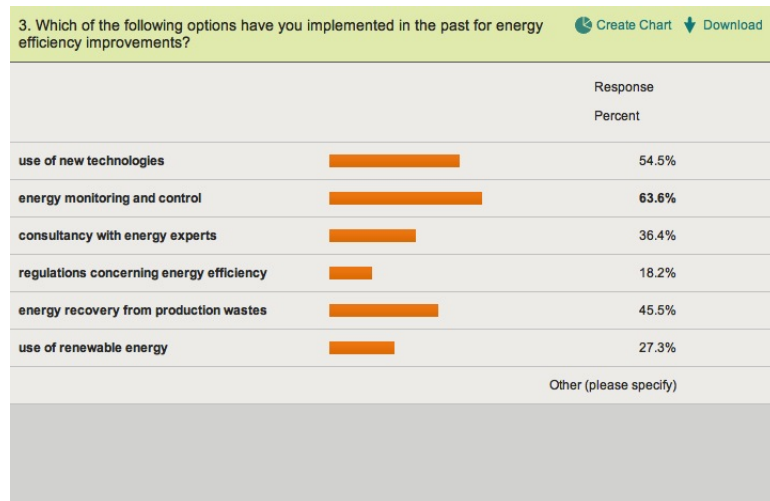


Figure 4.13: Question 3

Question number four specifically asks about the environmental regulations which are implemented in the companies. The purpose of this question is to find out which type of regulations are being mostly implemented mostly in the companies and the responses were interesting because as it is shown 72.7% chose ISO 14001 series which are Environmental Management Standards and this can be a reason that why in the suggested framework environmental regulations is introduced as one of the enablers toward sustainability assessments.

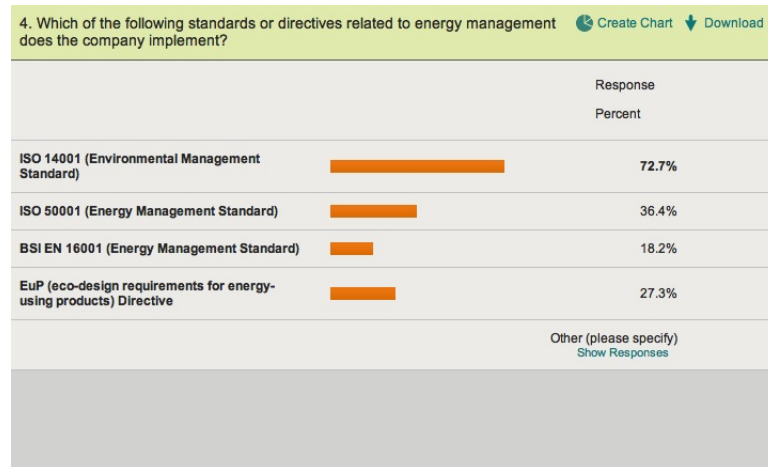


Figure 4.14: Question 4

The fifth question is dedicated to the incentives and drivers for companies to become energy efficient. mainly the purpose is to evaluate the different aspect and impacts of implementing energy efficiency with manufacturing systems. most of the alternatives in this question are directly or indirectly toward sustainability development and the responds show that the intention of industrial sector toward sustainability development is remarkable because the answers are mainly spinning around economic and environmental aspects which they are main pillars of sustainable development. and the interesting part is the tendency of the responds toward gaining these goals through energy efficient manufacturing and this can be a prove for considering energy efficiency as an enabler in the suggested framework.

Question number six intends to find out which kind of tools are mainly used in industrial sectors in order to support decision makers for considering energy efficiency in their decisions. it seems that the most popular tools are economic tools while energy assessment tools are in the second rank and finally benchmarking tools. integrating energy efficiency with manufacturing systems has significant economic impacts putting aside it's important role toward sustainability development. for the managers and decision makers it is normal to mainly use the help of cost calculating tools

5. Please rate the importance of the following drivers in your company for becoming energy efficient?						
	1 (unimportant)	2 (slightly important)	3 (moderately important)	4 (important)	5 (very important)	6 (vital)
reducing energy costs	0.0% (0)	9.1% (1)	9.1% (1)	36.4% (4)	36.4% (4)	9.1% (1)
reducing energy consumption	0.0% (0)	0.0% (0)	18.2% (2)	18.2% (2)	36.4% (4)	27.3% (3)
reducing carbon footprint	18.2% (2)	9.1% (1)	18.2% (2)	45.5% (5)	9.1% (1)	0.0% (0)
enhancing overall environmental performance	0.0% (0)	0.0% (0)	27.3% (3)	27.3% (3)	45.5% (5)	0.0% (0)
enhancing reputation	0.0% (0)	9.1% (1)	9.1% (1)	36.4% (4)	45.5% (5)	0.0% (0)
improving compliance with regulations	0.0% (0)	9.1% (1)	0.0% (0)	54.5% (6)	27.3% (3)	9.1% (1)
sustainability targets	0.0% (0)	9.1% (1)	9.1% (1)	36.4% (4)	36.4% (4)	9.1% (1)
changes in customer behavior	0.0% (0)	9.1% (1)	27.3% (3)	36.4% (4)	27.3% (3)	0.0% (0)

Figure 4.15: Question 5

in order to make required short term and long term decisions.

In the next question which is one the most important questions of this framework, the purpose was to discover the importance and also validity of the enablers for the energy efficiency assessments or in other words this question intends to recognize how proper are the the enablers which are introduced for assessments of energy efficiency and energy efficient manufacturing. by enablers of energy efficient manufacturing the purpose is the latest framework toward energy efficiency assessments which is proposed by (Gokan May, 2011). this framework considers four main enabler for energy efficiency which respectively are:

- Strategic approach
- Information and Communication Technologies
- Supporting tools and methodologies

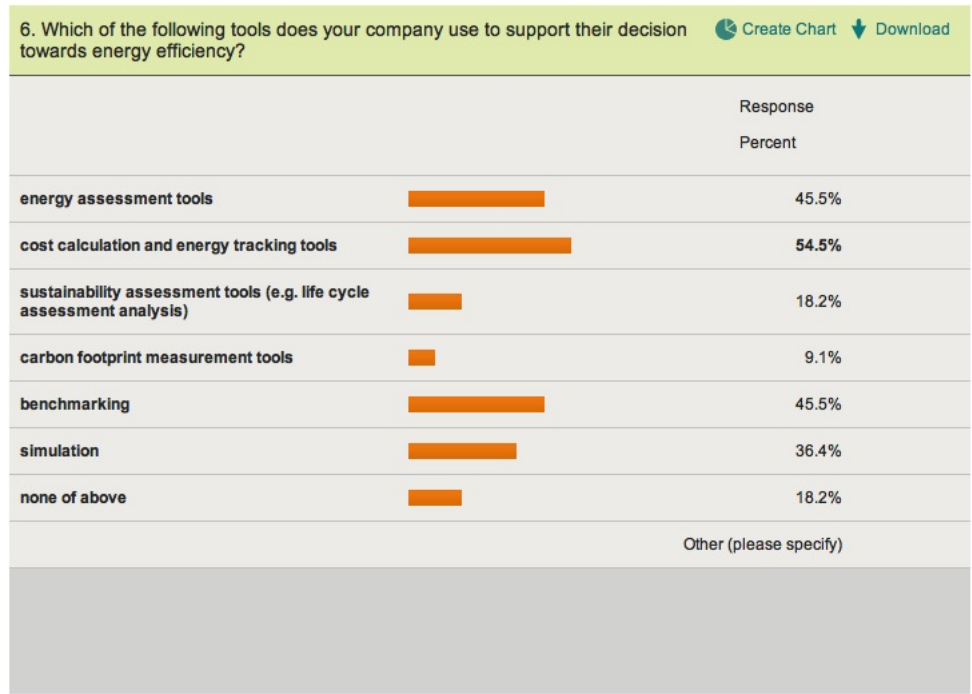


Figure 4.16: Question 6

- Manufacturing Process Paradigms

the responds to this question shows that almost all alternatives given in the choices for answer that are representatives of these four dimensions, have the importance of more than average and this is a prove for the validity of the introduced enablers or at least they show that in the industrial sectors they play a key role toward energy efficiency assessments.

The next question is trying to investigate firstly how interested are industrial sectors toward integration of energy efficiency in the manufacturing paradigm systems and secondly how applicable is integration of energy efficiency in industrial sectors. more over it also tries to investigate at which level industrial sectors are more interested to integrate energy efficiency with their processes. from the answers it is

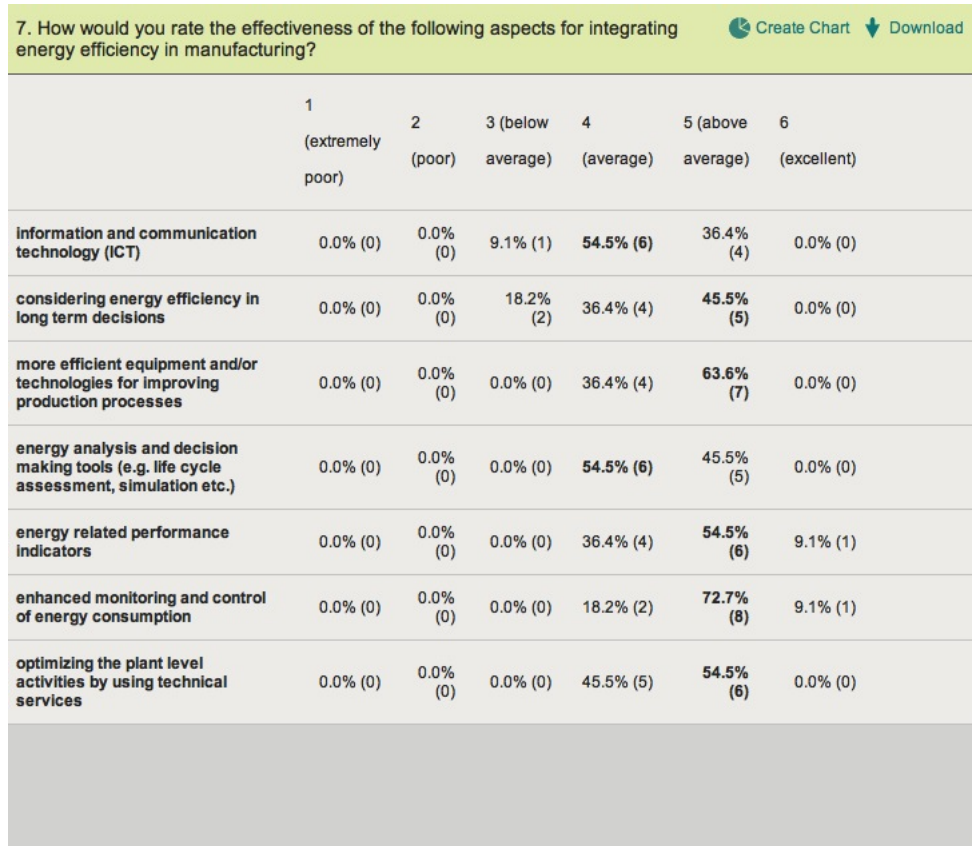


Figure 4.17: Question 7

possible to conclude the high interest of industrial sectors to involve their manufacturing paradigms with energy efficiency assessments with the intention of implementing energy efficient manufacturing which intact is a significant step taken toward sustainability development. going more in detail and analyzing the alternatives it is interesting that the use of new technology, machinery and/or materials and aligning production plans with energy efficiency practices have the heaviest wight among the the other alternatives. this can interpret the level of flexibility in which industrial sectors are interesting to show toward energy efficiency practices.

Question number nine ha the purpose of focusing specifically on the ICT as the most important enabler in the suggested framework by (Gokan May, 2011). the role of ICT in integrating energy efficiency with manufacturing systems is advancing as



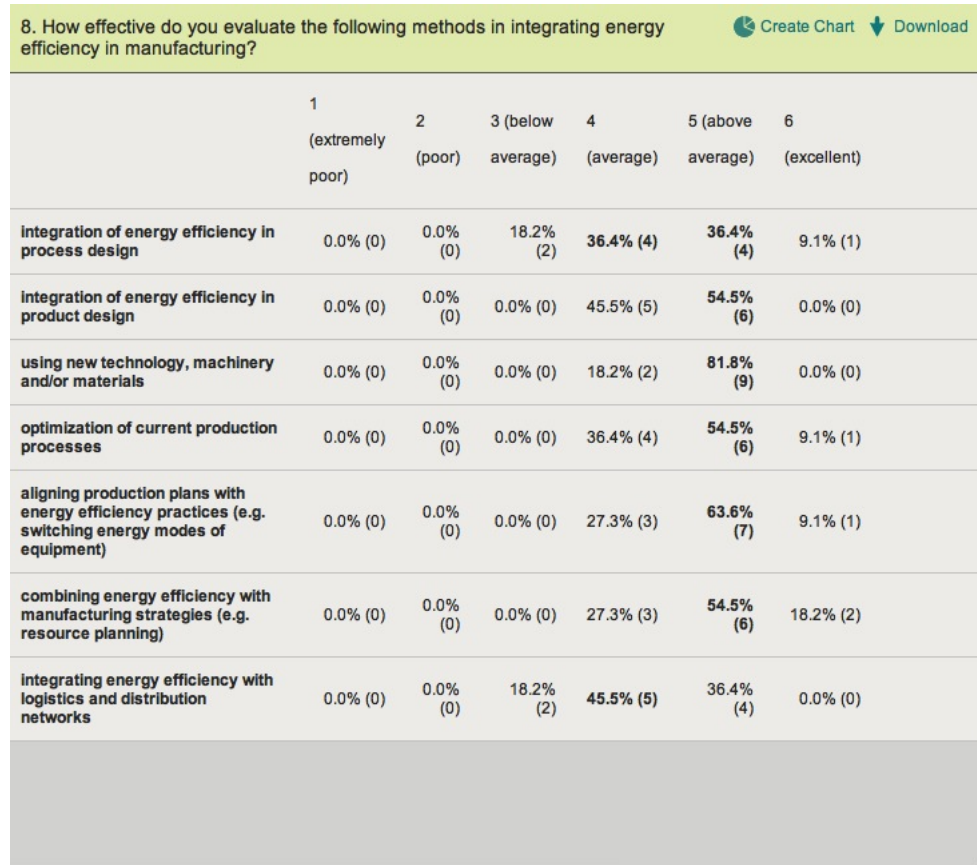


Figure 4.18: Question 8

it plays an important role because it can act as a multifunctional enabler which can facilitate energy efficiency improvements. The questions try to investigate how necessary and how effective industrial sectors think about implementation of ICT as a supporting tool and enabler for energy efficiency. The responses show that almost all the alternatives which in fact are different applications of ICT in energy efficiency assessments, have a high degree of importance for industrial sectors and this can also show that ICT has a high potential to be investigated in both industry and academia.

The last question of the survey has been dedicated to the barriers toward implementing energy efficiency. The alternatives have been extracted by analyzing 25 published papers about energy efficiency and the barriers toward its implementation.

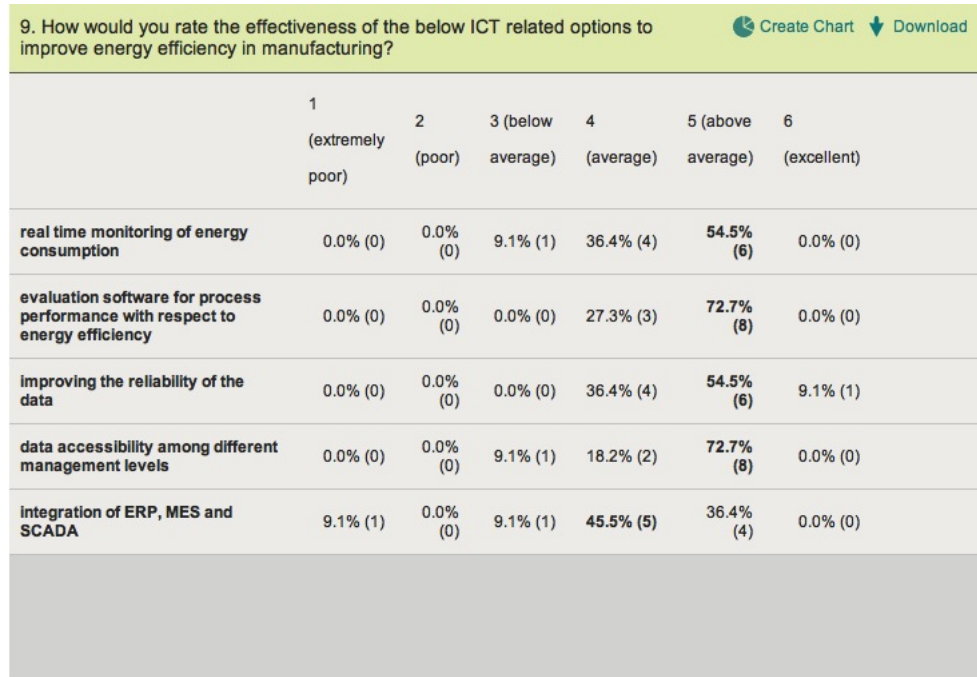


Figure 4.19: Question 9

after analyzing the responds it has been recognized that the wight of the answers for each is more or less the same. this represents that all of these choices can be considered as existing gaps toward execution of energy efficiency plus some of them are serious barriers toward sustainability developments too. so the question plays the role of a fact finding question.

The questionnaire has been tried to be a comprehensive one in order to cover all the required aspects and dimensions toward energy efficiency and sustainability regarding to the purpose of this thesis. to do so 30 international published papers have been analyzed to extract the questions in way that it assures that at the end all the objectives will be reached by covering the aim dimensions of the existed framework. to do so there was a big obstacle and it was the number of the questions because if there were a large number of questions and it changes to a long survey in which take more than ten minutes to be filled up almost nobody would be interested in answering the survey so it should be designed in way to be as short as possible no to take more

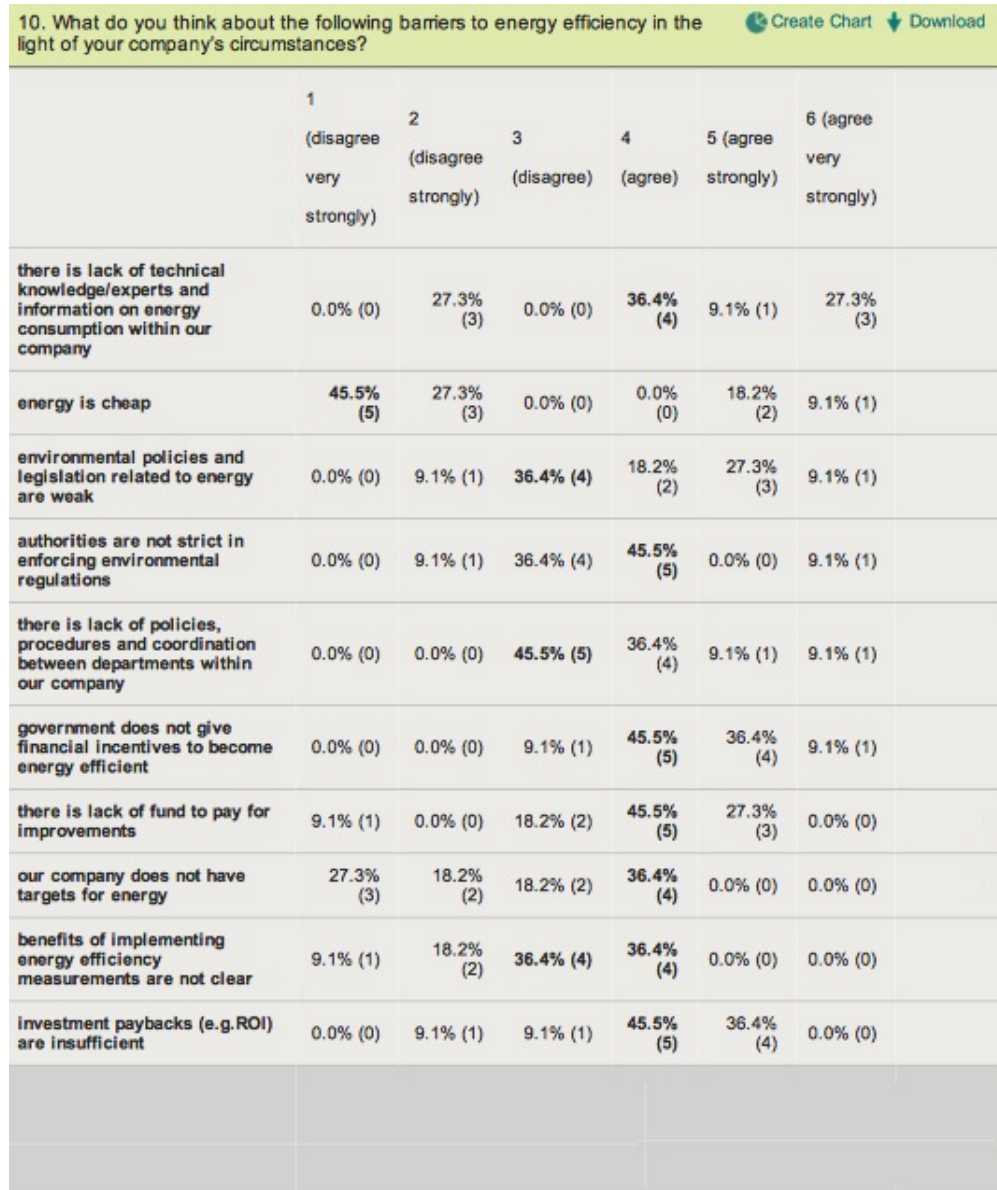


Figure 4.20: Question 10

than 10 minutes to be answered while at the same time it should assure that the required data will be gather in order to be able to develop the new framework which is the main objective of this thesis.

So after several revisions the presented survey has been approved as the final version of the survey and uploaded on line to be ready to send for the available contacts.

It has been sent almost for 300 company contacts that unfortunately large number of companies replied that because the existing policy in the company they are not able to answer to the survey. the rest have been notified to answer to the survey by mail that finally at the end 16 responds have been collected.

In this research, we investigated practices and viewpoint of the manufacturing industry with regards to energy efficiency. The findings revealed that although there has been a consistent progress in the industry toward energy efficiency, the implementation of the concept is still not mature enough. There is no sign of strong evidence regarding the integration of energy efficiency in manufacturing as a new performance target area.

# Chapter 5

## Result and Conclusion

Since sustainability has gained lots of attention as a result sustainability development assessments also became an important issue for companies and industrial sectors. there are large number of methods, regulations, frameworks and tools to reach this purpose.

In this thesis the effort was on developing a Rapid Sustainability Assessment tool. after evaluating the state of art a large number of frameworks and key performance indicators have been recognized in order to evaluate sustainability developments in different industries. the remarkable point is that most of these frameworks or KPIs are limited to a specific sector or area of activity or they are limited because they are not able to assess sustainability in a comprehensive way. in other words they mainly are focused in one of the pillars of sustainability and less focus to the other pillars at the same time.

The effort was on extracting a set of indicators that they are able to assess sustainability development by appreciating following conditions:

- have a holistic view on sustainability assessment
- considers all the sustainability pillars in assessment
- be applicable in all industrial sectors

- be able to evaluate a sector in less than a day

pursuing the goals mentioned above the effort was on extracting suitable set of indicators for sustainability development assessment that can satisfy the mentioned aims also.

To do so latest papers and state of art has been collected and after analyzing them a set of indicators which look more important and more influential toward sustainability assessment have been extracted to develop a new framework with a set of comprehensive indicators for sustainability assessment.

The important fact which is recognized is the importance of energy efficiency in sustainability practices. energy efficient manufacturing is a big step toward sustainability assessment which is gaining more attention in industrial sector. energy efficient manufacturing is becoming the aim of many industrial set ors due to it's huge advantages.

This thesis has a specific insist on energy efficiency and energy efficient manufacturing. to be able to do a gap analyze real data from industrial sector was needed so an on-line survey has been developed in order to answer to the research question (RQ): How to assess energy efficiency developments in an industrial sector?

In this research, we investigated practices and viewpoint of the manufacturing industry with regards to energy efficiency. The findings revealed that although there has been a consistent progress in the industry toward energy efficiency, the implementation of the concept is still not mature enough. There is no sign of strong evidence regarding the integration of energy efficiency in manufacturing as a new performance target area.

The research contributed to knowledge with the answers to some fundamental questions in the context of energy efficient manufacturing. It focused on the empirical aspect from one side and served as a picture (of course in the local context of the companies researched) for what the applications and practices in companies are regarding energy efficient manufacturing.

This kind of state of the art systemization established a useful base for comparison with further researches. Furthermore, the paper provided insights on how and what companies are doing currently to integrate energy efficiency into manufacturing as well. Of interest could as well be the explanations of those that are to serve as a reality check between what is being developed in theory and what is implemented in the real business context.

Further researches should be done taking more cases and samples to better understand the maturity level of integrating energy efficiency in manufacturing.

Due to limitations of a mast thesis, the designed framework and the introduced indicators are still not enough mature and more development it is needed to recognize it's weaknesses and improve them. so there will be some research questions to continue this work in future and develop a mature framework toward Rapid Sustainability Assessment.

Here are some recommendation for future works root from this research to be continued:

1. Developing indicators for a comprehensive Rapid Sustainability Assessment Tool.
2. Integrating continues sustainability development with manufacturing processes.
3. Energy efficient manufacturing an enabler toward sustainability development.
4. Integrating energy efficiency with manufacturing processes and sustainability developments.
5. Developing methods toward continues energy efficient assessments.

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