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Unorthodox measures of economic performance

Bachelor's thesis

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Abstrakt: Posouzení dlouhodobé ekonomické výkonnosti je palčivým problémem dnešní ekonomie. Existuje mnoho rozličných metod, jak toho docílit, především jsou to indexy udržitelnosti (Sustainable society index, Ecological footprint, Urban Sustainability index, etc.), které však trpí mnoha problémy (monetizace, vážení). V posledních letech byla vyvinuta metoda, která je založená na fuzzy logice a multikriteriální rozhodovací analýze, nazývaná NAIADE. Ta se vyrovnává s mnoha problémy, kterými trpí výše zmíněné indexy, avšak nebyla zatím aplikována v mnoha případech. Cílem mé bakalářské práce je podat přehled dnes používaných indexů, představit multikriteriální rozhodovací analýzu, provést výpočet pomocí NAIADE a vyhodnotit výsledky České Republiky v mezinárodní perspektivě.

Klíčová slova: udržitelný rozvoj, Česká republika, multikriteriální rozhodovací analýza, NAIADE, Sustainable Society Index.

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Abstract: Assessing long-term economic performance is persistent problem of current economics. Various methods exist, most often in form of indices (Sustainable society index, Ecological footprint, Urban Sustainability index, etc.), which however suffer from many issues (monetization, weighting). In recent years assessment method called NAIADE based on fuzzy logic and multi-criteria decision analysis has been developed. It deals with many problems of aforementioned indices. This approach has not yet been applied to data of many countries. Goal of my bachelor's thesis is to give overview of currently used indices, introduce multi-criteria decision analysis, perform computation of NAIADE and discuss rankings of the Czech Republic in international perspective.

Keywords: Multi-criteria decision analysis, NAIADE, Czech Republic, Sustainable development, Sustainable Society Index

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I herby declare, that I have written this thesis using only literature and other sources listed in bibliography. Furthermore, I declare that I have not used this thesis to acquire another academic degree. I acknowledge and agree with lending and publishing of the thesis.
Prohlašuji, že jsem svou bakalářskou práci napsal samostatně a výhradně s použitím citovaných pramenů. Dále prohlašuji, že jsem tuto práci nepoužil k získání jiného akademického titulu. Souhlasím se zapůjčováním práce a jejím zveřejňováním.

In Prague, 15^{th} May 2011 Tomáš Křehlík

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TEZE BAKALÁŘSKÉ PRÁCE

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Garant studijního programu Vám dle zákona č. 111/1998 Sb. o vysokých školách a Studijního a zkušebního řádu UK v Praze určuje následující bakalářskou práci

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Charakteristika tématu, současný stav poznání, případné zvláštní metody zpracování tématu:

Assessing long-term economic performance is persistent problem of current economic theory. Various methods exist, most often in form of indices (Sustainable society index, Ecological footprint, Urban Sustainability index, etc.), which however suffer from many issues (monetization, weighting). In recent years assessment method called NAIADE based on fuzzy logic and multi-criteria decision analysis was developed. It deals with many problems that were related with the indices mentioned. This approach has not yet been applied to data of many countries. Goal of my bachelor's thesis is to give overview of currently used indices, introduce multi-criteria decision analysis, perform computation of NAIADE and discuss rankings of the Czech Republic in international perspective. In the final part, I will discuss prospects of the Czech Republic in sustainable development.

Struktura BP:

1. Introduction
2. Sustainable development
    i. Definition
    ii. Methodological issues
3. Current indices
4. Multi-criteria decision analysis
    i. Introduction
    ii. Mathematical background (possibly as appendix)
    iii. New vs. the old method
5. Multi-criteria decision analysis in case of the Czech Republic

6. Prospects of sustainability of the Czech Republic
7. Remarks
7. Conclusion
A. Data

Seznam základních pramenů a odborné literatury:

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Podpis konzultanta

Podpis studenta

Contents

1. Introduction

> *Fundamentally transforming the foundations of the economy is the biggest contribution we can make towards building a sustainable future. The current economic crisis may be painful, but it will be nothing compared with the crises we will face if we continue to grow in a way that threatens the life-support systems on which we rely.*

Jonathon Porritt[1]

Current evaluation of economic performance is often reduced to looking at GDP and whether it is growing or not. This is, however, a very narrow-minded attitude towards such a complex problem as assessment of economic performance is. There might be two types of misunderstanding that lead to such problems.

The first type of fallacy is that the term *economic performance* is interpreted only as production of assets. But this is in sharp contrast with today's economic imperialism that tries to capture most of human actions as well as with Marxian stream of economic though, which dictates, as Schumpeter puts it, that economy *"had in the social engine the role of transmission belts."* (Schumpeter, 1997) Hence, when assessing economic performance, we also have to assess other aspects (the whole engine) of society than production. The theories should comprise social well-being, environmental issues, institutions, and the economy.

Nevertheless, one might argue, that GDP is a good proxy for most of the things to be looked at. This is the second issue that is often encountered – GDP is worth looking at as an indicator of well-being. I address this issue in detail in the first section of the theoretical part of my thesis. There, we look at GDP from different perspectives. Either from the side of the defendants, or from the side of *attackers*, and sum their most important arguments about GDP. Results of this part suggest that we should keep looking for other measures of economic performance.

Having a reason to search for different measures we dig further into the literature and find some important concepts that help us to define what exactly we are

[1]Jonathon Porritt, Chair, Sustainable Development Commission of the UK, announcing 'Prosperity Without Growth' report (March 2008)

looking for. In the second part of the theoretical section, the concept of sustainable development is thoroughly discussed as the basic definition from which we should derive any measures and against which we should test it.

In the following part, we discuss how we should approach the measurement. There are essentially three ways, and all have their pros and cons. The three methods are:

- index method – creating an index that aggregates some underlying indicators,
- accounting method – using national accounts to create measure of sustainability. That is, to use a similar approach GDP uses,
- multi-criteria decision analysis – a method that orders (and assigns numerical preference to) different years according to their sustainability. From such ranking we can distil information on the *sustainability trend*.

All the methods are explained, and their advantages and disadvantages are presented. The bigger part is devoted to introduction of multi-criteria decision methods. These are less known, and a large part of the thesis relies on them. Nevertheless, full and formally flawless definition and explanation of the methods is beyond the scope of this thesis. Some basic definitions are presented, but mostly we help ourselves with examples to demonstrate how the methods works.

In the empirical part, we examine evidence for the Czech Republic. The first section looks at indicators, namely Human Development Index and Sustainable Society Index. They are both first examined from the theoretical point of view, and then the results for the Czech Republic are presented and interpreted, keeping in mind all the critical remarks. Also comparison with five countries, that are in some aspects close to the Czech Republic, is done to bring about context to plain numbers.

The second section presents, to my knowledge first, application of a multi-criteria method for the Czech Republic to identify sustainability trend. The section was inspired by Shmelev and Rodríguez-Labajos (2009), who applied the same method for Austria. The method, as stated above, is rather complicated, and in this section I present a discussion of some issues related to setting it up. Through discussion we arrive to several scenarios. Comparison of Austrian and Czech trends contributes some interesting points of view to our study.

In conclusion, I try to present full picture of increasing sustainability trend that we have found. I try to add contours to it by identifying some issues. In the very end possible extensions to this work are presented.

2. Theoretical background

2.1 GDP and why not to talk about it.

Gross Domestic Product is the most widely used economic measure, hence the question that naturally arises is to ask whether we could use GDP or GDP per capita as a measure of sustainable development. There is wide range of arguments against it, let us summarize the most crucial ones stated in Dasgupta (2007), Daly (1992) and Stiglitz et al. (2009). To begin the survey of critiques Lawn (2003) notes about GDP:

> *The current paradigm of Orthodox Economics seeks to find out what makes the market function well. GDP is frequently utilized as a sign of a healthy market. The tendency to overlook the fact that GDP measures only some aspects of welfare and to treat it as a general index of national well-being is an archetypal instance of the fallacy of misplaced concreteness[.]*

First, we must note that GDP is a metric of economic production but neither measure of well-being nor of sustainability. Concerning well-being, we might imagine example, when old factory produces more products, however it emits more pollution at the same time. Were GDP a well-being indicator, it would mean, that well-being grown, despite the pollution. One can argue that we might adjust GDP for all such externalities. However, still GDP would contain items that can be valued ambiguously. For example, does consumption of alcohol increase our well-being? Other objection might be drawn from direction of Easterlien paradox. Easterlin (1974) claims that despite growing GDP per capita, human happiness has not increased at all since the second world war.

Moreover, sustainability is connected with efficiency of use of the natural resources, sole objective of maximizing GDP does not tell us anything as GDP might grow through extensive depletion of resources when effectiveness of use of the resources is in fact declining. Dasgupta (2007) defines a productive base of a nation as the variable that should be in focus. It consists of not only capital but also of institutions. This productive base is, according to Dasgupta source of nations well-being. In empirical example, he shows that such productive base may be shrinking even when GDP is growing.

Second, GDP is monetary measure and often prices for the goods might not even exist or be distorted because of market failure. Some of the prices might be guessed through imputations, but the data tend to be of lower quality. Connected issue is comprehensiveness – different methodologies are used for imputations in various countries. Other aspect of monetary measurement is that it often does not reflect quality change, which might be more important to well-being than price change.

Also, accurate GDP measurement relies on the very principle of markets – prices being accurate. However, in the theory of efficient markets there are many assumptions to make markets work accurately. The most interesting for us are: i) ability to choose freely, ii) having complete information. Many violations of these two assumptions can be found in the real world. For example, *"complex financial products are an example where consumer ignorance prevents market prices from playing their role as carriers of correct economic signals."* Stiglitz et al. (2009)

Connecting the last remark to sustainability agenda, which often copes with accurate pricing of natural resources; in case of non-renewable resources, the markets are inefficient until future generations would be allowed to access our markets and bid on them. Having flawed prices, in sustainability perspective, the GDP is also inherently flawed.

On the other hand, some defend GDP as reasonable indicator that is worth keeping in mind. In defence of GDP Anand and Sen (2000) say:

> *"At the level of objectives, the case for following Aristotle rather than Mun is not hard to appreciate. How can we possibly give priority to the means of living, which is what treasures and wealths are, over the ends of good and free human lives? While much of economic and financial writing proceeds as if there is nothing beyond opulence with which we need be concerned, it is fair to see that as a problem of presentation, rather than a reflection of some deep-seated eccentricity about ends and means. The really interesting debates must relate to instrumental effectiveness of overall wealth and opulence in promoting those things for which wealth and opulence are sought.*
>
> *There is, in fact, much more substance in the opulence-centred approach than the implausible view that opulence is an end in itself. This takes us to the second difference, which relates to the cause-effect relationships in the pursuit of the deeper objectives. Some have taken the view that while opulence is not to be valued at all for its own sake, it still is the most important instrument in promoting the more basic objectives—even the*

Aristotelian one of rich and fulfilling lives."

As we see even defence of GDP does not deny that GDP is not the goal. It only notes that GDP is important and should be watched in connection with other phenomena.

To sum up the arguments, GDP does not say whether we have cleaner environment to live in, GDP does not say whether we are healthier or happier as a nation and it does not say in what type of society we live in. Also for many aspects of sustainable development markets do not exist, thus they cannot by reflected in GDP. This is the main rationale for searching for other measures and pursuing the path of sustainable development.

2.2 The Concept of sustainable development

Sustainable development is an idea which has roots in 1970s, namely conference of the United Nations have declared: "*the need for a common outlook and for common principles to inspire and guide the peoples of the world in the preservation and enhancement of the human environment,*" (UN, 1972). The declaration was, however, mainly focused on ecological issues and it was not until 1987 when Brundtland Commission, which was also part of the United Nations, released a report called *Our Common Future*[1] (World Commission on Environment and Development, 1987) – document that described concerns about ecology and poverty. The term sustainable development was popularised by the commission and the report.

Distinguished and common cited definition of sustainable development was presented in Brundtland report itself. The Brundtland report (World Commission on Environment and Development, 1987) says:

> *Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts:*
>
> - *the concept of 'needs', in particular the essential needs of the world's poor, to which overriding priority should be given; and*
> - *the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs.*

Such definition, despite being simple, provides solid background for understanding the notion. However, study of development and sustainability led, among other

[1]It is often referred to as *Brundtland report*.

things, to creation of two conceptually different directions in looking at sustainable development – *weak sustainability* and *strong sustainability*[2]. These two offer different views of economical, ecological and also societal development. We shall look at them closely.

2.2.1 Weak sustainability

Most accepted definition and also the most simplistic one of the concept of weak sustainability is presented in Pearce and Atkinson (1993) in form of weak sustainability index. Weak sustainability indicator is presented in form

$$Z = (S/Y) - (\delta_M/Y) - (\delta_N/Y), \tag{2.1}$$

where
S – savings in the economy,
δ_M – depreciation of man-made capital,
δ_N – depreciation of natural capital,
Y – national income, GDP.

Then, we distinguish between economies with negative and with positive Z. We describe these cases:

$$Z \begin{cases} > 0 \Rightarrow & \text{economy is sustainable,} \\ = 0 \Rightarrow & \text{economy is marginally sustainable,} \\ < 0 \Rightarrow & \text{economy is not sustainable.} \end{cases} \tag{2.2}$$

In other words, Z presents how many percent from national income is turned into investment. An economy is said to be sustainable, if percentage of national income turned into investment is non-negative, otherwise it is not sustainable.

Hence, weak sustainability is in full compliance with the definition provided by the United Nations as it asserts that when economy is sustainable the stock of capital is non-shrinking in time. The definition also suggests that certain degree of substitution always exists. Solow describes notion, that we do not have any specific obligation to future as substitution exists: *"It attracts your attention, first, to what history tells us is an important fact, namely, that goods and services can*

[2]In literature, more elaborate decomposition might be found. One example adds two polar cases *very weak sustainability* (so-called) Solow sustainability and *very strong sustainability.* For more detail, see Turner (1992). Daly and Goodland (1996, pg. 1006) add to the base cases *absurdly strong sustainability* – total status quo defenders; and *intermediate sustanability* which defines some *"critical levels of each type of capital, beyond which concerns about substitutability could arise [...]".* (Daly and Goodland, 1996, pg. 1006)

be substituted for one another. If you don't eat one species of fish, you can eat another species of fish. [...] That is extremely important because it suggests that we do not owe to the future any particular thing. There is no specific object that the goal of sustainability, the obligation of sustainability, requires us to leave untouched." (Solow, 1993)

Weak sustainability as such is conceptually based pre-eminently on macroeconomic growth theory. Core discussion and results in the discipline were presented in 70ties and 80ties, mainly by Solow (1974), Stiglitz (1974) and Hartwick (1977). As Gutés (1996) puts it: *In fact, weak sustainability becomes nothing but a different name for Hartwick-Solow's rule expressed in the form of maintaining total capital stock.*

Anand and Sen (2000) discuss broader philosophical background of the concept and promote universalism in connection with sustainable development. Universalism is a doctrine that states that the concept should be applied to everybody – not only we should care about future generations, but we should also care about those with smaller political power in the current world. A natural critique of world's hypocrisy that we care about sufficient living conditions for future generation while overlooking problems of nowadays is presented in Anand and Sen (2000).

Several assumptions beyond the theory are, however, subject of critique. The main notion and problem at which all discussion is aimed is that by defining two categories of capital – man-made capital and natural capital, it follows that natural capital is homogeneous and thus *"substitutions are then studied on the basis of setting degrees of substitutability between these two categories."* Gutés (1996, pg. 151). Costanza and Daly (1992) present three arguments against common tacit assumption of high constant elasticity of substitution, they object:

> *If human-made capital were a perfect substitute for natural capital, then natural capital would also be a perfect substitute for human-made capital. But if the latter were the case there would be no reason to develop and accumulate human-made capital in the first place! Why does one need human-made capital if one already has an abundance of a near-prefect substitutes? Historically, we developed human-made capital as a complement to natural capital, not as a substitute. It should be obvious that the human-made capital of fishing nets, refineries, saw mills, and the human capital skill to run them does not substitute for, and would in fact be worthless without, the natural capital of fish populations, petroleum deposits, and forests.*

Such rather persuasive objections have to be taken in mind when talking about weak sustainability. They often lead to the second concept.

2.2.2 Strong sustainability

Belief that growth of GDP is our ultimate goal and technological progress through market will solve our problems is not shared by all. The non-believers have pursued different path, or we might say different paths, as many authors have proposed their own vision of stronger paradigm, which are today called strong sustainability.

Even though attitudes of different authors are various as Neumayer (2004, pg. 24) states, they share the opinion that *"the essence of SS[strong sustainability] is that it regards natural capital as fundamentally non-substitutable through other forms of capital."* Another common feature can be added. Most authors defend the precautionary position that even if the paradigm of weak sustainability was right, it is better to preserve what we can, and afterwards be pleasantly surprised that technology has solved our issues rather than trying our luck and be wrong. Daly and Goodland (1996, pg. 1006) say: *"Since we do not know exactly where the boundaries of these critical limits for each type of capital lie, it behoves the sensible person to err on the side of caution in depleting resources (especially natural capital) at too fast rate."*

Strong differentiation of development and growth is emphasized in the literature. Growth is seen as mere *"increase in size [...] by assimilation"* , however development is to *"bring out potentialities, capabilities"*. (Daly and Goodland, 1996, pg. 1004) Talking about sustainable development then does not necessarily imply economical growth. On contrary, Daly (1992) defends the idea that people do not really need growth and that there is no real argument why we should expect to have more[3] in the future than we have at the moment. Against historical evidence that zero growth brought but crisis, Daly defends his idea by notion that our system is built to depend on growth, however

> *The fact that an air plane falls to the ground if it tries to remain stationary in the air simply reflects the fact that air planes are designed for forward motion. It certainly does not imply that a helicopter cannot remain stationary.* (Daly, 1992)

Methodologically, authors differentiate among three to four different aspects of strong sustainability (goals of economic development, for more precise goals see figure 2.1): social sustainability, environmental sustainability, economic sustainability and, sometimes, institutional sustainability is included. The primary goal is environmental sustainability, however, having lost the ability to substitute natural capital for other forms of capital, it has been realised, that to achieve environmental

[3] *To expect to have more* is itself an exclamation of pure hyped greed when used in connection with European society. As Daly (1992) sarcastically says: *It is evidently impossible to have too much of a good thing.*

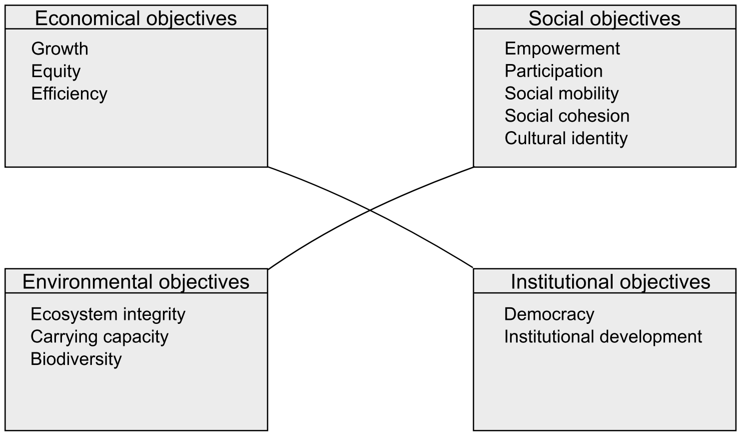


Figure 2.1: Development goals and interconnections (Modified from Daly and Goodland (1996))

sustainability, we need strong civil society, democracy, and during that we do not want to lose our living standards, thus we need to sustain economic capital.

Through specific needs we have postulated, we are starting to get to the problem of measuring the notion of sustainable development and its progress.

2.3 Measuring sustainability

Since the time of Brundtland report, much effort has been put into development of standardised tool to measure sustainability of development of a given country. Most notably we should mention *Beyond GDP conference* – initiative of the European Union – many reports by OECD focused on sustainable development indices and work of Eurostat and United Nations (UN) in developing standardised set of sustainable development indicators. Other example of work dedicated to reforming classical measures of economic performance may be found in France. Commission on the Measurement of Economic Performance and Social Progress has been constituted. Even though no sustainable development issue is explicitly mentioned in the name, the problems of measuring economic and social performance and measuring sustainable development are interrelated and the commission has done considerable work in addressing current problems. The results are summarised in Stiglitz et al. (2009).

Most of the work in the field has been concentrated on producing various indices, mainly composite indicators, which have one very appalling feature in common – simplicity. The reason behind it is, that the simpler the presentation of an idea (as in case of simple indicator) the easier it is to be adopted by policy-makers. Freudenberg (2003) says:

Technique	Equation
Standard deviation from the mean	$\frac{\text{actual value}-\text{mean value}}{\text{standard deviation}}$
Distance from the group leader	$100\left(\frac{\text{actual value}}{\text{maximum value}}\right)$
Distance from the mean	$100\left(\frac{\text{actual value}}{\text{mean value}}\right)$
Distance from the best and worst performers	$100\left(\frac{\text{actual value - minimum value}}{\text{maximum value - minimum value}}\right)$
Categorical scale	Assigning score

Table 2.1: Overview of normalization techniques, modified from Freudenberg (2003).

> *Despite their many deficiencies, composite indicators will continue to be developed due to their usefulness as a communication tool and, on occasion, for analytical purposes.*

However, with creation of a composite indicator comes also responsibility as *"indicators arise from values (we measure what we care about), and they create values (we care about what we measure)"*. (Meadows, 1998)

Creating a composite indicator poses a difficult problem, as many issues arise during the process. Bohringer and Jochem (2007, pg. 2) identify in literature five requirements for selecting sustainable development index, these are:

- the rigorous connection to the definitions of sustainability
- the selection of meaningful indicators representing holistic fields
- reliability and availability (measurability) of data for quantification over longer time horizons
- process orientated indicator selection; and
- the possibility of deriving political (sub) objectives.

More notably they address problem of normalization, weighting and aggregation, which is the most painful methodological problem in the process. Standardised set of steps to create an index exists; first, variables have to be identified, then the data have to be standardised – normalization technique is used, scale might be adjusted and the data has to be converted into common unit. Most commonly used normalization techniques are summed in table 2.1. After standardization comes aggregation which produces a single number from the standardised data. Bohringer and Jochem explain that reliable methods should be found, as they are essential to creation of a good indicator. Along with that they, however, explain that normalization and weighting inherently include value judgement, thus making the task for development of purely scientific method much more difficult. Munda (2008, pg. 72-74) comes to similar conclusion with emphasis on observation that the weights in classic composite indicator

$$I = \sum_i w_i x_i, \ \sum_i w_i = 1, \text{ where } w_i \text{ are weights.}$$

are never importance coefficients, but they are rather set substitution relations between variables.

Apart from composite indices, other approaches that try to assess sustainable development exist. We can identify two methods that are used the most. First is an accounting approach. The method tries to account for phenomena which are not reflected in common national accounts or calculation of GDP. Final output is usually monetary, ideologically close to GDP, and expresses net income.

The second approach, which will be used in this paper, is using multi-criteria decision analysis to assess sustainability trends. Multi-criteria approach is a set of methods, which have different attributes and ways of processing data, each more suitable in different case. Munda (2008) argues that multi-criteria approach possesses all necessary features for good measurement of sustainable development. Application of such methodology is, however, prone to *decision-making paradox* (Triantaphyllou, 1989). That means that if we want to apply the method, we first need to set some criteria. These criteria in turn influence the final ranking, hence the method cannot be totally objective.

Forthcoming part offers a survey of commonly used indicators and their description.

2.3.1 Indicators of sustainability

In their article Bohringer and Jochem (2007) present an overview of the currently most known sustainability indicators. They are summed up in table 2.2 and account of the most important ones is given below. Human Development Index and Sustainable Society Index are studied in the empirical part as results are better presented right after the description.

Living Planet Index

Living Planet Index is global biodiversity indicator that reflects changes in 8 000 species. LPI is created as an index, that tracks changes in species population. The index gives overview of changes in population from 1970 until 2007, when last data are available. (WWF, 2010, pg.20)

Index	Type	Reference
Living Planet Index (LPI)	Other	WWF (2010)
Ecological Footprint (EF)	Composite	Wackernagel and Rees (1996)
Human Development Index (HDI)	Composite	UN (2010)
Index of Sustainable Economic Welfare (ISEW)	Accounting	Daly et al. (1989)
Genuine Savings Index (GS)	Accounting	Hanley (2002)
Sustainable society index (SSI)	Composite	de Kerk and Manuel (2008)

Table 2.2: Overview of indices. Modified from Bohringer and Jochem (2007).

Ecological footprint

The index was described in (Wackernagel and Rees, 1996) and *"is based on the quantitative land and water requirements to sustain a living standard into infinity."* (Bohringer and Jochem, 2007) Simply, the index takes how much we consume, waste and what amount of Earth resources we need for it and compares it to the resources available. Such ratio is then interpreted as measure of sustainability.

The index is very popular and is published by WWF every year in Living Planet Report. (The last data and report in WWF (2010, pg.32).)

Index of Sustainable Economic Welfare

The index was developed in Daly et al. (1989) and the main notion of the index is to incorporate environmental and social externalities into our measurement of income. There are several approaches to computation of the index, but the main notion is the same. At the beginning we have inflation-adjusted consumption of households and we adjust it by income distribution, economic activities not included in the conventional GDP (so called *community income*), time adjustment, damage caused by economic activities and consideration of net capital endowment of foreign investors. (Bohringer and Jochem, 2007, p. 5)

Critics of the ISEW doubted the theoretical foundations of the concept. Lawn (2003) summarizes the theoretical background for ISEW. According to him, it is based on three main concepts. First is the *Economics for community – oikonomia* which is a realistic paradigm based on internalization principle and is based on strong sustainability model. The paradigm suggests in normal life we, as well as others, provide various services to our community (family, classmates) for free. The services would otherwise have to paid for and would be accounted for in GDP. However, this way they are not accounted for. The second notion is *Entropic Net Psychic Income* as defined by Irving Fisher in the *Nature of Capital and Income.* (Fisher, 1906) In this sense the income is defined as a flow of services. Thus not production, but only consumption should be reflected in the measurement of welfare. The last mentioned principle is social welfare function. The main issues that Lawn identifies are that

- in view of ISEW authors capital, service and society are viewed as separate from socio-economic system,
- economic relationships are viewed as dominating other aspects of the economy.

As a solution he suggests trying to integrate the concept with political economy or abandoning ISEW.

Even though, being relatively accepted by academic audience, the problem with this index is that it is hard to compute. Results of ISEW were published only for about 10 countries. Moreover, the results are not comparable, because often different approaches to computations are taken. To sum it up, the biggest weakness of the ISEW, despite some theoretical critiques, is that it is very hard to apply in the real world due to lack of data.

Genuine Savings Index

Next index that strives to improve the current system of national accounts is Genuine Savings Index published by the World Bank. It is based on the paradigm of weak sustainability as presented above. The process of calculation is described in detail including all the technicalities in Bolt et al. (2002).

As the base, gross national savings are taken and then depreciation of physical capital, rents from depletion and ecological damage are subtracted from it. Expenditure on education are then added to form the final amount of genuine savings. The genuine savings index is presented as percentage of gross national income. So, the formula is

$$GS = \frac{GNS - \delta_p - \sum R_i - ED + EDU}{GNI}.$$

where
GS – genuine savings,
GNS – gross national savings,
δ_p – depreciation of produced capital,
R_i – rents from natural resource i,
ED – environmental damage costs, mostly carbon dioxide,
EDU – expenditures on education.

The index as defined by the World Bank is subject to critiques. Ferreira and Vincent (2005) critically challenged the index with remarks of theoretical nature and then carried out extensive econometric testing of the indicator to check whether it corresponds to the theoretical definition.

In the first part the authors state several general problems. One significant is that education expenditure (the EDU value in the equation) relies only on UNESCO estimates of operating expenditures on education, that tend to be of lower quality. Moreover, the calculation *"assumes that a dollar of educational expenditure translates into a dollar increase in human capital. Studies in both rich countries (Jorgenson and Fraumeni 1992) and poor countries (Schultz 1988) indicate that this is a poor assumption."* The biggest source of bias in the data is, however, seen in the fact that the data are based on market prices which are very different from shadow-prices that would be needed to make model work flawlessly.

In the econometric part, they present model

$$\Delta_{it} = \beta_0 + \beta_1 S_{it} + \epsilon_{it}$$

which is based on theoretical model

$$\bar{C}(t) - C(t) = p(t)I(t).$$

and test it against the data. $\Delta_{it} = \bar{C}(t) - C(t)$ is the difference between current consumption and average future consumption at time t in country i. $S_{it} = p(t)I(t)$ is net investment at time t in country i with $p(t)$ being a vector of competitive prices for capital goods and $I(t)$ vector of net changes of those goods. β_0 is the intercept and ϵ_{it} is a randomly distributed error. The rationale behind the analysis is, that from theoretical point of view β_0 should be zero and β_1 should be one to confirm the theoretical model. The underlying hypotheses are built on this rationale.

Part of the analysis is done by evaluating genuine savings in parts and then running regression on partially adjusted figures. First, authors take GNS and deduct depreciation and fit the model. Then they deduct rents, fit the model and see how it has improved. Results of the analysis show, that the valuation of education expenditure is indeed poor because with every step of adjustment, the model improves in terms of R^2 and only in the last adjustment for education expenditure it deteriorates.

Apart from that, the authors tested the models for subsets of countries. Interesting result is that if the sample of countries in the data is divided into non-OECD and OECD countries, the model performs significantly better in case of non-OECD countries. Ferreira and Vincent (2005) note that it supports Solow residual, i.e. the residual value of actual GDP that cannot be explained by changes in capital and labour. However, neither for non-OECD nor for OECD countries the model gives very convincing evidence.

The bottom line for Genuine Savings Index, at least in form that is currently published by the World Bank, is that it should be used with most caution as data inputs are burdened with errors and the methodology is often controversial. Nevertheless, the indicator presents at least partial look at sustainability perspective.

2.4 Multi-criteria evaluation of sustainability

If we want to measure sustainability trends in dynamic perspective, multi-dimensional tools are of great use, because as many state, for example Singh et al. (2009), sustainability is generaly of four dimensions – economic, social, environmental and institutional. Various methods exist in the realm of multi-criteria decision analysis and the crucial step towards successful application is to decide which particular method to use.

2.4.1 Choosing multi-dimensional method

Multi-criteria decision methods are non-homogeneous set of methods that were developed to make policy-maker's life easier, that means to find compromise actions.

Let us start with real life example. Let us imagine that we are choosing a new car. In the beginning, when we see the range of different brands we might consider some of them more reliable or luxorious, so we would probably restrain our search only to some of them. Then, we omit all the van type cars (delivery type cars) from the range, because we want to buy, let us say, a family car. After that we would probably consider price and sort out options which are out of our budget. After that we consult petrol consumption, etc. Finally, we arrive to the best option (or multiple options which are equal for us) which we will buy.

This is basically what multi-criteria methods do. According to defined criteria the methods choose winners or order of the alternatives. The only significant difference from the example above is that the method takes all the criteria at once, because as we may imagine, different order of the steps might result in different results. On the way, methods face problems. In case of economics, it is mainly problem of normalization – how to compare different scales or ordinal data.

More formally speaking, multi-criteria problem is defined by a set of criteria for given set of alternatives. Every criterion has assigned evaluation for given alternative. Going back to our example, criteria are price, petrol consumption and personal opinion about design. Alternatives would be, for example, Skoda Octavia and Volkswagen Polo. Evaluation of price for Volkswagen Polo would be €41999.

Moreover, every criterion has a set goal that should be achieved, i.e. whether we want to maximise or minimise given criterion. Goal for price in our example would be to minimize it. Even right here we might see, that it is very subjective, because in general we cannot say whether the price should be minimized or maximized because of kinky preferences. Multi-criteria method is then an aggregate of all the data used.

Among the best known methods are ELimination Et Choix Traduisant la REalité (ELECTRE) family of multi-criteria decision analysis (MCDA) which was developed by B. Roy, Preference Ranking Organisation METHod for Enrichment Evaluations

(PROMETHEE) family by J.B. Brans and Ph. Vincke, and Novel Approach to Imprecise Assessment and Decision Environments (NAIADE) method developed by G. Munda. Idea behind the methods, that we should take our criteria evaluations and from them create preference graph, is the same, however approached from different directions. The main differences are data manipulation : how much uncertainty can be handled by the method and also what kind of data can serve as an input into the method; and degree of simplicity of the method. The more elaborate the method, the more data types it can process and yield precise results. However, with more complex methods more input is needed from user in form of setting parameters necessary for the method.

Roy (2005) lays out reasons in favour of multi-criteria methods, when he rightly presents classic (indicator) methods as creating itself a value objective while neglecting features of reality. For example, if we take Human Development Index, its creation created a value in improving HDI score. However, one must be very cautious in interpreting such movement, as it might have been achieved even though some very important underlying criterion had declined. On the other hand, MCDA methods simply rank alternatives according to policy-maker's (scientist's) taste without creating impression of value creation. It should be, however, kept in mind, that even if we have objective method, the results are only mapping of reality, which is not necessarily right. Also, the advantage of multi-criteria methods is in its case by case approach. If the methods were to be applied generally to, say, annual data to create ranking under some name, it would most probably lose its merit. Munda (2008) pins down an issue of data quality, when he notes that bad data lead to bad results as is the case in any method no matter how robust it is.

From methodological point of view several types of goals (or problematiques in parlance of MCDA) for MCDA were defined by Roy and Bouyssou (1993):

- α – the choice problematique – the goal is to select sufficiently small amount of candidates (alternatives), so that from the final group the ultimate winner may be chosen.

- β – the sorting problematique – each alternative is assigned to a group as to what should be done afterwards (Munda (2008) *"for instance, acceptance, rejection or delay for additional information."*)

- γ – the ranking problematique – goal of γ problematique is to rank all the alternatives. In practice, it is very useful in cases of negotiation, when we have our favourite alternative, but we know which *second best* we are willing to settle for.

- δ – the description problematique – output of this problematique is description of possible actions and results of these actions.

When choosing the appropriate tool to assess sustainable trend, we have to identify the ideal features that the method should have. It should be able to:

- provide us with total ranking, because we need to identify the trend in time, in other words, the methods must solve γ problematique;
- incorporate some method to deal with uncertain or missing data, as it might occassionally be our case;
- provide totally un-compensatory approach, as *strong sustainability* allows for no compensation, especially in ecological issues.

Method NAIADE by Munda (2008) fulfils all the requirements and thus is appropriate for sustainable development analysis. We shall introduce the method in the next section.

2.5 Novel Approach to Imprecise Assessment and Decision Environments

The Novel Approach to Imprecise Assessment and Decision Environments (NAIADE) method was developed by G. Munda, main theoretical concepts were developed in (Munda, 1995).

The concept is unique in several ways: It is one of the first methods to incorporate fuzzy approach to multi-criteria assessment, the method is very robust and complex – it takes into account various types of data. However, the advantages are provided only for the price of considerable complexity of the method.

To be explained shortly, fuzzy set theory is relatively new approach to logic systems that was created in sixties by Zadeh (1965). Fuzziness is a broadening of classical logic systems, like boolean system. Classical boolean logic works with two values - zero and one or true and false. On contrary, fuzzy logic works with the whole interval of values from one to zero to describe the degree of truth. For example, take statement “It is cold.” Boolean logic assumes it is either true or false, nothing else. Fuzzy logic permits us to present degree of truth, i.e. assign value 0.32. Sometimes fuzzy logic is compared to probabilistic logic which also takes into account the whole interval of values. In mathematical description, fuzzy logic is very similar to probabilistic logic. However, from conceptual point of view the two are all but similar. Probabilistic logic expresses only degree of probability of the two boolean values, i.e. the probability, that something is cold is 50%. On the other hand, fuzzy logic is superset of boolean logic, and value 0.5 could mean that it is not really cold, but it cannot be described as warm. This is exactly the case with preferences. We do not really want to say that the probability that we prefer one alternative to another is 40%, but we want to work with the notion that there is whole range of preferences.

In following sections, we explain the computation of NAIADE method. For interested reader, step-by-step car example with explicit calculations is included in appendix C. We recommend consulting this numerical example during reading the forthcoming theoretical explanation, in case of any mis-understanding.

2.5.1 Data types

NAIADE method works with most imaginable data inputs. For each type of data (see below specifically) it requires different parameters to be set. Some of the parameters are common to all types of data. As already said, in the general multi-criteria problem, every criterion first has to be set an objective, i.e. whether we want it to be maximised or minimised. Apart from that, in NAIADE, all criteria need four thresholds (crossover values) to define six preference relations. The preference relations are: much better, better, approximately equal, equal, worse and much worse. Preference relations are fuzzy numbers that present certain degrees of truth of the preference relations. The corresponding thresholds or *crossover values* will be denoted $t_{=}, t_{\simeq}, t_{\succ}, t_{\succcurlyeq}, t_{\prec}, t_{\preccurlyeq}$. They are values at which the degree of truth of the preference relation is 0.5. In NAIADE, we need only four thresholds, as much worse and much better are regarded as symmetric and the same applies to worse and better. Also approximately equal creates two symmetrical intervals. The preference relations basically say, how much we prefer or dislike the alternative in comparison with other alternative.

There are several different types of data, NAIADE defines these types: *quantitative crisp, quantitative fuzzy, quantitative stochastic and qualitative.* For all the data we need to compute value of all membership functions defined in table 2.3. For that computation of membership function, we need to evaluate the d parameter, which denotes distance. In NAIADE, this is done by a special metric, called semantic distance.

Definition 1 (Semantic distance) *Let us have two functions $f(x), g(y)$, called membership functions, for which it holds that*

$$\int_{-\infty}^{+\infty} f(x)dx = \int_{-\infty}^{+\infty} g(y)dy = 1.$$

Semantic distance is then defined as

$$S_d\left(f(x), g(y)\right) = \iint_{\mathbb{R}^2} |x-y|\, f(x)g(y)dx\ dy.$$

The computation of semantic distance is the only part of method, where data type matters. We shall see on example, what differences we have in mind and what is meant by membership functions for different types of data.

Let us continue with the car example. Now, we specify it a bit more. Let us assume, that we want to decide between two cars, say Skoda and Volkswagen. These are our alternatives. We have three criteria. They will be price, gas consumption and comfort. Evaluations of these criteria for our alternatives (i.e. our data) will have different types.[4]

First, let us have price of a car. We set the goal to minimize the criterion. The type of the data is set to be quantitative crisp as it is measured without any error. Then, let us assume that we set the threshold value for preference relation much better/much worse on 500 and better/worse at 200. In case of crisp data, we need no membership function, so the functions are set to be equal to 1. Then the integral is simple absolute difference of the data. If Volkswagen Polo is cheaper by €430 than Skoda Octavia, the method will translate the movement of the data to a judgement that we *probably* assess the situation to be much better for Volkswagen in comparison to Skoda. If the the price of Volkswagen was even lower the method changes the degree of how probably we would assess one alternative to be much better. Turning to numbers, NAIADE will yield fuzzy numbers for every preference relation (they will be defined more closely later on, see table 2.3, d is in our case 430 and t is either 500 or 200 for different preference relations). For much better it is 0.4109 as €430 is less than €500 (our threshold) and for better it is 0.8221 because the difference is much higher than threshold. If we increased the difference to €1000 the numbers would be 0.9061 and 0.9615, respectively. For equal and approximately equal, increasing the difference naturally causes decrease of probability that the situation is assessed equal or approximately.

Before proceeding to other data types, we need to define several things, as they will be used.

Definition 2 (Fuzzy set) *A fuzzy set is a pair* (A, μ) *where* A *is a set and* $\mu : A \to [0,1]$*.* μ *is called membership function. For each* $x \in A, \mu(x)$ *is called grade of membership of* x *in* (A, μ)*.*

Let $x \in A$*. Then* x *is called not included if* $\mu(x) = 0$*. It is called fully included if* $\mu(x) = 1$*, and* x *is called fuzzy member if* $\mu(x) \in (0,1)$*. The set* $\{x \in A | \mu(x) > 0\}$

[4]Full computation of the example is given in appendix C. The numbers in the example may differ. In the following text numbers are chosen for sake of simplicity.

is called support of (A, μ) *and* $\{x \in A | \mu(x) = 1\}$ *is called kernel.*

Definition 3 (Fuzzy number) *A fuzzy number is a convex, normalized fuzzy set* $A \subset \mathbb{R}$ *whose membership function is segmentally continuous and has the functional value* $\mu_A(x) = 1$ *at precisely one element.*

Theorem 1 (Standardising of fuzzy number) *Given two fuzzy numbers* $\mu_A(x)$ *and* $\mu_B(y)$*, there exists* $k_1, k_2 \in \mathbb{R}$*,*

$$f(x) = k_1 \mu_A(x), g(y) = k_2 \mu_B(y) \tag{2.3}$$

such that

$$\int_{-\infty}^{+\infty} f(x)dx = \int_{-\infty}^{+\infty} g(y)dy = 1.$$

For proof see (Munda, 2008).

In case, when we are not sure that the value of the criterion is sure we can use quantitative fuzzy or quantitative stochastic data types. If we use quantitative fuzzy we have to set type of fuzzy number used, most common types are presented in table A.2. Membership functions of these types then serve[5] as $f(x)$ of $g(y)$ functions in semantic distance definition. Using quantitative stochastic, user has to set density functions, which again are used during computation of semantic distance as $f(x)$ and $g(x)$ functions. Overview of the distributions is included in table A.3.

Let us continue with the example of buying a car. Second criterion is gas consumption. The problem is a bit more difficult, because we do not know exactly the value, we know the mean only or advertised value. Due to that, we set the data for criterion *gas consumption* to be fuzzy for all alternatives, and the advertised value as value where membership function of the fuzzy number attains one.[6] It could also be considered stochastic input, the difference is more of philosophical nature. In case of stochastic variable, we assume, that the value is true and only measure the probability of happening. In case of fuzzy numbers, we inherently assume that the value is only an estimation and provide more *true* values. Then again, we set thresholds, as what we would assess as much better, better or simply equal.

The last data type is qualitative. this type of data includes linguistic expressions of preference. Only objective has to be set, in this case, thresholds are already set.

[5]Of course they first need to be standardised to integrate to 1. This can always be done as shows theorem 1.

[6]There are several possible types of fuzzy number, see table A.2. l, u are lower and upper limit of the interval where we thing the value lies. For example, evident lower limit for gas consumption is 0, but it may be higher. m denotes value where the fuzzy number attains one. In the table, the only variable we do not set is x.

Set of standard linguistic variables (perfect, very good, good, more or less good, moderate, more or less bad, bad, very bad, extremely bad) can be renamed according to specific needs. The functions that serve as membership functions ($f(x)$ or $g(y)$) of linguistic variables are presented in table A.1

In our example the comfort criterion would be of qualitative type. We would only enter the values (i.e. (perfect, very good, good, more or less good, moderate, more or less bad, bad, very bad, extremely bad)) for cases of Skoda and Volkswagen, and the method would automatically compute preference relations.

For more information on qualitative data type, please, refer to Munda (2008, sec. 4.3). Full description is out of scope of this thesis and qualitative data will not be used in the empirical part.

Concluding the explanation of semantic distance, we should remark that the double integral cannot always be algebraically computed. As shown in appendix B.1.1 we can easily prove that semantic distance always exists and it holds that

$$S_d\left(f(x), g(y)\right) \geq \left|E(x) - E(y)\right|.$$

If it holds that $Y \cap X = \emptyset$, where X, Y are intervals and $f(x) = 0, \forall x \notin X, g(y) = 0, \forall y \notin Y$, semantic distance is equal to expected value of a fuzzy number

$$S_d\left(f(x), g(y)\right) = \iint_{\mathbb{R}^2} |x - y|\, f(x)g(y)dx\ dy = \left|E(x) - E(y)\right|. \tag{2.4}$$

Concerning integration over general region without any assumptions, Monte Carlo algorithm was developed by Munda (2008). Details can be found in appendix B.1.2.

Preference intensity index

After computation of semantic distance the next step is obtaining preference intensity index for the six different preference relations. By applying formulas from table 2.3, we get preference relations $\mu_j^i(A, B)$[7], where i is the criterion, A and B are alternatives and $j \in \{\gg, \succ, \simeq, =, \prec, \preccurlyeq\}$ is the preference relation. This number express degree (or probability) of the concerned preference of alternative A above B.

We have shown the numerical computation with example of price above. For more numerical examples refer to appendix C and table C.4.

Having the preference relations, aggregate preference intensity index is com-

[7] In the table, we give $\mu_j^i(d)$. However, as reader might have noted $\mu_j^i(A, B) = \mu_j(S_d(A_i, B_i))$, where A_i is the realisation of i-th criterion for alternative A.

Preference relation	Function
Much better *or* much worse	$$\mu_{\succeq/\preceq}(d) = \begin{cases} 0 & \text{for } d < 0 \\ \frac{1}{\left(1+\frac{t^2_{\succeq/\preceq}(\sqrt{2}-1)}{d^2}\right)^2} & \text{for } d \geq 0 \end{cases}$$
Better *or* worse	$$\mu_{\succ/\prec}(d) = \begin{cases} 0 & \text{for } d < 0 \\ \frac{1}{1+\frac{t^2_{\succ/\prec}}{d^2}} & \text{for } d \geq 0 \end{cases}$$
Approximately equal	$$\mu_{\simeq}(d) = e^{-\frac{\ln 2}{t_{\simeq}}\lvert d\rvert} \text{ for } \forall d$$
Equal	$$\mu_{=}(d) = e^{-\frac{\ln 2}{t^2_{=}}d^2} \text{ for } \forall d$$

Table 2.3: Preference relations functions; t – crossover values, d – semantic distance

puted. Preference intensity index of alternative A over B is defined as

$$\mu_j(A,B) = \frac{\sum_{i=1}^{n} \max\{\mu_j^i(A,B) - \alpha, 0\}}{\sum_{i=1}^{n} \lvert\mu_j^i(A,B) - \alpha\rvert}, \tag{2.5}$$

where α is a number that captures minimal required fuzzy relation credibility and $\mu_j^i(A,B)$ is concerned preference relation of A over B according to i-th criterion.

In our case, α has meaning of conservativeness. As we have said, the preference intensity ranges from 0 to 1. If we set α high the less sure preference relations (those which are less then α) will not be taken into account and will be treated as zero.

Entropy

When the preference intensity index is close to the crossover value, the certainty of the preference relation is not very high. To account for the degree of certainty, entropy concept is useful. Fuzzy number membership function is proposed as follows

$$\mu_{j,H}(A,B) = \begin{cases} 0 & \text{for } \mu_j(A,B) - \alpha \leq 0 \\ \mu_j(A,B) & \text{otherwise} \end{cases}$$

Entropy is then defined as

$$H_j(A,B) = -\frac{1}{n}\sum_{i}^{n} \mu_{j,H}^i(A,B)\ln_2 \mu_{j,H}^i(A,B) + (1-\mu_{j,H}^i(A,B))\ln_2(1-\mu_{j,H}^i(A,B)). \tag{2.6}$$

Entropy defined this way attains its maximum 1 at 0.5 value of the preference relation $\mu_j(A,B)$, i.e. at crossover values where we are the most hesitant. Entropy for values 1 and 0 is defined as 0.

Simply said, if we attain the crossover value of the preference relation, the method is not sure whether we really *feel this way*. Or in other words we are most hesitant when we are at the crossover value.

Calculating final results

Final results in NAIADE are presented in form of two partial rankings and preference diagram (or sometimes called domination web) which is a result of intersection of the two partial flows. The two flows are computed as follows

$$\Phi^+(A) = \frac{\sum_{i=1}^{N-1} \min\{\mu_{\gtrcurlyeq}(A,i), C_{\gtrcurlyeq}(A,i)\} + \min\{\mu_{\succ}(A,i), C_{\succ}(A,i)\}}{\sum_{i=1}^{N-1} C_{\gtrcurlyeq}(A,i) + C_{\succ}(A,i)} \tag{2.7}$$

$$\Phi^-(A) = \frac{\sum_{i=1}^{N-1} \min\{\mu_{\lesssim}(A,i), C_{\lesssim}(A,i)\} + \min\{\mu_{\prec}(A,i), C_{\prec}(A,i)\}}{\sum_{i=1}^{N-1} C_{\lesssim}(A,i) + C_{\prec}(A,i)} \tag{2.8}$$

where $C_{\gtrcurlyeq}(A,i) = 1 - H_{\gtrcurlyeq}(A,i)$, i are all alternatives different than A and the minimum operator can be replaced by different operators, which is, however, not a case of strong sustainability, where substitution is not possible.

The first preference flow Φ^+ is so called positive flow and it tells us, how much is the alternative A being preferred to all the other alternatives. The other flow, denoted Φ^- is the exact opposite. It explains how much is the alternative being dispreferred with comparison to the other alternatives.

3. Sustainable development – the case of the Czech Republic

In recent years, various indices and indicators are being evaluated and published for each country. However, studies that compare results of various indices for one country are quite rare. Recently, several papers that measure sustainability of specific countries were published. The case of Austria in Shmelev and Rodríguez-Labajos (2009), Scotland sustainability perspective in Hanley et al. (1999), and France empirical evidence is presented in Nourry (2008). In this part of the thesis we present and evaluate empirical evidence for sustainable development of the Czech Republic.

Sustainability literature in connection to the Czech Republic almost does not exist. Ščasný et al. (2000) present overview of alternatives to GDP in the Czech Republic with special emphasis on ISEW. Priorities of the Czech Republic are summed up in Ministry of the Environment of the Czech Republic (2010).

In the text, we first identify desirable time scale for our analysis. Afterwards, we introduce two classic measures of sustainable development Human Development Index and Sustainable Society Index, provide critiques of the indices and evaluate empirical results for the Czech Republic. Then multi-criteria analysis of sustainability in the Czech Republic is carried out.

3.0.2 Time scale of the analysis

In the beginning we should set ourselves time dimension in which we want to analyse the development.

The problem of time scale is predominantly connected with historical reality of the Czech Republic. Easily accessible data appear in 1990, when democratic institutions were starting to take shape after the Velvet Revolution in 1989. Before this date, statistics can be acquired from communist annual statistical reports. They have to be carefully distilled as these publications were burdened by political and ideological supervision of the communist party. Milestone of 1990 is unfortunately not sufficient, as at that time, Czech Republic was part of bigger state : Czechoslovakia, which was split in the end of 1992. Taking in account historical reality only, we have to set the beginning of our enquiry at year 1993. The end of the analysis should ideally be year 2010, however, reliable and free data often end earlier.

In case of Human Development Index, we will look at results from 2005 to 2010. Sustainable Society Index data are available from year 2006 up to 2010 in two year intervals. Our NAIADE analysis will be from 1995 to 2006, for which available data end.

3.1 Orthodox empirical evidence

First, we will focus on empiric data that is widely accepted to be measures of sustainability. These are, as we have already mentioned earlier indices of various form. Inquiry in results of these measures will provide expectation against which we will compare results from less frequented measure of economic sustainability – multi-criteria decision analysis.

3.1.1 Human development index

Human development index (HDI) is well known index produced by the United Nations which accounts for three dimensions: education, income and health. The index has been published yearly since 1990 in *Human Development Reports*.

The index itself is not an indicator of sustainable development in its full scope. Main goal of the indicator is to evaluate social and health conditions of people in a given country. As these factors are an integral part of sustainable development, the indicator should at least provide an insight into our issue.

In the next part, we explain computation of the index, next we provide critique of HDI. Then, we discuss rankings and comment on the theoretical critiques in connection to the data.

Methodology

HDI is a composite index that aggregates data based on standard normalizing technique, which will be described below. Starting from 2010, UN has introduced new methodology of calculation of HDI. We discuss and compare both methodologies as well as results.

The old methodology, used until 2010, was based on normalizing technique described by the following formula

$$I_i = \frac{x_i - \min\{x_i\}}{\max\{x_i\} - \min\{x_i\}}, \tag{3.1}$$

where I_i is the normalized value, x_i is the value of the indicator for country i and min$\{x\}$,max$\{x\}$ is the minimum/maximum value of the indicator across all the countries.

That means that if we want to turn life expectation into scale-free index ranging from 0 to 1, we take the life expectation of our country subtract minimal life expectation among all the countries in scope and divide it by range of values. Such ratio gives relative position of our country in the range. In HDI, maximal and minimal values are set not from data, but artificaly, thus it is theoretically possible to acquire value higher than 1. In the old methodology, the indices for education, income and health were computed as follows

1. Life expectancy index $= I_{\text{LE}} = \frac{\text{Life expectancy} - 25}{85 - 25}$
2. Education index $= I_{\text{EI}} = \frac{2}{3} \cdot \frac{\text{Adult literacy} - 0}{100 - 0} + \frac{1}{3} \cdot \frac{\text{Gross enrolment} - 0}{100 - 0}$
3. Income index $= I_{\text{II}} = \frac{\ln(\text{GDP per capita}) - \ln(100)}{\ln(40000) - \ln(100)}$

The results were then aggregated by sum with equal weights of $\frac{1}{3}$. The old HDI is then

$$\text{HDI}_{\text{old}} = \frac{1}{3} \cdot I_{\text{LE}} + \frac{1}{3} \cdot I_{\text{EI}} + \frac{1}{3} \cdot I_{\text{II}}$$

In the new methodology, the normalization technique remains in principle the same for life expectancy index and income index. However, in case of life expectancy index, the minimum and maximum boundaries have been shifted. New maximum boundary is set as 83.2 (Japan's life expectancy) and minimum as 20. In case of income index, the underlying data were changed from GDP per capita to GNI per capita. The education index underwent the most substantial change. New underlying indicators are mean years of schooling and expected years of schooling. These are normalized by the procedure presented by equation 3.1 and then aggregated by means of geometric mean. After normalization they create the new education index. The new methodology is summed by the following formulas

1. Life expectancy index $= I_{\text{LE}} = \frac{\text{Life expectancy} - 20}{83.2 - 20}$
2. Education index $= I_{\text{EI}} = \frac{\sqrt{\frac{\text{Mean years of schooling} - 0}{13.2 - 0} \frac{\text{Expected years of schooling} - 0}{20.6 - 0}} - 0}{0.951 - 0}$
3. Income index $= I_{\text{II}} = \frac{\ln(\text{GNI per capita}) - \ln(163)}{\ln(108211) - \ln(163)}$

The results are then aggregated by geometric mean. That means

$$\text{HDI}_{\text{new}} = \sqrt[3]{I_{\text{LE}} \cdot I_{\text{EI}} \cdot I_{\text{II}}}$$

Critical analysis

Human development index as composite indicator raises straightforward question. Does the indicator brings us any insight, that is not obvious from the dataset? Another natural issue is, whether the indicator is capable of truly reflecting human development. The last remark will be committed to implicit valuation of human life in the HDI and usefulness of HDI for developed countries. Deeper discussion of these problems can be found in Sagar and Najam (1998), Kelley (1991), McGillivray (1991) and Ravallion (2010).

To answer the question of providing new perspectives to human development, useful tool is correlation. The correlation to be studied is correlation between the final HDI value and the input data for HDI. Strong correlation shows strong relationship and thus similar conclusions can be drawn from the original dataset. Detailed analysis of correlations provided by McGillivray (1991) shows evidence for strong correlations among variables and old HDI index itself. Such finding tells us that we might even have used the underlying data and get very similar results.

Defining human development itself is a problematic issue. As Kelley (1991) remarks, *"Human development is defined in the HDR [Human Development Report] as 'a process of enlarging people's choices'."* Measuring the process of development is problem even more difficult and potentially harmful. Given the construction of HDI we might find *troubling trade-offs* in valuation of marginal year of life expectancy. Ravallion (2010) calculates the price of marginal year of life expectancy in terms of marginal rate of substitution with GNI and finds disturbing trade-off in form of inverse relationship. He also shows that the new construction of the index have considerably lowered weights on longevity. Conscious interpretation of HDI thus suggest that another year of life expectancy is less worth in Zimbabwe than in Japan. Drawing on that conclusion, if increasing HDI, regardless the underlying data, would be the goal, the index would provide problematic suggestions for policy makers. Ravallion (2010) presents an example: *"the 2010 HDI implies that if Zimbabwe takes a policy action that increases national income by a mere $0.52 or more per person per year at the cost of reducing average life expectancy by one year, then the country will have promoted its 'human development'."*

Given the publicity of HDI one should also inspect operation-ability of the index. The old version of the index, as Kelley (1991) notes, *"assumes that little or no progress in human development can be made by the developed countries. They all are close to the maximum values in literacy and life expectancy [...]. The HDI values for the developed countries vary from .96 to 1.00. As a result, the HDI has operational meaning only for the developing countries."* For the new methodology the results are similar.

To conclude, HDI seems to be unable to provide us with substantial information on human development, which is part of sustainable development. Given the strong correlations of the HDI with gross national income per capita, logarithm of the gross national income per capita provides equally apt measure of development for developed countries for reasons presented above. Moreover it provides dubious and potentially undefendable conclusions for valuation of marginal year of life expectancy and other trade-offs. Nevertheless, we discuss the results for the Czech Republic.

Analysis of results for the Czech Republic

In the Human Development Report 2010 (UN, 2010), the Czech Republic ranks 28^{th} with HDI[1] equal to 0.841. Years 2008 and 2009 are burdened by world economic crisis and connected decline in GNI per capita. For that reason, we see very small decline in HDI of the Czech Republic in these years. The highest ranking country in 2010 is Norway with HDI value 0.938. The lowest ranking country from the European Union is Bulgaria with HDI of 0.734. The CR ranks 15^{th} among countries of the European Union. HDI data and ranking[2] for last five years for the Czech Republic and five comparison countries are presented in the table 3.1. The values plotted on a graph can be found in figure A.1. We select four most developed countries of the former Eastern block, as comparison between those is natural and a proxy from western Europe that is the closest geographically and historically to the Czech Republic – Austria.

First, we shall examine current rankings of the Czech Republic in comparison with above mentioned countries. To identify strengths and weakness we examine figure 3.1. It depicts values of the three underlying indicators of HDI against corresponding country. In case of income, it is evident that all the post-communist countries tend to be relatively poor in comparison with Austria. From this analysis, it seems as common feature to the former communist countries. Regarding life expectancy, the Czech Republic is the third ranking country in the sample leaving it to be its highest underlying score. Generally, life expectancy at birth is the highest score for all the countries in our sample. Surely, it is advantage in comparison with the whole sample (all the approximately 150 countries), as life expectancy would be much lower in most of the countries included in the ranking. Education indicator is wildly different for all the countries in the sample and the Czech Republic is relatively strong in this aspect. Here, the communist heritage seems to be inverse to the case of income as all the formerly communist countries perform better than Austria in this domain.

Summing up, the biggest strength of the Czech Republic in terms of HDI is its

[1] All values of HDI used in the analysis are calculated based on the new index definition.
[2] The rank among all other countries for which HDI data are computed, i.e. about 150 countries.

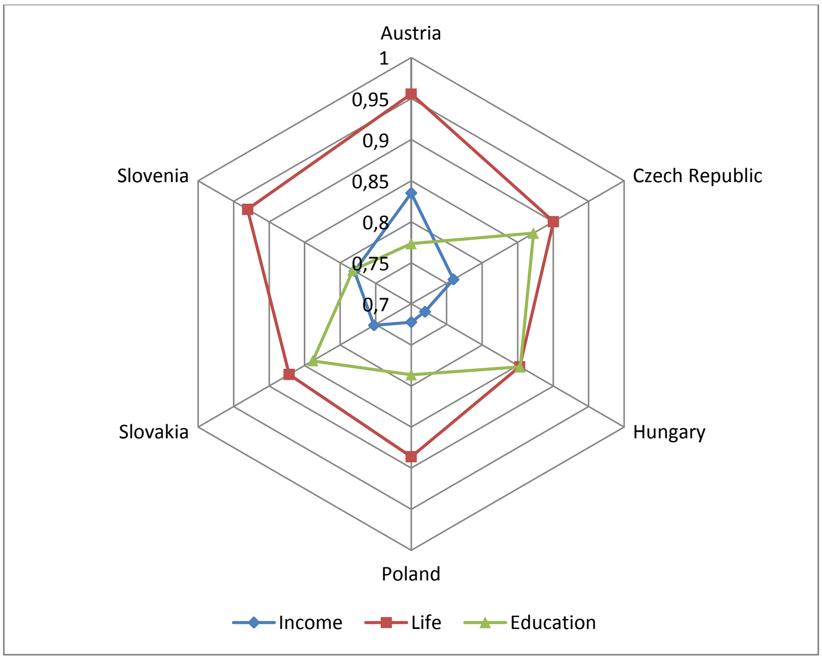


Figure 3.1: Human development index 2010 - Comparison of countries' scores in three dimensions. Source: UN (2010)

	2005		2006		2007		2008		2009		2010	
Country	HDI	Rank	HDI	Rank	HDI	Rank	HDI	Rank	HDI	Rank	HDI	Rank
Czech Republic	0.84	26	0.84	27	0.84	27	0.84	27	0.84	27	0.84	28
Slovenia	0.81	29	0.82	29	0.83	29	0.83	29	0.83	29	0.83	29
Slovakia	0.8	36	0.8	34	0.81	32	0.82	31	0.82	31	0.82	31
Hungary	0.8	35	0.8	35	0.8	38	0.8	37	0.8	37	0.81	36
Poland	0.78	41	0.78	42	0.78	43	0.79	42	0.79	40	0.8	40
Austria	0.84	24	0.85	24	0.85	25	0.85	25	0.85	25	0.85	25

Table 3.1: HDI, data source: UN (2010) and web page of Human Development Reports

education index as it provides biggest relative advantage against its competitors. The highest absolute value is received for life index, however, other countries in the example are stronger in this component of HDI. The least strong is income indicator. In respect to construction of the index (geometric mean) income yields biggest relative losses.

We now shall analyse HDI ranking in time. Looking at table 3.1, the stability of positions of the countries in the rankings stands out. Apparently, for developed country it is very difficult to climb up or down on the rankings, to leap over other country. This is confirmed by looking at human development trends for very high human development index, which is defined as the first quarter of the countries. Only nine from 42 countries that are in that section have changed their position in last year. This suggests that either no or synchronous development occurs among those countries with only a few exceptions.

Other interesting fact is that Czech Republic ranks higher than Slovenia despite having lower GNI per capita which is often taken as a proxy for measuring welfare. Difference in ranking is caused by significantly higher mean years of schooling of adults indicator. As we have mentioned above, education index is the relatively strongest part of HDI for the Czech Republic. For last five years, mean years of schooling are about 9 for Slovenia and about 12.5 for the Czech Republic. The value is comparable to highest ranking countries such as Norway or the United States of America.

In the literature, the troubling trade-off between GNI per capita and life expectancy was identified and it is surely of interest to count it for the Czech Republic. The valuation is computed as an extra GNI per capita needed to compensate for lost year in life expectancy at birth. In case of the Czech Republic, the value is $2366, which is ridiculous number in perspective of real life.

Overall, we conclude that HDI is indeed hardly operational at least for the Czech Republic as a measure of sustainable development, because the scope of the index is very limited. Taking into account all the critiques we find evidence (yet unpersuasive) of mild human development growth trend in the Czech Republic.

3.1.2 Sustainable Society Index

One of the most recent indices created is Sustainable Society Index. It has been computed in 2006 for the first time. The need to create new index is advocated by claim that *"not one [indicator] gives a complete and good insight into all relevant aspects of sustainability in a transparent, simple and easily understandable way, showing at a glance to what extent a society is sustainable or not."* (de Kerk and Manuel, 2008) The early version was described in (de Kerk and Manuel, 2008). Commented results for about 160 countries are presented in the same paper. So far, there were three releases of the index : 2006, 2008 and 2010. In the last release, old methodology was reconsidered and new methodology was produced. We describe only the new version of methodology and important differences.

As inspiration, when creating the indicator, Brundtland definition of sustainable development (see Section 2.2) was taken. In the article (de Kerk and Manuel, 2008) the definition was explicitly enriched by one more point

> *Sustainable society is a society [...]*
>
> - *in which each human being has the opportunity to develop itself in freedom, within a well-balanced society and in harmony with its surroundings.*

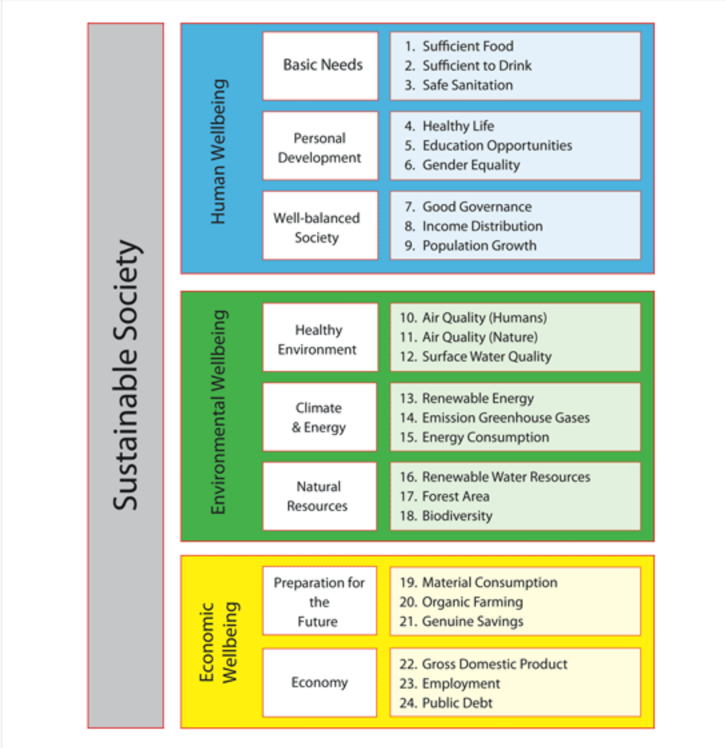


Figure 3.2: Sustainable Society Index – diagram of criteria; Source: www.ssfindex.com

Hence, we see more focus on well-being, freedom and other non-material aspects of social systems.

Methodology

Sustainable Society Index is a composite indicator by construction that is based on 24 indicators grouped to three clusters.

The final score as well as scores of all the indicators are normalized to have values from zero to ten. Different formulas apply to individual indicators. The final score of Social Sustainability Index is produced by sample mean.

Various criteria of different degrees of reliability are included in the index. The overview of all the criteria is presented in figure 3.2. The underlying data can be found in van de Kerk and Manuel (2010a). The indicators were chosen to describe three dimensions: human well-being, environmental well-being and economic well-being.

In the article (de Kerk and Manuel, 2008) the authors comment on two indicators that have been left out on purpose from the old version of SSI. The first is Gross Domestic Product per capita. They remark

Very few people still consider GDP per capita to be a useful indicator

> *for development towards sustainability. In that respect, other indicators, such as the ISEW (Daly and Cobb, 1989; Bleys, 2008) [...] are far more indicative. Unfortunately, they cannot be used for the SSI, since these two indicators are available for no more than a couple of countries.* (de Kerk and Manuel, 2008)

However, in the new version, the GDP per capita is included in the criteria. In the van de Kerk and Manuel (2010b) the inclusion is explained as only temporary, until better data on economic dimension are available. The second purposely omitted indicator is depletion of natural resources. Authors state that the indicator should be included, however no reliable and useful data are available and no proxy indicator was included.

Analysis of results of the Czech Republic

	2006		2008		2010	
Country	SSI	Ranking	SSI	Ranking	SSI	Ranking
Austria	7.43	2	7.50	2	7.42	3
Czech Republic	6.57	23	6.69	23	6.79	16
Hungary	6.83	11	6.81	18	6.81	14
Poland	6.45	28	6.64	26	6.60	26
Slovak Republic	6.81	13	6.96	11	6.73	18
Slovenia	6.99	7	7.12	6	6.95	8

Table 3.2: Results Sustainable Society Index. Source: Sustainable Society Foundation, http://www.ssfindex.com

As well as in the previous indicator, the selected countries for comparison stay the same. Final results with rankings for our countries are presented in table 3.2. The ranking is from about 150 countries for which the index is computed. Detailed results are presented in table A.4, where HW means Human Well-being, EnW is Environmental Well-being and EcW is Economic Well-being. In this situation when we have rather abstract data, graphical analysis is very helpful.

In figure 3.3, we see that the Czech Republic was the only country for which the Sustainable Society Index is strictly increasing in time. Also, obviously the position of the Czech Republic has been improving from 2008 to 2010 it climbed from 5^{th} to 4^{th} place in our sample.

Overall rankings are presented in table 3.2. The growing tendency of the Czech Republic had different causes in transition from 2006 to 2008 and from 2008 to 2010. According to SSI, the biggest improvement from the first period to the second happened in Economic Well-being. The improvement happened in five out of six

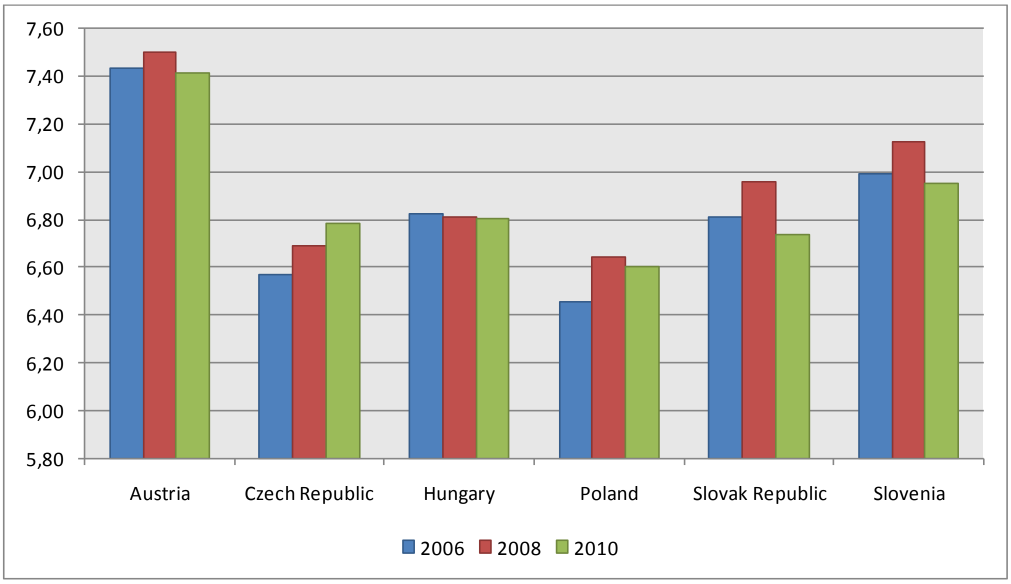


Figure 3.3: Sustainable Society Index – results comparison. Source: Sustainable Society Foundation, http://www.ssfindex.com

indicators that measure Economic Well-being. Rise in GDP influenced GDP per capita factor as well as public debt factor which is calculated from public debt as percentage of GDP. Unemployment reduction was very significant factor in the improvement. Improvement in Human Well-being was partially off-set by deterioration in Ecological Well-being domain.

Improvements from 2008 to 2010 was caused by significant improvement in Environmental Well-being, which was partially off-set by effects of economic crisis that worsened Economic Well-being dimension. The biggest absolute change in the ecological domain was surprisingly in Air Quality indicator. Here, SSI uses data from Environmental Performance Index which is computed by Yale University, more specifically it is improvement in levels of indoor and outdoor pollution. The data are based on models rather than on real measurements, and thus the data quality should be of great concern.

	2006			2008			2010		
Country	HDI	SSI	Diff.	HDI	SSI	Diff.	HDI	SSI	Diff.
Czech Republic	25	23	**2**	25	23	**2**	25	16	**9**
Poland	35	28	**7**	36	26	**10**	34	25	**9**
Slovakia	29	13	**16**	27	11	**16**	27	18	**9**
Hungary	30	11	**19**	32	18	**14**	32	14	**18**
Slovenia	26	7	**19**	26	6	**20**	26	8	**18**
Austria	22	2	**20**	23	2	**21**	23	3	**20**

Table 3.3: Difference in rankings in SSI and HDI. Source: Own computations.

To compare the two indices, we have taken results of both indices for all available countries, recounted the ranking to the restricted sample and computed the differences. The results for our countries are summed up in table 3.3.

In comparison with Human Development Index, big differences in positions occur in case of Austria, Hungary and Slovenia. Generally, if we look at results of European countries for HDI and SSI, the values differ significantly. Differences for all European countries are presented in annex in table A.5. If we look at the country with the biggest difference from our sample of six, we see it is Austria. The difference in the rankings is probably caused by the range of factors taken into account, especially environmental factors that are not taken into account in HDI at all.

The biggest absolute difference is for Belgium, that ranks 18^{th} in HDI and 65^{th} in SSI for year 2010. This is exactly the opposite to the Austrian case, when HDI rank is better then SSI. When looking more closely at the underlying parts of SSI for Belgium, it performs very poorly in Environmental Well-being and Economic Well-being. In Economic Well-being the variables consumption and organic farming are on very low level. In Environmental Well-being consumption of renewable energy and emission of greenhouse gases are the driving factors.

Again, the bottom line for Sustainable Society Index is that it provides us with positive evidence of sustainability as well as sustainability trend.

3.2 Multicriteria trend analysis

3.2.1 Data selection

One of the crucial steps towards valid research is selection of data. In our case, the first step was to identify desirable data and afterwards identify time scale in which the analysis can be done based on availability of the data.

The first part, i.e. selection of desirable indicators, is approached in various directions in the literature. UN report (Sitarz, 1993) identifies about 140 indicators for sustainable development. EuroStat selects ten leading objectives for which twelve aggregate indicators are monitored. After summing up, Eurostat follows more than 100 indicators, too. For more detail, see (European Commission, 2009). Shmelev and Rodríguez-Labajos (2009) present reasonable set of indicators of medium-term trend development. They are concerned with four dimensions of sustainability : economic, social, environmental, and institutional. The underlying criteria can be found in table 3.4. We will use these indicators in our analysis for two reasons. First, the indicators can be looked at as sound in respect to theory of sustainable development. Secondly, we will use these for sake of partial comparability of medium-term analysis of Austria in the case study of Shmelev and Rodríguez-Labajos (2009).

Domain	Criterion	Goal
Economic	Gross domestic product per capita	Maximize
	Total primary energy supply per capita (TPES)	Minimize
	Contribution of renewables to energy supply	Maximize
	Municipal waste generated	Minimize
Social	Life expectancy	Maximize
	Gini index	Minimize
	Unemployment	Minimize
	Population growth	Minimize
	Tertiary attainment	Maximize
	Number of recorded crimes per 10 000 people	Minimize
	Life satisfaction	Maximize
Environmental	Carbon dioxide emissions	Minimize
	Organic water pollutants	Minimize
	Forest trees damaged by defoliation	Minimize
	Domestic material consumption	Minimize
Institutional	Expenditure on R&D	Maximize

Table 3.4: Sustainability criteria, taken from (Shmelev and Rodríguez-Labajos, 2009)

Sources from which the data for the indicators were extracted are presented in table A.9. The particular dataset can be found in table A.6. Data for most recent years are not available at the time of writing. Due to that, the final time scale is 1995-2006, for which all data are readily at hand.

Nature of phenomena measured

Looking at the indicators we have chosen, question should be asked, whether nature of the phenomena behind the indicator allows for exact measurement, or our data are uncertain in fashion that is worth mentioning. When talking about the data we should always bear in mind these facts and differentiate between data that can be burdened by application of statistical method or the nature of the thing measured itself. We apply such knowledge during setting the type of data for NAIADE analysis.

First, there are indicators that can be considered precise with high degree of confidence; phenomena behind the indicator has been measured for long time and reliable processes have been introduced to make our measurement precise. This category comprises: gross domestic product, total primary energy supply, life expectancy, unemployment, population growth, contribution of renewable resources, tertiary attainment, expenditures on R&D and number of recorded crimes.

Second category are indicators that are based on panel research and complementary usage of statistical methods to infer value of the indicator – those are Gini and life satisfaction. For these data, we should set data type that allow for more relaxed evaluation of change of the indicators.

The last category presents indicators that try to provide us with information about phenomenon, which is inherently hard to capture and thus based on estimation and models. Those are CO_2 emissions, water quality, domestic material consumption, municipal waste generated and forest defoliation. Data types for these indicators should again reflect credibility of the data.

3.3 Sustainability trend analysis

After selection of data and time-frame we want to apply NAIADE assessment to measure the sustainability trend.

First, we should recapitulate, how is the problem defined, what remains to be set for the method to work and what will be the outcomes of the method. In the previous text we have used the example of cars and we shall stick to it. In the example, we had alternatives such as Volvo, Skoda, etc. In the sustainability trend analysis, the alternatives will be the years for which we have data, i.e. 1999 or 2004. Concerning cars, we wanted to select the best option for us to buy and we guided the method by defining criteria their goals and thresholds. It will be the same in sustainability analysis. We have already defined criteria and their goals, see table 3.4. Thresholds and data types will be defined below. Last thing that NAIADE needs to work is the α parameter that measures conservativeness of the method. We will not set the parameter and during the analysis we shall investigate how the method outcomes change with different degrees of conservativeness. There will be several results of the method. First, there will be two flows. Φ^+ that tells us, how much is the given year preferred against the other years (alternatives) in terms of sustainability, or simpler it aggregates all the much better and better preference relations into one number. The other Φ^- does the opposite. It aggregates the worse and much worse preference relations into one number. The values of the flows are always in the interval of 0 and 1, and they would change if we included other alternatives, thus they cannot be regarded as a sustainability indicator, but through regression on the flows, we can extract the trend and say whether it is headed the right way. Both flows are normalized, thus comparable. If we take $1 - \Phi^-$ (sometimes we might use simplified notation Φ^{1-}), linear regressions on this adjusted flow and positive flow should manifest the same sign in coefficient of explanatory variable. Otherwise, as Shmelev and Rodríguez-Labajos (2009) say, *"diverging lines or up-and-down evolution indicate likely incomparability between periods and irregular performance in terms of a sustainable progress of the country."* In other words, we may experience situation when from one year to the next (two alternatives) some criteria are going the right way (GDP is growing, Gini is lowering) while other are going the wrong way (emissions go up, expenditure on R&D goes down). If this behaviour would be manifested by several years in line, the Φ^+ flow would grow for every year (alternative), because with every year we will have higher positive (better, much better) preference relations for GDP and Gini. And this would be the same with the Φ^- flow, because with every year negative preference relations for emissions and expenditures on R&D would increase the flow. Taking $1 - \Phi^-$ and Φ^+ and linear regressions on them, we would get diverging lines. This is what Shmelev and Rodríguez-Labajos mean by *incomparability and irregular performance*. From perspective of strong sustainability only two positively sloped regression lines can be taken as an evidence of sustainable development.

The last crucial step towards the procedure is setting of thresholds and data types. We will carry out two analyses with different set of thresholds and data types. These will be:

- Scenario 1 that will replicate thresholds from case study of Austria by Shmelev and Rodríguez-Labajos (2009) for comparability. Data types will be set to crisp, as there is no information in the paper suggesting the data types. (Table A.7)
- Scenario 2 that will different data types for several criteria to account for the nature of the data and measurement procedures. The changes to the scenario one will be clearly described. (Table A.8)

3.3.1 Scenario 1

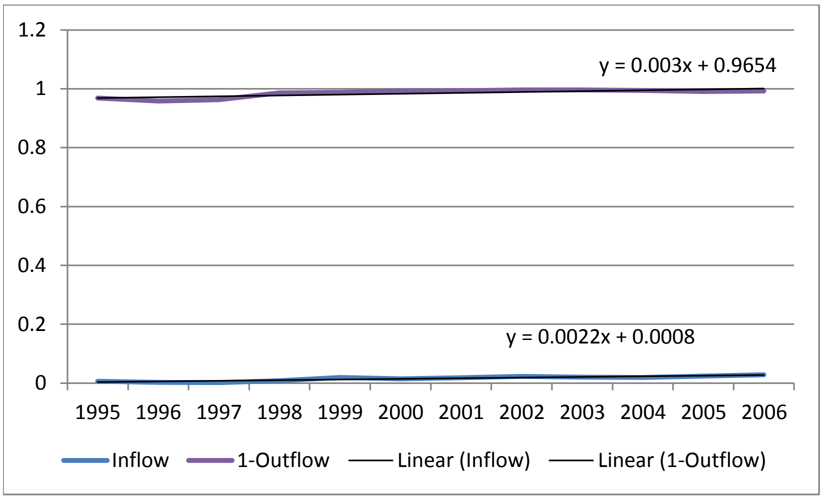
As we have explained before given the conservativeness (the higher α is the more conservative is the assessment) the main output of the method is an analysis of the two flows. The first flow can be called positive (denoted as Φ^+) and represents how much is the alternative preferred to the other alternatives. The other one, negative (denoted as Φ^-) tells us how much is the alternative being rejected with respect to the other alternatives. Charts of flows for selected degrees of conservativeness are shown in figure 3.4.

Regression lines in case of $\alpha = 0.5$ are given by the expressions (x is year)

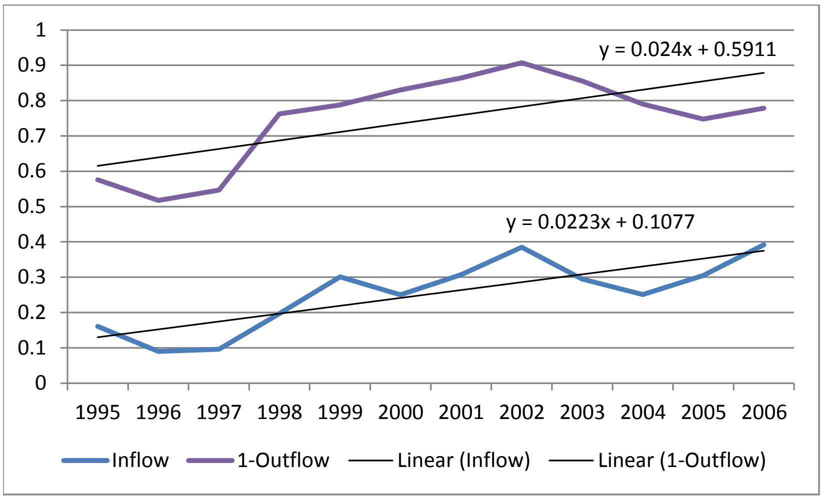
$$\Phi^{1-} = 0.024 * x + 0.5911, \Phi^+ = 0.0223 * x + 0.1077.$$

In case of $\alpha = 0.1$ the regression is given by

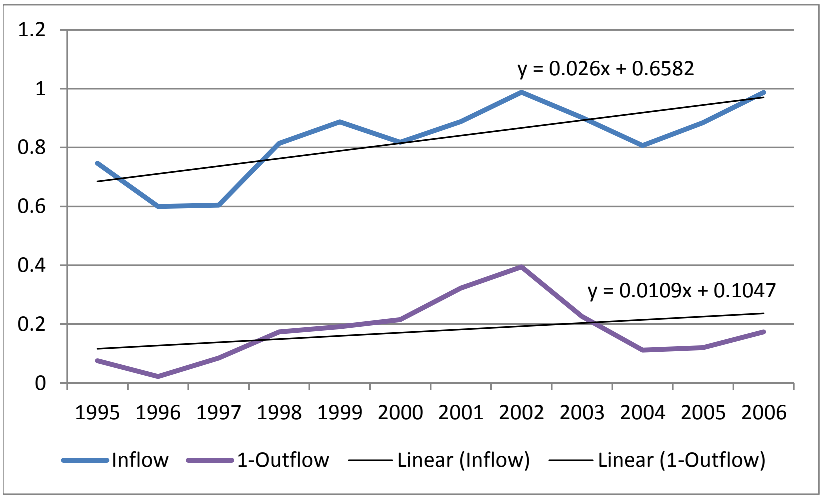
$$\Phi^{1-} = 0.0109 * x + 0.1047, \Phi^+ = 0.026 * x + 0.6582.$$



(a) Flows analysis; $\alpha = 0.9$



(b) Flows analysis; $\alpha = 0.5$



(c) Flows analysis; $\alpha = 0.1$

Figure 3.4: NAIADE - Flows analysis, scenario 1

Flow	Austria			Czech Republic		
	$\alpha = 0.1$	$\alpha = 0.5$	$\alpha = 0.9$	$\alpha = 0.1$	$\alpha = 0.5$	$\alpha = 0.9$
Φ^+	0.0218	0.0272	0.0015	0.041	0.0387	0.0036
Φ^{1-}	0.016	0.0227	0.0017	0.0476	0.0462	0.0043

Table 3.5: Comparison of results of NAIADE analysis, source: (Shmelev and Rodríguez-Labajos, 2009) and own computations.

The last case of $\alpha = 0.9$, i.e. the most conservative case is given by

$$\Phi^{1-} = 0.003 * x + 0.9654, \Phi^+ = 0.0022 * x + 0.0008.$$

In all cases, the regression line shows increasing trend. Thus, medium-term trend to sustainable development is identified by linear regression on data received from NAIADE method. With more conservativeness introduced by the α parameter the swings are more and more smoothed as only very strong evidence of given preference is taken into account.

Looking at rankings we can see that from point of view of positive flow, first two alternatives are ultimately occupied by years 2002 and 2006. The same applies to the other end of ranking when three last places are held by year 1995, 1996, 1997. Last place of 1997 alternative is probably caused by the economic crisis in the year and subsequent changes in indicators, most notably life satisfaction indicator and unemployment.

In case of negative flow, the best alternatives (more precisely speaking the least against alternatives) are much less clear. The other end of ranking, however, gives the same picture as the positive flow ranking 1995, 1996, 1997 always among three worst alternatives.

Comparison with Austria case-study

To be able to compare results of the Czech Republic to results of Austria, we have to be able to replicate the same process applied in the Austria case-study. Concerning the data, we have the same dataset. Our time scale is even broader than in Austria study, so we have to limit the exercise only to the same time-scale. The thresholds were set at the same values. The biggest problem in our case is that Shmelev and Rodríguez-Labajos (2009) do not state what type are the data. We assume, that the easiest approach was used and all data were set to be crisp quantitative.

The results are presented in table 3.5, where the numbers are slopes from linear regression of the flows. From it we can see that the trends identified in case of the Czech Republic are much higher in both flows. We suggests two possibilities of interpretation of the results.

The first, less appealing, is that the data types in the Austrian case were set in very different manner to be assumed very vague. In such case, the method would interpret the results as being less sure, thus the degree of preference would be lower and the resulting trend would also be lower.

The second explanation comes more natural. As in 1993 the Czech Republic was very *undeveloped* country in terms of western Europe. From 1993 on, process of convergence towards western Europe was started and the leaps in the indicators were naturally higher than in case of Austria which *only* continued its development. The convergence process in many ways culminated by accession to the European Union in 2004, one year after the end of our time scale. Thus we indeed identify stronger sustainability trend in case of the Czech Republic, but most of it would probably be accounted to very different starting positions.

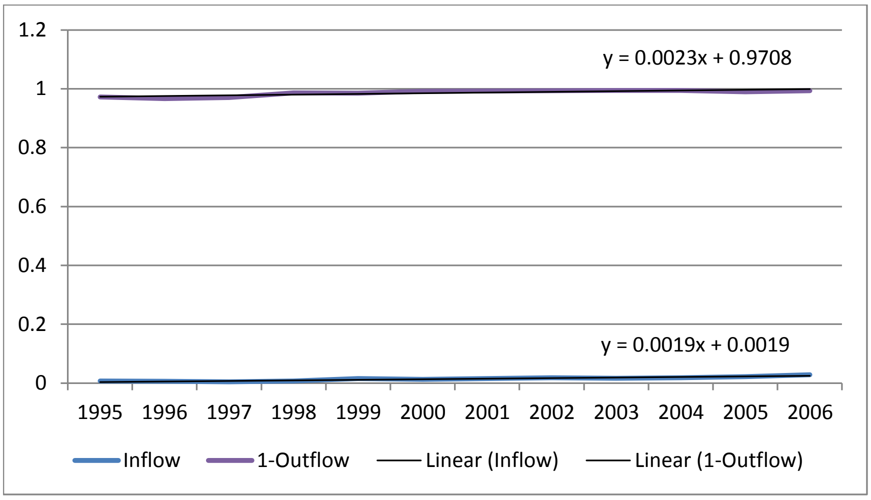
3.3.2 Scenario 2

In this scenario, we adjusted the data types to correspond with the nature of phenomena they measure, as we have described in the data selection section. Setting for this scenario is captured by table A.8. Changes with respect to first scenario are underlined. Given this setting, we expect to discover less strong sustainability trends than in the first case, because setting of the data types to absorb some uncertainty makes the preference relations less clear.

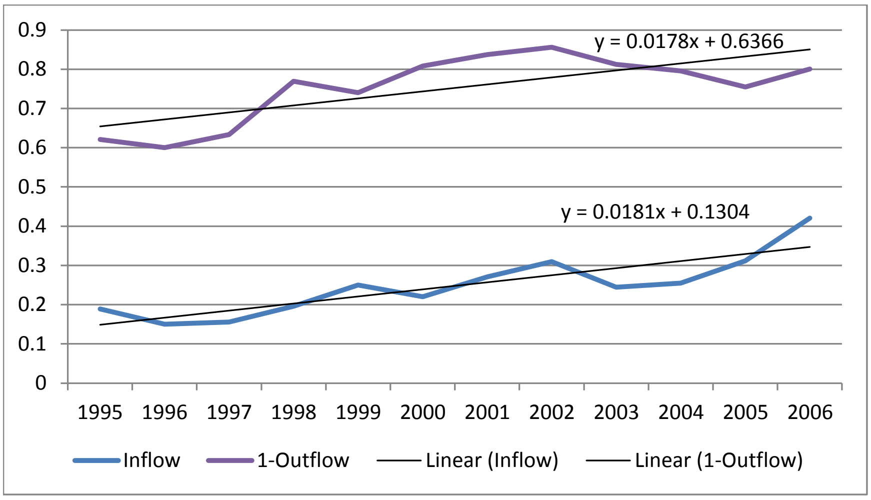
In the process of setting data types, we made several assumptions. As studying every single methodology for given data is beyond scope of this thesis, we assume that, because of the data are from very reliable resources, standard deviation of measurement is at most 5% of the value. In all cases, we are concerned with measurement error and thus we set data type to be stochastic. We use Gaussian type of distribution with mean as our given value and standard deviation equal to 5% of the value. This arguably very simplistic approach will nevertheless produce results that are more robust against errors.

Looking at the results, we find that all except one regression slope coefficients are lower than in previous scenario. But we still find trends towards sustainability.

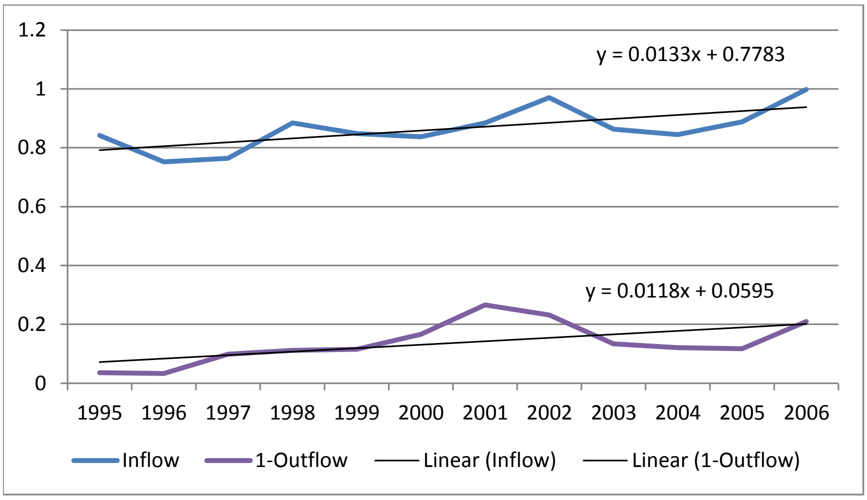
The bottom ranking of the alternatives has not changed. Again years 1995-1997 are still assessed as the least sustainable in all cases. With the opposite part of the ranking the situation is much less clear. Positive flow (how much criteria are preferred) selects 2005-2006 years to be among three best alternatives regardless conservativeness level. But in terms of alternative negative flow these two alternatives range from 3^{rd} to 7^{th} place which tells us that some of the criteria were developing against sustainability. This is, however, overweighted by the general trend to sustainability. Graphical representation of it might be helpful. The flows are to be



(a) Flows analysis; $\alpha = 0.9$



(b) Flows analysis; $\alpha = 0.5$



(c) Flows analysis; $\alpha = 0.1$

Figure 3.5: NAIADE - Flows analysis, scenario 2

found in figure 3.5.

After carrying out these two measurements we conclude, that we have identified an increasing trend towards sustainability for years 1995-2006, because under any settings of the method, the method did not yield results rejecting the hypothesis.

4. Conclusion

In my thesis, I set myself a goal to explore methods of assessing long-term development measures and study the case of the Czech Republic. Current most known method that should measure sustainability (and is often presented is it does) – GDP per capita – is found not to be suitable for this goal as it depicts only production, however, it omits many important aspects of human development. Because of that we turn to explore the theoretical background of long-term development.

In the theoretical part, concept of sustainability is presented. It is synonymous to long-term development. Explicitly, sustainability has been defined in the seventies by the United Nations. The presented definition is very wide and comprises many aspects of our world. The most important and discussed are economic, environmental, institutional and social aspects. These four dimensions should be developed in harmony in order not to lower quality of life for future generations. In the literature, two main schools of sustainability may be identified. The first, called weak sustainability, basically states that the only thing needed is to keep net investment positive and the rest will be done through markets. Thus, this school supposes possibility of infinite substitution between different types of capital (human, natural, etc.). On the other hand, the second school called strong sustainability criticises this attitude and states that such substitution cannot be assumed.

These two concepts are measured by various methods. We may divide them into two approaches. First approach is so called accounting approach, that strives to derive measure of sustainability from national accounts. This approach may be regarded as constructing *better GDP*. The second approach is to construct various indices from some selected indicators. These indices are connected with several technical issues, namely normalization of indicators, aggregation procedures and weighting. There exists also theoretical issue that is quite obvious: which indicators should we select for construction of the index. This problem has been addressed by many organizations and nowadays standard sets of the indicators exist. We thoroughly investigated two sustainability measures that use the accounting approach – ISEW and Genuine Savings Index. From theoretical point of view both indicators are sound. The problem with the two methods arises mainly from lack of reliable data needed to make them work according to the theoretical propositions. Other problems seem to be of minor nature.

Accounting and index approaches are most common. However, in recent years multi-criteria decision assessment methods were used to measure sustainability trends. Such approach is quite different, because it does not create cardinal measure of sustainability, but it only orders the alternatives (in our case years) according to inserted criteria and goals. There exist many different MCDA methods and we selected NAIADE method, which incorporates fuzzy logic theory. This theory is especially useful when dealing with preferences, because in real world they are never strict. Other advantage of the method is that it can process various data types, from qualitative data to quantitative fuzzy data.

In the case of the Czech Republic we first looked at results of two classical indices that measure sustainability – Human Development Index and Sustainable Society Index. Human Development Index may be regarded as the *basic* sustainability index, as only three indicators are taken into account. Those are income, education and longevity. Hence, the index is surely useful, but in case of European countries, most of the pressing goals in terms of income, education and longevity has been solved and the question should probably be about distribution of the income among people, social and other issues. For that reason HDI should be regarded as necessary condition to sustainability, but not sufficient. Concerning theoretical critiques we may conclude, that they are often objective, but remain in realms of economic theory. One example may be same HDI reached by lowering life expectancy (for example by restraining medical care to elderly) and boosting GDP per capita on account of that.

Yes, the index surely works this way, but the incentives for such actions probably would not be boosting of HDI. Apart from that, such development can be pinned down by looking at underlying indicators. Czech Republic performs quite well in this index ranking around 27^{th} place from about 160 countries for the 2005 – 2010 period.

Sustainable Society Index is more elaborate index of sustainability when compared to Human Development Index. The complexity is created by inclusion of wide range of underlying indicators. The index measures three dimensions of sustainability: economic, social, environmental. There are 24 underlying indicators that are normalized to create scores from 0 to 10. Final SSI score is created by averaging the values. Results of the Czech Republic in this index confirm previous results from HDI, it ranks 23^{rd} for 2006 and 2008 and 16^{th} for 2010 from around 150 countries. Apart from ranking, pleasant result is that SSI score grows continually for the three years.

Hence, from common measures of sustainability we may conclude that there exists certain trend to sustainability and that the Czech Republic is not performing under expectations.

Last part, evaluation of sustainability trend by means of NAIADE requires selection of time-scale, dataset and setting parameters needed to make the method work. The first two problems were approached pragmatically. At the beginning, there were two goals: i) make our computation comparable with similar case-study for Austria, and ii) provide sustainability trend evidence on the widest time-scale that is possible by chosen dataset. For reasons of comparability, indicators were selected the same as in the Austrian case study. (Nevertheless, the indicators can be considered as standard ones.) The time scale we needed for comparison was from 1993 up to 2003. However, we were able to get data for longer period up till 2006. The last problem, parameters, was addressed by creating two possible scenarios. The biggest difference between the two scenarios was in degree of assumed uncertainty in the data. The first scenario works with the assumption that all the data are certain and the second one allows for uncertainty in case of estimated data such as life satisfaction or carbon dioxide emissions, as those data are acquired on basis of inference from a sample.

Both scenarios yielded evidence for sustainable trend in the Czech Republic in period from 1993 to 2006. In comparison with Austria, Czech Republic manifested higher trend towards sustainability and this can be explained by the fact that during period 1993–2003, Czech Republic was quickly converging to western Europe and this quick convergence was translated by the method as higher trend towards sustainability, while Austria was only continuing its development. In other words, the difference can be explained by different starting positions.

Overall, we found empirical evidence for hypothesis of sustainable development of the Czech Republic. Robustness of the result should be provided by three different sources that unanimously lead to conclusion of existence of sustainable development.

There are surely many possible extensions to this work. Two approaches manifest. First way is quantity. There are other indices that were discussed in this work, such as Ecological Footprint for which data exist, or ISEW which has not been computed for the Czech Republic, and the computation could yield very interesting results. Second way of improvement is deepening of NAIADE method. One could choose different criteria or add other criteria to the method to create different scenarios for sustainability. Also as the method is very complicated, many parameters have to be set. Exploring robustness of the results under various set of parameters would be of big interest. Also, during writing of the thesis I have encountered very poignant aspect of many indices of sustainable development. There is one indicator of sustainable development that should be included in the evaluation but almost never is. This indicator is government debt. As we might have seen in year 2010, the bankruptcy of a state could have severe outcomes for current and future generations. Hence possible extension of the thesis could be inclusion of government debt data into the NAIADE analysis.

A. Figures and tables

Linguistic variable	Membership function
Perfect	$\mu_p(x) = \begin{cases} 1 & \text{for } x = 1 \\ 0 & \text{for } x \neq 1 \end{cases}$
Very good	$\mu_{vg}(x) = \begin{cases} 4\left(\frac{x-0.8}{0.2}\right)^4 & \text{for } 0.8 \leq x \leq 0.9 \\ \left(1-2\left(\frac{1-x}{0.2}\right)^2\right)^2 & \text{for } 0.9 \leq x \leq 1 \\ 0 & \text{otherwise.} \end{cases}$
Good	$\mu_g(x) = \begin{cases} 0 & \text{otherwise.} \\ 2\left(\frac{x-0.6}{0.2}\right)^2 & \text{for } 0.6 \leq x \leq 0.7 \\ 1-2\left(\frac{x-0.8}{0.2}\right)^2 & \text{for } 0.7 \leq x \leq 0.9 \\ 2\left(\frac{1-x}{0.2}\right)^2 & \text{for } 0.9 \leq x \leq 1 \end{cases}$
More of less good	$\mu_{mlg}(x) = \begin{cases} \sqrt{2}\frac{x-0.5}{0.2} & \text{for } 0.5 \leq x \leq 0.6 \\ \sqrt{1-2\left(\frac{x-0.7}{0.2}\right)^2} & \text{for } 0.6 \leq x \leq 0.8 \\ \sqrt{2}\frac{0.9-x}{0.2} & \text{for } 0.8 \leq x \leq 0.9 \\ 0 & \text{otherwise.} \end{cases}$
Moderate	$\mu_g(x) = \begin{cases} 2\left(\frac{x-0.3}{0.2}\right)^2 & \text{for } 0.3 \leq x \leq 0.4 \\ 1-2\left(\frac{x-0.5}{0.2}\right)^2 & \text{for } 0.4 \leq x \leq 0.6 \\ 2\left(\frac{0.7-x}{0.2}\right)^2 & \text{for } 0.6 \leq x \leq 0.6 \\ 0 & \text{otherwise.} \end{cases}$
More or less bad	$\mu_{mlb}(x) = \begin{cases} \sqrt{2}\frac{x-0.1}{0.2} & \text{for } 0.1 \leq x \leq 0.2 \\ \sqrt{1-2\left(\frac{x-0.3}{0.2}\right)^2} & \text{for } 0.2 \leq x \leq 0.4 \\ \sqrt{2}\frac{0.5-x}{0.2} & \text{for } 0.4 \leq x \leq 0.5 \\ 0 & \text{otherwise.} \end{cases}$
Bad	$\mu_b(x) = \begin{cases} 0 & \text{otherwise.} \\ 2\left(\frac{x}{0.2}\right)^2 & \text{for } 0 \leq x \leq 0.1 \\ 1-2\left(\frac{x-0.2}{0.2}\right)^2 & \text{for } 0.1 \leq x \leq 0.3 \\ 2\left(\frac{0.4-x}{0.2}\right)^2 & \text{for } 0.3 \leq x \leq 0.4 \end{cases}$
Very bad	$\mu_{vb}(x) = \begin{cases} 4\left(\frac{0.2-x}{0.2}\right)^4 & \text{for } 0.1 \leq x \leq 0.2 \\ \left(1-2\left(\frac{x}{0.2}\right)^2\right)^2 & \text{for } 0 \leq x \leq 0.1 \\ 0 & \text{otherwise.} \end{cases}$
Extremely bad	$\mu_{eb}(x) = \begin{cases} 1 & \text{for } x = 1 \\ 0 & \text{for } x \neq 1 \end{cases}$

Table A.1: Linguistic variables – membership functions

Name	Membership function	Parameters
Gaussian	$\mu_G(x) = \begin{cases} e^{-k(x-m)^2} & \text{for } l \le x \le u \\ 0 & \text{otherwise.} \end{cases}$	l, m, u, k where $k \ge 0$
Flat	$\mu_F(x) = \begin{cases} 0 & \text{for } x \le l \\ 2\left(\frac{x-l}{m_1-l}\right)^2 & \text{for } l < x \le b_1 \\ 1-2\left(\frac{m_1-x}{m_1-l}\right)^2 & \text{for } b_1 \le x < m_1 \\ 1 & \text{for } m_1 \le x \le m_2 \\ 1-2\left(\frac{x-m_2}{u-m_2}\right)^2 & \text{for } m_2 < x \le b_2 \\ 2\left(\frac{x-u}{m_2-u}\right)^2 & \text{for } b_2 \le x < u \\ 0 & \text{for } x \ge u. \end{cases}$	l, m_1, m_2, u $b_1 = \frac{l+m_1}{2}$ $b_1 = \frac{u+m_2}{2}$
Left-right general	$\mu_{LRG}(x) = \begin{cases} 0 & \text{for } x \le l \\ 2\left(\frac{x-l}{m-l}\right)^2 & \text{for } l < x \le b_1 \\ 1-2\left(\frac{m-x}{m-l}\right)^2 & \text{for } b_1 \le x < m \\ 1 & \text{for } x = m \\ 1-2\left(\frac{x-m}{u-m}\right)^2 & \text{for } m < x \le b_2 \\ 2\left(\frac{x-u}{m-u}\right)^2 & \text{for } b_2 \le x < u \\ 0 & \text{for } x \ge u. \end{cases}$	l, m, u $b_1 = \frac{l+m}{2}$ $b_1 = \frac{u+m}{2}$
Symmetrical	$\mu_X(x) = \begin{cases} 0 & \text{for } x \le l \\ 2\left(\frac{x-l}{m-l}\right)^2 & \text{for } l < x \le b_1 \\ 1-2\left(\frac{m-x}{m-l}\right)^2 & \text{for } b_1 \le x < m \\ 1 & \text{for } x = m \\ 1-2\left(\frac{x-m}{u-m}\right)^2 & \text{for } m < x \le b_2 \\ 2\left(\frac{x-u}{m-u}\right)^2 & \text{for } b_2 \le x < u \\ 0 & \text{for } x \ge u. \end{cases}$	l, u $m = \frac{l+u}{2}$ $b_1 = \frac{l+m}{2}$ $b_1 = \frac{u+m}{2}$

Table A.2: Basic types of fuzzy numbers

Name	Density function	Parameters
Uniform	$f_U(x) = \begin{cases} \frac{1}{b-a} & \text{for } x \in [b,a] \\ 0 & \text{otherwise} \end{cases}$	a, b where $a < b$ $\mu = \frac{a+b}{2}$ $\sigma = \sqrt{\frac{a^2+b^2+ab}{3}}$
Triangular	$f_T(x) = \begin{cases} \frac{b-\lvert x-a\rvert}{b^2} & \text{for } (a-b) \le x \le (a+b) \\ 0 & \text{otherwise} \end{cases}$	a, b $\mu = a$ $\sigma = \sqrt{\frac{b}{6}}$
Normal	$f_N(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$	μ, σ
LogNormal	$f_{LN}(x) = \frac{1}{x\sigma\sqrt{2\pi}} e^{-\frac{(\ln x-\mu)^2}{2\sigma^2}}$	μ, σ

Table A.3: Stochastic data entries

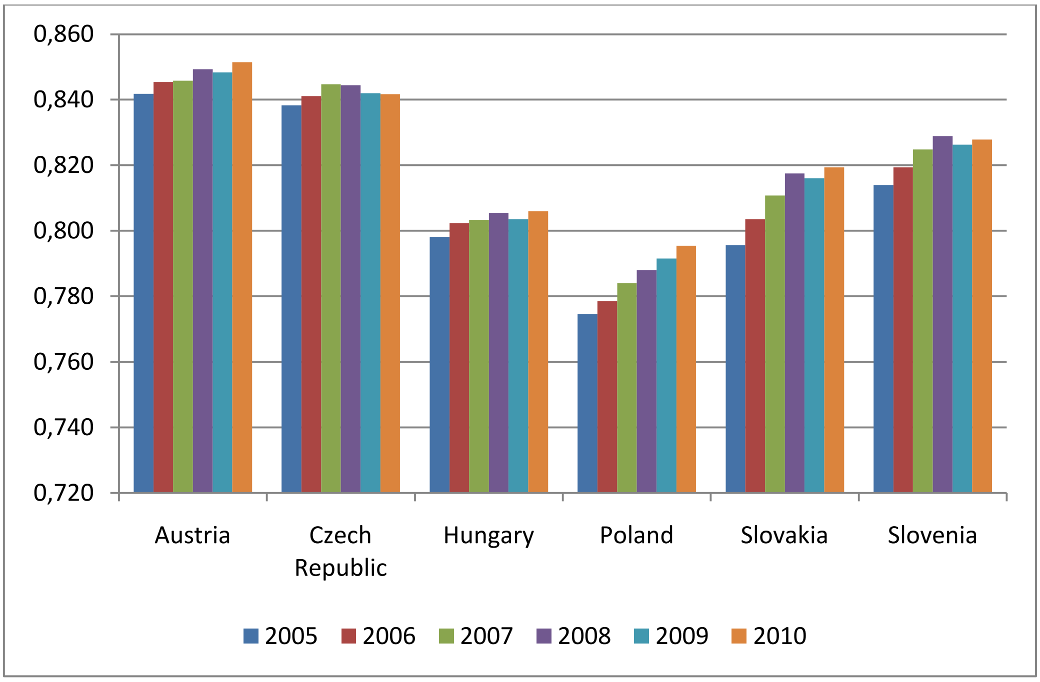


Figure A.1: HDI comparison

	2006					2008					2010				
Country	HW	EnW	EcW	SSI	Rk	HW	EnW	EcW	SSI	Rk	HW	EnW	EcW	SSI	Rk
Austria	8.62	6.51	7.04	7.43	2	8.71	6.50	7.19	7.50	2	8.71	6.53	6.80	7.42	3
Czech Republic	8.27	5.44	5.71	6.57	23	8.54	5.19	6.15	6.69	23	8.53	5.71	5.79	6.79	16
Hungary	8.52	5.90	5.67	6.83	11	8.58	6.14	5.17	6.81	18	8.44	6.35	5.05	6.81	14
Poland	8.01	6.06	4.71	6.45	28	8.13	6.16	5.14	6.64	26	8.12	6.11	5.06	6.60	26
Slovak Republic	8.16	6.15	5.79	6.81	13	8.22	6.39	5.92	6.96	11	8.26	6.66	4.57	6.73	18
Slovenia	8.63	5.91	6.14	6.99	7	8.61	5.98	6.61	7.12	6	8.50	6.02	6.03	6.95	8

Table A.4: Full results Sustainable Society Index, source: Sustainable Society Foundation, http://www.ssfindex.com

	2006			2008			2010		
Country	HDI	SSI	Diff.	HDI	SSI	Diff.	HDI	SSI	Diff.
Greece	21	43	**-22**	20	46	**-26**	20	58	**-38**
Ireland	5	20	**-15**	5	21	**-16**	5	26	**-21**
Netherlands	9	19	**-10**	6	15	**-9**	6	34	**-28**
Romania	43	47	**-4**	43	22	**21**	42	19	**23**
Germany	10	14	**-4**	8	14	**-6**	8	12	**-4**
Spain	20	24	**-4**	19	29	**-10**	19	35	**-16**
Norway	1	4	**-3**	1	4	**-3**	1	4	**-3**
Denmark	15	17	**-2**	17	12	**5**	18	10	**8**
Italy	23	21	**2**	22	20	**2**	21	23	**-2**
Czech Republic	25	23	**2**	25	23	**2**	25	16	**9**
France	17	15	**2**	16	17	**-1**	13	15	**-2**
Luxembourg	19	16	**3**	20	16	**4**	22	9	**13**
Sweden	6	3	**3**	8	3	**5**	8	2	**6**
Finland	13	8	**5**	11	8	**3**	15	5	**10**
Poland	35	28	**7**	36	26	**10**	34	25	**9**
Portugal	36	27	**9**	34	33	**1**	34	27	**7**
Estonia	27	18	**9**	27	10	**17**	30	11	**19**
Switzerland	12	1	**11**	11	1	**10**	12	1	**11**
United Kingdom	24	9	**15**	24	19	**5**	24	20	**4**
Slovakia	29	13	**16**	27	11	**16**	27	18	**9**
Hungary	30	11	**19**	32	18	**14**	32	14	**18**
Slovenia	26	7	**19**	26	6	**20**	26	8	**18**
Austria	22	2	**20**	23	2	**21**	23	3	**20**

Table A.5: Differences in rankings between HDI and SSI indices. Source: Own computations.

Criteria name	Alternatives 1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Gini index	21.5	22.9	22.6	22.6	23.8	23.8	22.8	23.2	22.8	23.5	25.8	24.2
Unemployment	4.1	3.9	4.8	6.4	8.6	8.7	8.0	7.3	7.8	8.3	7.9	7.1
Life expectancy at birth	73.3	73.9	74.1	74.7	74.9	75.1	75.3	75.4	75.3	75.9	76.1	76.7
Tertiary attainment	10.6	10.4	10.6	10.4	10.8	11.0	11.1	11.9	12.0	12.3	13.1	13.5
Carbon dioxide emissions	124.0	126.0	124.0	118.0	111.0	122.0	122.0	117.0	121.0	122.0	120.0	121.0
Gross domestic expenditure on R&D	1.0	1.0	1.1	1.2	1.1	1.2	1.2	1.2	1.3	1.3	1.4	1.6
Contribution of renewables to energy supply	1.5	1.5	1.7	1.7	2.4	2.0	2.1	2.5	3.7	4.1	4.3	4.6
Total primary energy supply per capita	4.0	4.1	4.1	4.0	3.7	3.9	4.0	4.1	4.4	4.5	4.4	4.5
Number of recorded crimes per capita	3568.1	3755.4	3861.0	4137.3	4148.8	3809.0	3505.1	3648.7	3504.7	3441.9	3361.3	3276.3
Gross national income per capita	12813.0	13644.0	13829.0	13962.0	14312.0	14994.0	16176.0	16872.0	17990.0	19300.0	20366.0	21827.0
Population growth	-0.1	-0.2	-0.1	-0.1	-0.1	-0.1	-0.5	-0.2	0.0	0.1	0.3	0.3
Forest trees damaged by defoliation	56.0	71.3	68.7	43.4	41.3	42.4	43.1	44.9	46.2	50.3	50.7	51.1
Organic water pollutants	176836.0	186398.0	180262.0	177801.0	170230.0	142492.0	154949.0	143589.0	152620.0	152422.0	148863.0	146529.0
Municipal waste generated	302.0	310.0	318.0	293.0	327.0	334.0	273.0	279.0	280.0	278.0	289.0	296.0
Life satisfaction	55.7	60.2	53.2	54.5	56.4	60.5	58.9	59.4	60.0	58.1	57.2	61.7
Domestic material consumption	187.7	197.9	196.8	180.7	171.6	176.1	175.1	167.6	171.8	181.3	181.4	185.0

Table A.6: Dataset

Criteria name	Criteria type	Goal	Much better/worse	Better/worse	Approximately equal	Equal
Gini index	Numeric	Minimize	1	0.4	0.2	0.1
Unemployment	Numeric	Minimize	2	1	0.5	0.25
Life expectancy at birth	Numeric	Maximize	1	0.5	0.2	0.1
Tertiary attainment	Numeric	Maximize	5	3	1	0.5
Carbon dioxide emmissions	Numeric	Minimize	3	1	0.2	0.05
Gross domestic expenditure on R&D	Numeric	Maximize	0.25	0.1	0.05	0.025
Contribution of renewables to energy supply	Numeric	Maximize	1	0.2	0.1	0.01
Total primary energy supply per capita	Numeric	Minimize	0.3	0.1	0.075	0.05
Number of recorded crimes per capita	Numeric	Minimize	1000	500	100	50
Gross national income per capita	Numeric	Maximize	1000	200	50	10
Population growth	Numeric	Minimize	0.2	0.1	0.02	0.01
Forest trees damaged by defoliation	Numeric	Minimize	3	2	0.8	0.4
Organic water polutants	Numeric	Minimize	4500	2750	1150	550
Municipal waste generated	Numeric	Minimize	125	75	30	15
Life satisfaction	Numeric	Maximize	5	4	2	1
Domestic material consumption	Numeric	Minimize	7	4	2	1

Table A.7: Thresholds for NAIADE analysis scenario 1

Criteria name	Criteria type	Goal	Much better/worse	Better/worse	Approximately equal	Equal
Gini index	Stochastic	Minimize	1	0.4	0.2	0.1
Unemployment	Numeric	Minimize	2	1	0.5	0.25
Life expectancy at birth	Numeric	Maximize	1	0.5	0.2	0.1
Tertiary attainment	Numeric	Maximize	5	3	1	0.5
Carbon dioxide emmissions	Stochastic	Minimize	3	1	0.2	0.05
Gross domestic expenditure on R&D	Numeric	Maximize	0.25	0.1	0.05	0.025
Contribution of renewables to energy supply	Numeric	Maximize	1	0.2	0.1	0.01
Total primary energy supply per capita	Numeric	Minimize	0.3	0.1	0.075	0.05
Number of recorded crimes per capita	Numeric	Minimize	1000	500	100	50
Gross national income per capita	Numeric	Maximize	1000	200	50	10
Population growth	Numeric	Minimize	0.2	0.1	0.02	0.01
Forest trees damaged by defoliation	Stochastic	Minimize	3	2	0.8	0.4
Organic water polutants	Stochastic	Minimize	4500	2750	1150	550
Municipal waste generated	Stochastic	Minimize	125	75	30	15
Life satisfaction	Stochastic	Maximize	5	4	2	1
Domestic material consumption	Stochastic	Minimize	7	4	2	1

Table A.8: Thresholds for NAIADE analysis scenario 2

Year	**Source**	**Link**
Gini index	World Income Inequality Database	http://www.wider.unu.edu
Unemployment rate	OECD FactBook 2010	OECD (2010)
Life expectancy at birth	OECD FactBook 2010	OECD (2010)
Tertiary attainment	OECD FactBook 2008/2009	OECD (2008)
Number of recorded crimes	Czech Statistical Office	http://www.czso.cz/
Population change	OECD FactBook 2010	OECD (2010)
Life satisfaction	Sociological data archive	http://nesstar.soc.cas.cz/webview/
Carbon dioxide emissions	OECD FactBook 2010	OECD (2010)
Gross national income per capita	OECD FactBook 2010	OECD (2010)
Total primary energy supply per capita	OECD FactBook 2010	OECD (2010)
Contribution of renewables to energy supply	OECD FactBook 2010	OECD (2010)
Gross domestic expenditure on R&D	OECD FactBook 2010	OECD (2010)
Municipal waste generated	Eurostat	http://epp.eurostat.ec.europa.eu
Forest trees damaged by defoliation	Eurostat	http://epp.eurostat.ec.europa.eu
Organic water pollutants BOD	World Bank Database	http://data.worldbank.org
Domestic material consumption	Eurostat	http://epp.eurostat.ec.europa.eu

Table A.9: Data sources

B. Computations

B.1 Semantic distance

B.1.1 Existence and algebraic computation

Existence of semantic distance can be shown using the following theorems:

Theorem 2 *Let $M \subset \mathbb{R}^n$ and f be function of n variables such that integral $\int_M f$ exists. Then $\int_M |f|$ exists and it holds that*

$$\left| \int_M f \right| \leq \int_M |f|.$$

Theorem 3 *Let $M \subset \mathbb{R}^n$ be convex and f be bounded non-negative function on M, which is continuous in all points of M except for countably many. Then $\int_M f$ exists.*

Let us define $z(x, y) = (x - y)f(x)g(y)$, where $x \in [a, b], y \in [c, d]$ and functions f, g are altered membership functions as defined in equation 2.3 or probability density function. Then, f, g are non-negative and bounded. Given assumption that f, g are continuous on the intervals, according to Theorem 3 $\int_{\mathbb{R}^2} z$ exists. Now, we may conclude from Theorem 2 that $\int_{\mathbb{R}^2} |z|$ exists and $| \int_{\mathbb{R}^2} z| \leq \int_{\mathbb{R}^2} |z|$. It suffice to show that $\int |z| = S_d$.

Semantic distance is defined as integral of function $|x - y|f(x)g(y)$ where, as stated above, f, g are non-negative functions. Given that assumption, we may write that

$$|x - y|f(x)g(y) = |(x - y)f(x)g(y)|.$$

The formula on the right side of the expression is, however, our defined function z.

We have then shown that given the existence of continuous membership functions or probability density functions semantic distance always exists and it holds that

$$S_d(f(x), g(y)) \geq |E(x) - E(y)|.$$

As already said, semantic distance can be algebraically computed only given some assumptions. Then, let's compute semantic distance for restricted case $Y \cap X = \emptyset$, where X, Y are intervals and $f(x) = 0, \forall x \notin X, g(y) = 0, \forall y \notin Y$. We have

$$S_d(f(x), g(y)) = \iint_{X,Y} |x - y| f(x)g(y)dx\ dy \tag{B.1}$$

given the no-intersection condition, (x-y) has always the same sign. Hence, without loss of generality we can write

$$\iint_{X,Y} |x - y| f(x)g(y)dx\ dy = \left| \iint_{X,Y} (x - y)f(x)g(y)dx\ dy \right| \tag{B.2}$$

from Fubini theorem we can write

$$\left| \int_Y \left(\int_X xf(x)g(y) - yf(x)g(y)dx \right)\ dy \right| \tag{B.3}$$

from definition $\int_X f(x)dx = 1$, hence

$$\left| \int_Y g(y) \left(\int_X xf(x)dx \right) - yg(y)dy \right| \tag{B.4}$$

straightforwardly

$$\left| \int_X xf(x)dx - \int_Y yg(y)dy \right|. \tag{B.5}$$

This expression is, however, equal to expected values of the fuzzy numbers. Hence,

$$S_d(f(x), g(y)) = |E(x) - E(y)|, \forall x \in X, \forall y \in Y. \tag{B.6}$$

B.1.2 Algorithmic computation

Munda (2008) presents a solution to finding numeric approximation of semantic distance in form of Monte Carlo type algorithm. It is build on the fact that

$$S_d(f(x), g(y)) = \lim_{N \to \infty} \frac{\sum_{i=1}^{N} |x_i - y_i|}{N}$$

For finding suitable pairs of x_i, y_i the procedure[1] is:

1. Draw a random number r_0 from uniform distribution on $[0, 1]$.
2. $x_0 = r_0 l + (1 - r_0)u$, where l, u are numbers by which the fuzzy number is defined, see table A.2.

[1]For further assumptions, see Munda (2008, pg. 161).

3. Draw a random number Z_0 from uniform distribution on $[0, \max\{f(x)\}]$.
4. If $Z_0 \leq f(x_0)$, where $f(x)$ is membership function for fuzzy number x, then go to the next step, else return to step 1.
5. Draw random number r_1 from uniform distribution on $[0, 1]$.
6. $y_1 = r_1 l + (1 - r_1)u$, where l, u are numbers by which the fuzzy number is defined, see table A.2.
7. Draw a random number Z_1 from uniform distribution on $[0, \max\{g(y)\}]$.
8. If $Z_1 \leq g(y_1)$, where $g(y)$ is membership function for fuzzy number y, then compute $|x_0 - y_1|$ and increase N by one, else return to step 5.

The approximation is then arithmetic mean of the distances.

C. NAIADE calculation example

Let us have an example defined by following table:

	Skoda Octavia	Volvo C5	Volkswagen Polo	Renault Clio
Price	41 500	42 231	41 999	42 145
Comfort	Very Good	Perfect	Good	Good
Gas Consumption	6	7	6.4	7.3

Table C.1: Definition of an example

We use threshold and data type settings as in the following table

Criteria name	Criteria type	Goal	$t_{\succcurlyeq/\preccurlyeq}$	$t_{\succ/\prec}$	$t_{\simeq}$	$t_{=}$
Price	Numeric	Minimize	500	200	100	75
Comfort	Linguistic	Maximize	Thresholds are not needed.			
Gas consumption	Fuzzy	Minimize	2	1	0.4	0.2

Table C.2: Example threshold settings

For gas consumption we set fuzzy number type to be LeftRight, m is equal to value from table C.1, l is equal to $m - 1$ and u is equal to $m + 2$. (We have reasons to believe, that the bias upwards will be higher than downwards.)

Moreover let us have conservativness given as $\alpha = 0.5$.

First step is to calculate semantic distance. This step is done based on algorithm presented in appendix B.1.2 or in case of numeric data type by mere absolute value of the difference of the two values. Semantic distances are calculated in table C.3.

Given the distances and thresholds we are able to compute preference relations by using the functions from table 2.3 (semantic distance from the table is d and $t_.$ are thresholds in the expressions in aforementioned table C.2). These preference relations express the strength of given preference relation for the two alternatives of a given criterion. Results are presented in table C.4.

Having these relations we want to create aggregate preference relation of all criteria for given pair of alternatives, i.e. we want to aggregate all much better, better, etc. preferences of Skoda Octavia versus Volvo C5. Now, measure of conservativeness comes into action. $\alpha = 0.5$ tells us, that we want to account for preferences that are stronger than 0.5. The aggregation procedure is done based on equation 2.5. Results are in table C.5.

Price	Expected value difference	Semantic distance
Skoda vs. Volvo	-731	-731
Skoda vs. Volkswagen	-499	-499
Skoda vs. Renault	-645	-645
Volvo vs. Volkswagen	232	232
Volvo vs. Renault	86	86
Volkswagen vs. Renault	-146	-146

Comfort	Expected value difference	Semantic distance
Skoda vs. Volvo	-0.04625	0.04625
Skoda vs. Volkswagen	0.15375	0.15381
Skoda vs. Renault	0.15375	0.15381
Volvo vs. Volkswagen	0.2	0.2
Volvo vs. Renault	0.2	0.2
Volkswagen vs. Renault	0	0.089

Gas consumption	Expected value difference	Semantic distance
Skoda vs. Volvo	-1	1.06678
Skoda vs. Volkswagen	-0.4	0.646
Skoda vs. Renault	-1.3	1.34858
Volvo vs. Volkswagen	0.6	0.78888
Volvo vs. Renault	-0.3	0.61462
Volkswagen vs. Renault	-0.9	0.9806

Table C.3: Semantic distance

Price	M. better	Better	App. equal	Equal	Worse	M. Worse
Skoda vs. Volvo	0.702	0.930	0.006	0.000	0.000	0.000
Skoda vs. Volkswagen	0.499	0.862	0.031	0.000	0.000	0.000
Skoda vs. Renault	0.641	0.912	0.011	0.000	0.000	0.000
Volvo vs. Volkswagen	0.000	0.000	0.200	0.001	0.574	0.117
Volvo vs. Renault	0.000	0.000	0.551	0.402	0.156	0.004
Volkswagen vs. Renault	0.029	0.348	0.363	0.072	0.000	0.000

Comfort	M. better	Better	App. equal	Equal	Worse	M. Worse
Skoda vs. Volvo	0.000	0.000	0.845	0.793	0.033	0.001
Skoda vs. Volkswagen	0.087	0.274	0.571	0.077	0.000	0.000
Skoda vs. Renault	0.087	0.274	0.571	0.077	0.000	0.000
Volvo vs. Volkswagen	0.171	0.390	0.482	0.013	0.000	0.000
Volvo vs. Renault	0.171	0.390	0.482	0.013	0.000	0.000
Volkswagen vs. Renault	0.000	0.000	0.723	0.424	0.000	0.000

Gas consumption	M. better	Better	App. equal	Equal	Worse	M. Worse
Skoda vs. Volvo	0.142	0.500	0.157	0.000	0.000	0.000
Skoda vs. Volkswagen	0.008	0.138	0.326	0.001	0.000	0.000
Skoda vs. Renault	0.255	0.628	0.097	0.000	0.000	0.000
Volvo vs. Volkswagen	0.000	0.000	0.255	0.000	0.265	0.032
Volvo vs. Renault	0.003	0.083	0.345	0.001	0.000	0.000
Volkswagen vs. Renault	0.108	0.448	0.183	0.000	0.000	0.000

Table C.4: Preference relations

	M. better	Better	App. equal	Equal	Worse	M. Worse
Skoda vs. Volvo	0.19027	0.46257	0.29191	0.22672	0	0
Skoda vs. Volkswagen	0	0.38093	0.09901	0	0	0
Skoda vs. Renault	0.17649	0.70556	0.07331	0	0	0
Volvo vs. Volkswagen	0	0	0	0	0.09107	0
Volvo vs. Renault	0	0	0.22731	0	0	0
Volkswagen vs. Renault	0	0	0.3293	0	0	0

Table C.5: Preference intensity

In the next step, we want to know how sure the preferences are, so we apply the entropy concept presented in theoretical part. If the value from table C.5 is close to 0.5, it means that we are not sure about the preference, so the entropy attains high value, i.e. 1. The procedure is done based on equation 2.6.

	M. better	Better	App. equal	Equal	Worse	M. Worse
Skoda vs. Volvo	0.29307	0.45486	0.20762	0.24511	0	0
Skoda vs. Volkswagen	0	0.19335	0.32853	0	0	0
Skoda vs. Renault	0.31392	0.46027	0.32853	0	0	0
Volvo vs. Volkswagen	0	0	0	0	0.32809	0
Volvo vs. Renault	0	0	0.33083	0	0	0
Volkswagen vs. Renault	0	0	0.28389	0	0	0

Table C.6: Entropy calculation

The last step is getting together information from table C.5 and table C.6. We want to penalise high entropy, as it suggest hesitancy. This is achieved by creating the two flows as described in equations 2.7 and 2.8. The results are displayed in table C.7. The three zero values in the table are interesting as those show how the conservativeness parameter works. In table C.4, we may see some positive preference relations for Volvo[1], but they are very low and thus eliminated by the α.

	Positive	Negative
Skoda	0.4084	0.0000
Volvo	0.0000	0.1511
Volkswagen	0.0161	0.0656
Renault	0.0000	0.1371

Table C.7: Flows

As the positive flow can be interpreted as how much we prefer the alternative against the other, we may construct preference diagram. The same might be done with negative diagram which is interpreted as how much is the alternative worse. See the diagram below.

$$\text{Skoda} \longrightarrow \text{Volkswagen} \longrightarrow \text{Renault} \rightleftarrows \text{Volvo}$$

Figure C.1: Graphical representation of positive and negative flow

Usually the two diagrams are not the same, this is only because of using very simple example. From this two flows domination web is constructed. It is defined as an intersection of these two flows. In other words if alternative A is preferred to alternative B in both positive and negative flow, than also in domination web A is

[1]For example, Volvo is 0.171 much better in comfort criterion compared to Volkswagen. But our conservativeness threshold is 0.5, thus the preference relation is interpreted to be 0.

preferred to alternative B. Otherwise it is not. For our case, the domination web is printed below.

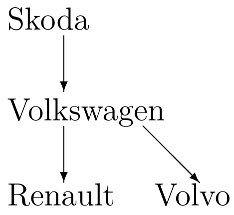


Figure C.2: Graphical representation of dominance web

From this domination web we can clearly see the preference relations and this graphical representation helps a great deal to interpret the results.

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