TURUN KAUPPAKORKEAKOULU
TULEVAISUUDEN TUTKIMUSKESKUS

TURKU SCHOOL OF ECONOMICS AND BUSINESS ADMINISTRATION
FINLAND FUTURES RESEARCH CENTRE

FUTU-publication 4/99

**Pentti Malaska, Jari Kaivo-oja &
Jyrki Luukkanen**

SUSTAINABILITY AND ECONOMIC GROWTH: A THEORETICAL FRAMEWORK AND EMPIRICAL DEMONSTRATIONS

The purpose of the research programme *Citizenship and ecomodernization in the information society – the futures approach* – is to study the social and ecological dimensions of emerging information society. Particularly we aim at assessing social impacts of new informational structures that are impinged on citizens. We also focus on analyzing the ways application of information technology influences on targets and realization of sustainable development. The study programme comprises of ten individual research project organized around above sketched themes.

The paper is submitteed for publication to Encyclopedia of Life Support Systems (EOLSS) published by UNESCO and EOLSS Publishers and this FUTU issue shall not be quoted or referred to.

Pentti Malaska
D. Tech., Professor emeritus
Finland Futures Research Centre
Turku School of Economics and Business Administration

Jyrki Luukkanen
D. Tech., Senior researcher
Department of Regional Studies and Environmental Policy
University of Tampere

Jari Kaivo-oja
Lic. (Adm. Sc.), Researcher
Finland Futures Research Centre
Turku School of Economics and Business Administration

ISBN 951-738-959-0
UDK 330.34
504

TABLE OF CONTENTS

ABSTRACT

In the article fundamental principles of sustainable development are discussed first from general points of view. Sustainable development is seen as a late-modern idea of progress, i.e. an ethos for improvement of human partnership within the earth's life support system in the current late-industrial times and the future. Secondly a macro-oriented conceptual framework of conditions necessary for advancement of ecological sustainability of the economy and society is formulated and analyzed. The theoretical framework presented is a set of logical identities, which define relationships between the total environmental stress (TES) and basic indicators of economic, technological and social development. The framework, called the Total Environmental Stress Approach of FFRC, provides necessary but not sufficient conditions for advancing ecological sustainability.

The explanatory power of the theory is demonstrated with new important concepts and empirical results. Dematerialization of production, sustainable economic growth, sustainable technological development, gross rebound effect on total environmental stress, employment and automation dilemma, structural shift of the economy, immaterialization of consumption, sustainable welfare growth, welfare productivity are introduced and analyzed. The empirical applicability of the theory is demonstrated through an analysis of (Finland) case data.

KEY WORDS: SUSTAINABLE DEVELOPMENT, SUSTAINABLE GROWTH, DEMATERIALIZATION, IMMATERIALIZATION, WELFARE PRODUCTIVITY, EMPLOYMENT, AUTOMATION, STRUCTURAL SHIFT, GROSS REBOUND EFFECT.

1. THE DISCOURSE ON SUSTAINABLE DEVELOPMENT

1.1. Roots of the Discourse

The roots of the discourse on sustainable development as an internationally recognized issue extend to the first UN Conference on the Human Environment in Stockholm in 1972 and to some earlier influential studies (see e.g. Carlson 1962, SCEP 1970, Meadows et al. 1972). The concept ”sustainable development” first became prominent in the World Conservation Strategy published by the World Conservation Union in 1980 (IUCN 1980). It was formulated in more detail by the UN World Commission on Environment and Development in 1987 in the so-called Brundtland’s report ’Our Common Future’ (WCED 1987). And finally the global ethos of sustainable development was agreed on and confirmed by national governments at the UN World Conference on Environment and Development (UNCED 1992) in Rio de Janeiro in 1992.

Sustainable Development (SD) is generally expressed by the Brundtland Report as an ethos that ”humanity has the ability to ensure that it meets the needs of the present without compromising the ability of the future generations to meet their own needs” (WCED, 1987, 8). From the discussion that followed it became evident that the ethos of SD is made up of three dimensions: economic, ecological and socio-cultural. In the ecological dimension, SD refers to the adaptation of economy and technology to the earth’s ecological constraints and environmental challenges. In the social dimension it refers to giving attention in welfare creation to social equity rather than the share-holders' profit issue. SD policies should give special priority to those who currently live in poverty, and to achieving better equity both within generations (intragenerational equity) and across generations (intergenerational equity).

Provided with unlimited natural resources and with adequate accumulation of appropriate scientific knowledge we were easily able to meet the fundamental human needs of our generation without denying similar opportunities to succeeding generations. However, in a finite world such as ours the human population is estimated to double while natural capital is depleted and degraded in increasing pace. For these reasons we have to challenge the pace of knowledge accumulation and assume that resources may become to constrain severely the task of meeting fundamental needs for all. Basically, the major options before humans are either a co-evolution towards global sustainable society based on advancing knowledge and wisdom, or a competitive fragmentation and collapse, - in the worst case - extinction. The choice is primarily an ethical and socio-cultural one, and only in second place economic and technological in nature. (Malaska 1971, 1972).

Sustainability ethos is possible because of the enduring solar radiation, which maintains adequate exergy flow and entropy exchange on the earth (see e.g. Wall 1986). Within this planetary frame a conscious human drive for ecological sustainability becomes rational for the sole reason that without it the human species itself causes deterioration of the sound conditions of human life in unwise and counter-scientific ways. The sustainable development ethos is an expression of moral intention of the late-modernity to keep the earth living and humankind capable of co-evolving with Nature (Malaska 1997b). Nature has made us knowledgeable; we have a responsibility to make ourselves wise.

1.2. Sustainable Development and Economics

1.2.1. Mainstream Views

Since the early days of the 1870s to the 1970s the mainstream economists (with some notable exceptions) appeared to believe that continuous economic growth as such could be sustained indefinitely, a claim which made a special discourse on sustainability superfluous. After 1970 the majority of mainstream economists continued to argue that continuing economic growth as usual remained both feasible and desirable, i.e. a growing economy does not run out of natural resources nor cause too much environmental harms. Economic growth was considered not only to bring with it the overall improvement of life and more equal opportunity for people, but also it was regarded necessary in order to finance improvements of the deteriorated environment. What was called for, however, because of growing environmental awareness, was a more efficiently functioning price system and effective substitution. Such a system would be capable of accommodating economic activity while still preserving an acceptable level of ambient environmental quality. Many economists claimed also that the economic valuation of environmental externalities would make the economy more efficient and thus also sustainable. However, the inherent contradiction of these thoughts is evident, because the increasing efficiency does not necessarily imply improving intragenerational equity nor equity between present and future generations (Howarth and Norgaard, 1992).

On the other hand, economists also thought that the depletion effect of resource exhaustion would be countered sufficiently and in due time by new technology, e.g. recycling and resource substitution. The technical development was claimed to increase the quality of labor and capital and allow, among other things, for the economic extraction of non-renewable resources to ever lower quality and maintenance of the quality of environment regardless of increasing amount of wastes, pollution and discharge emissions. There is, however, hardly any knowledge available about the technical development, which would be needed or adequate to meet the challenges agreed on.

In the 1970s a minority of ‘revisionists’ aimed at to alter the ‘hard core’ of the conventional economic research program, in order to speed up the evolution of economies towards what was ‘relevant’ to the coming zero-growth society (Daly 1992). Others saw a challenge in trading the environmental constraints of a growth economy with other goals of society, by using modified but not radically different economic models. The majority's optimistic view about continuing growth perspectives remained, however, prevailed, with thinkable ‘Ricardian scarcity’ offset by technological development and compensating market processes (Pearce & Turner 1990, 13).

1.2.2. Ecocentric Views

From outside the circle of ‘hard core’ economists, ecocentrically oriented environmental economists tried to move serious doubts about the acceptability of the conventional growth paradigm, it’s strategies and objects to the centre of public debate. The influential Limits to Growth Report to the Club of Rome (Meadows et al 1972) adopted the distinctively Malthusian position that the environmental protection policy and the promotion of economic growth objectives were incompatible (i.e. that no long-run - more than 100 years - growth objectives as usual were feasible). This line of thinking led to calls for a steady state (zero growth) economy (Daly 1992). The zero-growth argument was buttressed by socio-economic analyses, which sought to highlight the social and environmental costs of living in a ‘growth society’. Several lines of reasoning and empirical findings were marshalled to demonstrate that material growth was not the sole indicator of human wellbeing and development, but only one complementary dimension of it.

As a good representative of ‘social limits’ thinking several references may be mentioned. The famous Easterlin’s paradox indicates that material affluence and human happiness are not correlated. According to Hirsch’s concept of ‘positional goods’, the enjoyment of a range of commodities is necessarily restricted to a small group of high income earners, contrary to the claim that all sections of society might one day participate in such a consumption ‘party’. And further, Scitovsky’s classical concept of ‘joyless economy' emphasizes the importance of human needs other than more material affluence, and Giarini’s patrimony and his limits to certainty concepts introduce a new unconventional frame of reference (Pearce & Turner 1990, 15, Boskin 1979, Hirsch 1977, Scitovsky 1979, Giarini 1980).

The only dimension commonly agreed on and left unconquered by controversies in the discourse was the cultural one. The accumulation of ethical awareness, scientific knowledge and new technology was widely accepted as a sound base of the resolution for sustainable development.

2. ETHOS OF SUSTAINABLE DEVELOPMENT

Meeting the needs of the present is an important part of the ethics and the practice of sustainable development. To the developing countries this social dimension of sustainable development seems the most important and challenging. In this sense sustainable development necessarily means fighting poverty and multifaceted deprivations, and eradicating them within a reasonable time frame. Increasing poverty and diminishing solidarity among citizens is, however, also an acute trend against sustainability ethos in many other countries too, industrialized countries included. The eradication of poverty requires e.g. abandoning local and global social institutions maintaining unjust human conditions, and it calls for social development in terms of justice, equal opportunity and solidarity (Lemma & Malaska 1989, United Nations 1995). The development of just and democratic orders is one of the constitutional dimensions of the process of sustainable development.

The second dimension of sustainability is inevitably ecological one, and this paper is primarily on meeting necessary conditions of ecological sustainability. Material affluence and poverty both contributes to ecological unsustainability at present. This vicious circle from poverty to affluence of ecological unsustainability must be better understood and, finally, broken through social, economic and technological renewal, effective global economic strategies, and practical civil society actions for sustainable development. Especially the ecological dimension of sustainability is vital to all the nations in the same way, because it is really global in nature and approaching it is possible only by joint efforts.

The third constitutional dimension of sustainable development is to empower liberal and creative cultural opportunities of people that may generate kinds of scientific knowledge, technology, arts and humanistic values intrinsic to sustainable development.

Sustainable development as a whole may thus be seen rather than an end state in itself as an interaction between the three processes. The following table presents a summary of the ethos of sustainable development described (Jokinen, Malaska & Kaivo-oja 1998).

A. To fight poverty, multifaceted deprivations and unequal economic standing, especially in developing countries.

B. To stop the depletion of nature and destruction of the environment, and to accept ecological sustainability as a quality standard in human affairs.

C. To secure for future generations the same opportunities for wellbeing and the freedom of choice enjoyed by us.

D. Sustainable development is an interaction process in three dimensions, which provides a human future that is socially just and equal, ecologically and economically sustainable, and politically and culturally free and innovative.

Table 1. Ethos of Sustainable Development

3. SUSTAINABILITY APPROACHES

When sustainable development is regarded as a goal or direction, it is important to be able to monitor to what extent it is attained. This requires, in turn, that a way to judge is made available. In the literature there are many suggestions for how to monitor SD, and we will review the most important ones in what follows.

3.1. Hartwick-Solow Approach

Early works in the neoclassical growth theory already incorporated natural resource constraints on the economic doctrine (Solow 1974, Hartwick 1977). In these economic models the idea of progress was defined to as the non-declining consumption of goods (and natural resources) over time. This approach may be regarded as a narrowing metaphor of SD, which substitutes the concept of SD with that of a constrained growth (Cassier 1946, 1985). As a consequence from the main concern was defined to be intergenerational efficiency rather than equal opportunity. It is well demonstrated by the Hartwick-Solow approach.

According to this approach a non-declining consumption through time is possible to obtain, even in the case of an economy that makes use only of non-renewable resources (such as oil) in its economic processes. Hartwick demonstrated that as long as the stock of capital did not decline over time, non-declining consumption was possible. In theoretical terms, the stock of capital could be held constant by reinvesting all Hotelling rents from non-renewable resource extraction in man-made capital (Hotelling 1931, Kasanen 1982). According to this rule, as the stock of oil (a type of natural capital) is depleted, the stock of man-made capital is built up to replace it. This result was very important for the development of new ideas of SD economics. The Hartwick-Solow approach is based on strong substitution assumptions between natural and human capital.

Criticism of the Hartwick rule runs along three lines. First, individuals derive diverse utility from Nature and do not view her merely as an input resource for production. If this is the case, non-declining consumption is not equivalent to non-declining welfare over time. Second, the Hartwick rule depends specifically on the particular aggregate production function, i.e. the Cobb-Douglas form. Hartwick was later able to restate his rule for a CES (constant elasticity of substitution) production function as well (Hartwick 1978). This function has the property that the elasticity of substitution between natural resources and man-made capital is greater than one, which means that the limited supply of the natural resources is actually irrelevant (Common and Perrings 1992). The third criticism against the Hartwick rule is that natural resources and man-made capital are not nearly as substitutable as the Hartwick-Solow approach suggests. Natural capital can be exploited by man, but cannot be created by man. According to the 'thermodynamic' school natural capital and man-made capital are in most cases complements rather than substitutes. For example, Christensen terms the various elements of the natural capital stock 'primary inputs' and man-made capital and labor the 'agents of transformation' (Christensen 1989). It seems that while substitution is possibly high within each of the factor groups, the substitution possibilities between the two groups are very low. Increasing output and gross domestic product in societies thus means increasing the use of both types of input in most cases, and the threat of unsustainability of economic growth is maintained.

3.2. London School Approach

A different approach to solving the problem of the limited benefit from substitution to sustainability between natural capital (K_n) and man-made capital (K_m) is that of the London School Approach (Pearce et al 1990, Klaasen and Opschor 1991, Pearce and Turner 1990). According to the London School some substitution is possible between certain elements of K_n and K_m, while many other elements of K_n provide only non-substitutable services to the economy. For example, there are certain species, which must be preserved (Turner 1993). The important strategic question here is: how much of K_n should be preserved? Three possible views are: (1) all of them at the existing level, (2) the level consistent with maintaining the critical elements of K_n, or (3) some amount in between these two. The crucial problem of this approach is that we must assume that we can measure the value of K_n at any point in time. In practice, it is also difficult to measure different elements of K_n in physical and monetary terms. With the help of material flow analysis, some aspects of K_n have been analyzed. Van Pelt (1993) has identified another problem with the constant natural capital stock concept. There are questions of spatial aggregation: within which geographic area should we hold stock constant? One solution would be to work with less aggregated data and analyze various elements of K_n separately. Yet another problem arises when Nature's intrinsic rate of change is taken into account. Human effect should be measured against the natural rate of change. Nature changes over all time scales. At least in some cases these rates are necessary for the persistence of life, because life is adapted to them and depends on them. What is the character of Nature when it is undisturbed by human influence, asks Botkin, and what are the effects of human beings on the changing non-human world? (Botkin 1990)

Supposing that the aggregation problem for natural capital can somehow be overcome, the London School proposes a rule of how to prevent depletion of K_n below some prescribed fixed level. The rule is based on the discounted monetary valuation of environmental impacts or contributions, whether they are costs or benefits. In this fashion the whole of sustainable development is reduced to monetary economy and economics. However, the problem of sustainability of the given fixed level remains then unsolved.

Pearce and Atkinson (1995) have been attempting to develop indicators and measures of SD. The most widely accepted definition of SD, they claim, is economic and social development in per capita terms over time. There is a major problem one confronts at this point. It is if development is to be measured in narrow terms (such as GDP per capita) or in broad terms (such as measures of social and economic welfare, possibly including indices of human development, health and educational attainment etc.). Today most researchers would choose the broader criterion as the relevant measure. According to Pearce and Atkinson (1995) an additional essential condition for sustainability is that a nation's capital stock should not decline over time. The concept of capital used in their study is very broad; it includes physical, human and natural capital. It is worth of mentioning for further information, that a broad concept of capital was introduced also by Orio Giarini and called it patrimony in a report to the Club of Rome in 1978 (Giarini 1978). The rule of so called constant stock of capital of Pearce and Atkinson has two variants, the rule of weak and of strong sustainability.

Weak sustainability is prevailing when the *total capital stock* – physical, human and natural – is not declining through time. An economy is sustainable when its savings exceed the depreciation on its man-made and natural capital. In this variant, development is sustainable even if one component (e.g. the natural capital) is declining, provided that the total capital stock is not falling. For this to be a meaningful criterion, it is necessary that different elements of capital stock can be substituted for one another. For example if a loss of a particular ecosystem is compensated by an increase in the stock of human knowledge. This means that the environmental and economic losses related with the ecosystem are more than outweighed by benefits in human capital, and that the overall system stability and resilience does not suffer in this substitution process.

The second variant, strong sustainability, affords environmental capital (or natural capital) a special place. SD is attainded, in a strong sense, if especially the nation's stock of environmental capital is non-decreasing. Pearce and Atkinson (1995) have pointed out that one may wish to modify this rule. Some parts of the capital stock is likely to be of particular importance, providing invaluable and nonsubstitutable environmental services to the economic process. If we call this critical natural capital, then the modified version of strong SD requires that development does not lead to a decline through time of the nation's stock of the critical natural capital.

It their studies Pearce and Atkinson evaluated their view of sustainability with some country data, and presented accordingly that e.g. Finland is a sustainable economy in the weak sense but not in the strong sense (Pearce & Atkinson 1995, 173-174).

3.3. Safe Minimum Standard Approach

Very closely linked to the non-declining natural capital stock approach is the safe minimum standards (SMS) approach identified primarily with Ciriacy-Wantrup (1952) and Bishop (1978, 1993). SMS approach originates from decision making under uncertainty. Societies are deemed to be unsure about the future costs of current environmental degradation. In environmental policies, two classes of action may be taken: (1) to conserve environmental resources (such as wilderness areas) or (2) not to conserve them. The SMS rule is: prevent all reductions in natural capital stock below the safe minimum standard identified for each component of this stock unless social opportunity costs of doing so are ‘unacceptably’ high. According to the SMS approach deciding to conserve today is shown to be the risk-minimizing way to proceed (Tisdell 1990).

There are at least three generic ignorances in the application of safe minimum standard approach. One is that the current generations are ignorant of the preferences of future generations, and accordingly it has a need to preserve options to cover uncertainty. Second is the uncertainty about the possible threshold of the ecological processes and about limits and collapsing properties and uncertainties related to the risk-taking behaviour of decision-makers. Thirdly there is an ignorance of the intrinsic value of species and natural phenomena.

The SMS approach contains the following problems: (1) difficulties in identifying critical SMS levels and (2) problems in defining ‘unacceptable large’ opportunity costs of preservation. And, at the borderline, it includes acceptance of a conduct known to be ecologically unsustainable, if the social situation so demands. The criteria selects the best decision of the smallest mistake, i.e. safe minimum standard is basically the same criterion as the minimax regret. The SMS approach shifts the burden of proof from those who wish to conserve to those who wish to develop. In practical terms, the safe minimum standard criterion rejects projects with catastrophic outcomes, e.g. any decisions which could lead to species extinction would be rejected, unless the social costs of doing so are "intolerably high" (Ciriacy-Wantrup 1968 and Bishop 1978). Because the meaning of "intolerably high" is not precise, that reservation is difficult to take into account, or, in each case, it may be left for the democratic political process to decide what it means (Common 1995).

3.4. Daly's Steady-state Approach

In 1990, Herman Daly identified what he termed the ‘operational principles’ of SD. If these principles were followed, nations would move in the SD direction (Daly 1990, 1992). The principles are as follows:

OP1: Set all harvest levels of renewable resources (fish, forest, game) at less than or equal to the population growth rate for some predetermined population size.

Daly emphasizes population policy in sustainability analysis and he sees that a steady-state population is a necessity. What holds for the population of human bodies must also hold for the populations of cars, buildings, livestocks, and for each and every form of physical wealth accumulated by humans. In an empty world the human population is complementary with the various populations of wealth. But in a full world they tend to become substitutes because they compete for the same space and maintenance throughput of low-entropy resources. (Daly 1996, 199)

With the concept of density-dependent growth, Daly (1992, 270-274) wants to emphasize that we cannot separate scale problems from allocation problems. According to Daly (1992, 273) we cannot hide issues of scale and carrying capacity within the issue of improving allocation realisable through a better definition of property rights, as neo-classical economists often propose.

OP2: Establish for degradable pollutants assimilative capacities of the receiving ecosystems and maintain waste discharges below these levels. The discharge of cumulative pollutants should be set adequately close to zero.

OP3: Divide the financial receipts from non-renewable extraction into an income stream and investment stream. The latter part should be invested in renewable substitutes (for example biomass for oil) so that by the time a non-renewable resource reaches the end of its economic extraction, an identical level of consumption is available from the renewable substitute as the level available from the renewable resource at the start of the depletion programme. According to Daly (1990), only the income stream can be available for consumption. The proportion of funds necessary to be diverted to the renewable substitute will depend on its growth rate, the rate of technical progress, the discount rate and the size of the renewable resource (see details in El-Serafy 1989).

OP4: Minimize matter and energy throughput in societies. In the economy there must be some controls on macroeconomic scale. These controls must be quantitative and exercised for population and resource use.

Some critical authors (Hanley, Shogren & White 1997, 432) have noted that it is not clear to what extent Daly's rules are actually operational. Much scientific uncertainty exists about the assimilative capacity of ecosystems for many pollutants. Also, the calculation of the investment stream for non-renewables would be difficult. In addition, the identification of the maximum or optimal scale of the world economy, and designing policies to ensure these scales are extremely difficult tasks.

The discussion of sustainability rules has shown that monetary valuations of the environment will not necessarily result in SD (see Howarth & Norgaard 1992), and that there may be many other non-monetarized rules that better define sustainability over time (Pezzey 1994). One of these is the total environmental stress approach of this paper.

3.5. World Bank Approach

World Bank approach is quite similar to the conventional neoclassical approach. In World Bank, Pezzey (1992) has widely analyzed sustainability concepts, such as sustainable growth, sustainable development and sustainable resource use, in terms of the conventional neoclassical theory of economics, where sustainable means mainly the same as continuing or enduring economic growth. According to Pezzey's survey, the mainstream interpretations of sustainability require that the "quality of life" must not decline in the long-term future. Pezzey's neoclassical formalization of the core ethic is that utility (equivalent to quality of life measured most often with economic consumption) should not decline, although this may allow tradeoffs between various aspects of life that some think should be non-tradable (Pezzey 1992, 48).

According to the World Bank approach the definition of capital stock is the central issue in sustainability policy, because many definitions can be interpreted in terms of maintaining an economy's capital stock. This means judging how significant, essential or substitutable the various natural and man-made resource inputs to the economy's production processes are. Deriving sustainability conditions inevitably requires judgements about which natural and human resources are essential to production and to welfare, and about the extent these resources can be substituted for each other (Pezzey 1992, 48-49).

Pezzey argues that at different stages of economic growth different tradeoffs may be made between consumption and environmental quality. It means that environment is reducible to economic consumption and the SD approach is reduced to economic analysis. The main results of the neoclassical models imply that only inadequate technical development and open access to environmental resources may be the factors that cause non-sustainability, if non-renewable resource inputs are essential. Government intervention, in the form of resource conservation subsidies or depletion taxes can correct the open access problem and improve sustainability. On one hand, government subsidies for more use of resources aimed at encouraging development will harm sustainability. But on the other hand according to the neoclassical theory, advancing sustainability by slowing down resource depletion may lead to a lower level of consumption and utility (Pezzey 1992, chapters 2-4).

The World Bank approach emphasizes property rights. Pezzey summarizes this point clearly: “Conventional environmental policies need not always mean making the polluter pay for externalities. More important is that property rights over the environment are first defined and enforced, if this is possible.” (Pezzey 1992, ix, 30-32).

According to Pezzey (1992, 35-39) a simple model with renewable resources shows that population growth can threaten sustainability and that poverty and environmental degradation can be interlinked. The link between poverty and environmental degradation establishes the case for development assistance. Pezzey notes that giving environmental property rights to the poor may both reduce poverty and improve the environment. This is true whether the poor are the polluters or the victims of pollution.

In the World Bank approach there are two levels of policy intervention: the system level and the project level. At the system level aggregate constraints (either regulatory or economic) must be imposed to control the depletion of whatever resources have been determined to be important for sustainability. Such constraints should drive up the price of such resources to whatever level is necessary to induce the required conservation efforts throughout the system. Such efforts are equivalent to intergenerational compensation investments. Pezzey (1992, 46-48) agrees with some others (see e.g. Pearce 1993) that making sustainability operational at the project level is much harder, even conceptually.

3.6. Wuppertal Approach

The Wuppertal approach to sustainable development uses Total Material Requirement (TMR) and Direct Material Input (DMI) concepts as indicators to the potential ecological impact of the economic processes (Femia, Hinterberger & Renn 1999). The main issue of the Wuppertal approach is on the ecological side, i.e. to what extent is the growth of the economy dependent on disturbances of the physical structure of Nature, and of withdrawal of material from the natural sites? The basic tenet is that, if ecological system is to be sustained and maintained supportive to human existence, an absolute reduction of material flows is necessary.

Since the citizens or governments will not voluntarily accept non-growing material well being, de-linking the production of the income from exploitation of Nature of which well-being consists is necessary. If GDP is to grow, the de-linking will have to bridge an increasing gap in order to establish a sustainable path of development. If a factor 10 reduction of material input is necessary from an ecological point of view, it is obvious that it is impossible to rely on either pure efficiency or pure sufficiency strategies to reach the desired results. In the Wuppertal approach a requisite form of economic growth and its relation to material use is the main aspect studied. Even if the resource intensity decreases the absolute resource use may continue to grow due to increasing level of activity of human population. This may mean and actually it means that the cleaner production (reduction of environmental impact intensity) is not, as such, sufficient to fulfil sustainability condition.

Substitution processes between different natural resources in the production may give rise to a relation called Environmental Kuznets Curve (EKC). But this can be observed only with specific substances and it is not a general law of resource substitutability (about EKC see e.g. Ekins 1997). From this point of view TMR and DMI do not suffer the drawbacks of usual measures. They are very little affected by shifts in the mix of materials used, but they do reflect growing efficiency or inefficiency of extraction and harvesting techniques and take into account used as well as hidden materials. The TMR is neither sensible to changes in the foreign trade pattern which may imply real changes in the environmental consequences of the production process considered as a whole, across the national boundaries.

In the Wuppertal approach the well-being is expressed as a function of service, service intensity, material productivity, material input and environmental impact (see Femia, Hinterberger & Luks 1999).

The Wuppertal approach has similarities with the TES-approach of FFRC in this paper more than the other approaches. One of the differences compared with the TES-approach of FFRC is that automation and employment issues and structural changes of the societies are not included.

3.7. Total Environmental Stress Approach of FFRC

In next sections we will work out a general framework of analysis for advancing ecologically sustainable development. The ecological sustainability is defined on the basis of the total environmental stress (TES) caused by human affairs. It is postulated, that a decreasing TES is a necessary (albeit not sufficient) condition of advancing ecological sustainability. Environmental stress is generated not only when natural resources are taken from Nature and used in production and consumption, but also when wastes and pollution are discarded and thus returned to Nature, thereby depleting her space and interfering with her functions. To generate environmental stress is inescapable to human existence and progress, and there are many factors that lead to increasing stress. However, the sustainable development ethos is based on a firm conviction that some of stress is not inevitable but mainly a symptom of ignorance and a lack of better technology and wisdom of proper welfare. That part of the stress is avoidable, and to realize it by proper actions offers ways to sustainable development. Sustainable development is not an unattainable utopia.

The approaches reviewed see the sustainable development ethos mainly through the economic growth paradigm and as a constraint to the continuing growth. The TES Approach of the Finland Futures Research Centre (FFRC) regards sustainability in this paper basically as an ecological concept, much like the Wuppertal Approach with which it has a lot in common. But the Approach of FFRC analyses the issue of sustainability from more multiple perspectives than any other approaches.

The quantitative level of the TES may be indicated in various ways, e.g. with the total material flow (MF) or energy flow (EF) from Nature through the technosystem back to Nature (see e.g. Ayres 1978, Malaska 1971, Spangenberg 1995, Femia-Hinterberger-Luks 1999) or with the anthropogenic gas flow like CO2. In the mathematical formulation of the theory, the material flow (MF) is used as an indicative measure of TES. How to measure the material throughput (MF) is studied by Hoffrén (1999a, 1999b) and Femia-Hinterberger-Renn (1999).

4. CONCEPTUALIZATION OF ADVANCING SUSTAINABILITY

A theoretical framework for advancing sustainability is worked out in this chapter. The theory is formulated as a set of two basic postulates of the necessary condition and four logical identities called the master equations of the theory. They relate the total environmental stress (TES) to basic indicators of economic, technological and social development. The explanatory power of the theory is demonstrated by new important concepts and formulas derived and with the empirical analyses conducted.

4.1. The Postulates of Advancing Sustainability with Total Environmental Stress and Welfare

Decreasing TES with time is postulated as the first necessary condition for advancement of ecological sustainability. The other necessary condition of sustainability postulated is that of welfare growth. Whether the present state is sustainable or not is not addressed in the present analysis, and it would need another kind of a theory. According to Spangenberg (1996, 2) the use of raw materials already exceeds the sustainable level of consumption in industrialized countries. According to other researchers there are countries which do not, as yet, exceed the sustainability level of material consumtion, but the global consumtion level in the world is too high (see e.g. Weizsäcker, Lovins & Lovins 1997, Part III). The theoretical frame of this paper is about change of a prevailing situation either towards sustainability or away from it.

The postulates of advancing sustainability from the present state are formulated in (P1) and (P2):

P1. Without the total environmental stress decreasing sustainability is not advancing:

$$\mathbf{D(}\text{TES}\mathbf{)} < \mathbf{0} \qquad (1)$$

P2. Without the welfare growth sustainability is not advancing:

$$\mathbf{D}(\mathrm{WF}) > \mathbf{0} \qquad (2)$$

D(.) means an operator of change in-between an end year and the base year, i.e. **D(**X**)** = (X - X_o) with X as the end year value of a quantity, TES is for the total environmental stress and WF for the welfare.

The postulates define what is meant with advancing ecological sustainability. Economic and social-cultural decisions, which do not meet the conditions of the postulates are regarded as ecologically unsustainable, i.e. the ecological sustainability is not advancing with them. However, if the decisions or policies meet the conditions described, it is not as yet sufficient but only possible that sustainability advances with those decisions. That is the logic of a necessary condition per se. The theory conceptually circumscribes on the whole set of possible decisions a domain where sustainable decisions can be found and the exterior of it where sustainable processes are impossible to occur. Evidently, this demarcation between the feasible region and unfeasible region outside of ecological sustainability is analogue to the feasibility frame of thermodynamics of the material processes more generally. The ecologically sustainable domain of human development is but one sub-domain within the thermodynamic feasibility frame.

4.2. The Theoretical Framework of Identities

The logic of the analysis is built on theoretical identities called the master equations of the theory. As identities they are logically tautologies and thus true of their intrinsic nature without any need for empirical or other verification. In the latter part of the article the explanatory power of the theory will, however, be demonstrated also empirically.

The four master equations of the theory are presented in the equation (3) to (6). The first equation relates the TES-indicator of MF to the supply side of economy with a quantity called the material intensity of production, in the second one the TES is related to employment and automation. The third equation relates TES to the material intensive and less intensive sectors of the economy in advancement of sustainability. The fourth identity is of the demand side with welfare and two new concepts called welfare productivity of GDP and material intensity of welfare. From each identity important new concepts of sustainable development are derived for use in policy formulations and empirical studies.

4.2.1. Production Master Equation

On the supply side, the production identity relates the TES-indicator, i.e. the total material flow (MF), to population (POP), GDP production volume per capita (GDP/POP) and material intensity of production (MF/GDP) as follows:

$$MF \equiv POP \times \left(\frac{GDP}{POP} \right) \times \left(\frac{MF}{GDP} \right) \qquad (3)$$

Here MF stands for the material flow through the technosystem, POP stands for population and GDP, the gross domestic product, stands for a measure of the total supply.

The first identity tells us that the larger the human population and the higher the level of economic supply per capita, the stronger the environmental stress is. And further, the more materially intensive the economy is, the stronger environmental stress it affects. Researchers have been familiar with this formula since the 1970s (Malaska 1971, Ayers 1978), and it is similar to more recent statements of Paul and Anne Echrlich’s (1990) and the familiar Wuppertal MIPS concept (see Femia, Hinterberger & Luks 1999). Our approach, however, discusses the environmental impacts of economic and social activity in a larger frame and both from the supply side and demand side respectively.

4.2.2. Employment Master Equation

The second identity relates the TES to employment (EMP), employment population ratio (EMP/POP), and to a quantity of (MF/EMP), i.e. the amount of material throughput per employed worker in production.

$$MF \equiv POP \times \left(\frac{EMP}{POP} \right) \times \left(\frac{MF}{EMP} \right) \qquad (4)$$

The identity states that the higher the employment ratio, or the material throughput per worker, the higher the total environmental stress caused by the production. And of course - ceteris paribus - the stress is the higher the larger the population

4.2.3. Structural Shift Master Equation

A structural shift of the economy means that a more diversified and enriched mode of supply and demand emerges and substitutes the prevailing monolithic supply and demand profile in the economic development. The on-going change from the industrial economy to a service economy provides a demonstration of such a structural shift. With the master equation (5) it is possible to show that this kind of a shift can also play an important role in advancing ecological sustainability. The structural shift master equation is:

$$\frac{MF}{EMP} = \frac{MF_0}{EMP_0} x W_0 + \frac{MF_n}{EMP_n} x\left(1 - W_0\right) \qquad (5)$$

and

$$W_0 = \frac{EMP_0}{EMP} \quad \text{and} \quad \left(1 - W_0\right) = \frac{EMP_n}{EMP} = W_n \ (5a)$$

In Equation (5) W_o stands for a share of employment of the materially more intensive sector of the total employment of the economy, and $(1-W_o)=W_n$ is then the complementary share of the other materially less intensive sector. Subscript o and n refers to the two different sectors of the economy, and subscript o stands for the sector of loosing weight in the profile, and subscript n for the sector of gaining weight. The theory assumes that the material throughput per worker (MF/EMP) of the former sector is much bigger than that of the other, or

$$\frac{MF_n}{EMP_n} << \frac{MF_o}{EMP_o} \qquad (5b)$$

4.2.4. Welfare Master Equation

The GDP measure can be understood from two sides of the national accounting balance: as a measure of the total supply and as a measure of the final demand. From the environmental point of view consumption and investments need not be separated. In what follows GDP is seen as a measure of final demand.

The welfare identity relates the TES with welfare (WF) and a quantity of material intensity of welfare, i.e. with (MF/WF) ratio.

$$MF = \left(MF/WF\right) \times WF \qquad (6)$$

Another identity relates the welfare to the economic growth (GDP) through a concept of welfare productivity (WF/GDP).

$$WF = \left(WF/GDP\right) \times GDP \qquad (6a)$$

Here WF stands for welfare as postulated in (P1). We assume that it can be measured independently from the economic growth. In recent years there have been many attempts to define and measure it (e.g. with ISEW, HDI, GPI concepts), and numerous indicators are already available for this purpose (see e.g. Daly & Cobb 1989, Stockhammer et al 1997). Then it becomes possible and sensible to talk about the concept of (WF/GDP) as the welfare productivity of GDP.

4.3. Remarks on the Theory

Some preliminary remarks on the theory:

Remark 1: There are two kinds of variables in the theory, extensive and intensive variables. Material flow (MF), population (POP), volume of production (GDP), welfare level (WF), employment (EMP) are extensive variables, whereas the variables defined by a quotient of two extensive variables are intensive variables. There is an essential difference between them. The extensive variables are additive under aggregation, i.e. when any two subsystems with their pertinent values of the extensive variables are aggregated, the values of the extensive variables of the integrated system is the direct sum of the subsystem values. This does not apply to the intensive variables; their aggregate features are more complex. The other differentiation between terms of the theory is between the theoretical concepts derived from the identities and empirical observables.

Remark 2: The master equations define a non-linear effect of the variables on the TES through the intensive variables. This complex nature of the theory makes it possible to formulate new concepts as dematerialization of production, immaterialization of consumption, gross rebound effect, and welfare productivity. It also allows to define the new concepts of sustainable economic growth and effective economic growth, and to diagnose dilemmas between advancing sustainability and social development and demonstrate how a structural shift of the economy may have a role to play in advancement of sustainable development.

Remark 3: The theory may be applied diachronically, i.e. using time series data of an observed system, or synchronically using cross-section data of many subsystems observed at he same time, or combining the two approaches. In this paper only a diachronic analysis is applied.

Remark 4: In order to make results of diachronic analyses of different countries or regions comparable with each other dimensionless per unit value variables may be used instead of the original quantities with their pertinent unit of measure. Another advantages offered by the per unit value mode are obtained in synchronic aggregation or disaggregation analyses. Per unit value is defined as the value of a variable divided by a fixed base year value of the same variable. The per unit value of a variable at the base year is 1.0 by definition.

When the difference operator **D(.)** is applied to the multiplicative forms of the equation (3) to (6) with three variables, it is easily seen that the formula with the pertinent units of measure is $\mathbf{D(}XYZ\mathbf{)} = YZ\mathbf{D(}X\mathbf{)} + X_oZ\mathbf{D(}Y\mathbf{)} + X_oY_o\mathbf{D(}Z\mathbf{)}$. By dividing this from both sides with the base year values of the variables, i.e. with ($X_oY_oZ_o$), we get the per unit formula as follows: $\mathbf{D(}xyz\mathbf{)} = yz\mathbf{D(}x\mathbf{)} + z\mathbf{D(}y\mathbf{)} + \mathbf{D(}z\mathbf{)}$ with the per unit value coefficients y, and z as the end year values. The per unit values of the extensive variables have no longer their extensive variable characteristics, but the proper unit value need to be carefully observed.

The formulas from (1) to (6) above are valid both for absolute and per unit values, but the formulas in the theoretical analysis from (7) to (14) are valid only for per unit values. In addition the values in empirical analysis defined through the difference operator **D(.)** are either cumulative values from the base year to the end year or annual rate values at any given moment as indicated in the context.

Remark 5: In a synchronic analysis the system under study is either formed by aggregating it from a number of relevant subsystems, or vice versa a larger whole is dissolved to subsystems. Synchronic analysis can be conducted with a decomposition method (see Malaska, Luukkanen & Kaivo-oja 1999, Sun 1996).

5. THEORETICAL DERIVATIONS

From the eq. (1) to (6) several important new features of the ecologically sustainable development is derived. Some of them may challenge current aims of economic and technological development. It comes relevant even to speak about dilemmas between our present aims of development and our desires for sustainable development. The theory makes it possible to understand them and create solutions for these dilemmas and to formulate better policies for sustainable development

5.1. Analysis of Production Dilemma

Starting with the supply master equation (3) we get the per-unit value formula (7) for the change of material flow as the TES:

$$\mathbf{D(}\mathrm{MF}\mathbf{)} = (\mathrm{MF/GDP})\mathbf{[}(\mathrm{GDP/POP})\mathbf{D(}\mathrm{POP}\mathbf{)} + \mathbf{D(}\mathrm{GDP/POP}\mathbf{)]} + \mathbf{D(}\mathrm{MF/GDP}\mathbf{)} \quad (7)$$

The intensive variables of the coefficients take the value of the end year. If the base year is kept fixed the difference operator extends cumulatively over the span from the base-year to the end-year. If instead an annual change or rate is of more interest the base year is kept moving along with the end year. Because the difference operator itself is linear the cumulative value of the difference equals the sum of the annual changes over the same time span, if the unit value is kept constant. However, with a changing unit value as in calculating the annual rates, the relationship of the cumulative value and rates is more complicated.

The quantity in the brackets [ ] of the formula (7) is the economic growth:

$$\mathbf{D(}\mathrm{GDP}\mathbf{)} = (\mathrm{GDP/POP})\mathbf{D(}\mathrm{POP}\mathbf{)} + \mathbf{D(}\mathrm{GDP/POP}\mathbf{)} \quad (7a)$$

Eq. (7a) shows how the change of the economic growth is comprised or divided between the population growth effect and the economic growth per capita effect. We do not take the population growth problem into explicit analysis in this paper, but only the total economic growth.

It is evident that the world population continues to grow, i.e. $\mathbf{D(}\mathrm{POP}\mathbf{)} > 0$ and that continuing economic growth per capita will remain a dominant objective in every economy in the foreseeable future meaning that $\mathbf{D(}\mathrm{GDP/POP}\mathbf{)} > 0$, The necessary condition for advancing ecological sustainability, i.e. **D(**MF**)** < 0, can be met only by forcing the last term of (7) to decrease in order to counter-act the sum effect of the two other terms. This condition means decreasing material intensity of production, in other words obtaining more production output from less use of natural resources. This is called here dematerialization of production, and it is a sine qua non to advancing sustainability.

5.1.1. Dematerialization Effect

The dematerialization process of production or the supply side of the economy stated above is defined in the mathematical form in (8):

D(MF/GDP**)** < 0 (8)

The quantitative change of the total environmental stress due to dematerialization is called the dematerialization effect. It is termed as Dem-effect and defined in an empirically measurable way in (8a):

Dem-effect = **D(**MF/GDP**)** (8a)

When the ecological sustainability is advancing the Dem-effect shows negative values. Dem-effect is from the base year to a current year and it is by definition zero at the base year.

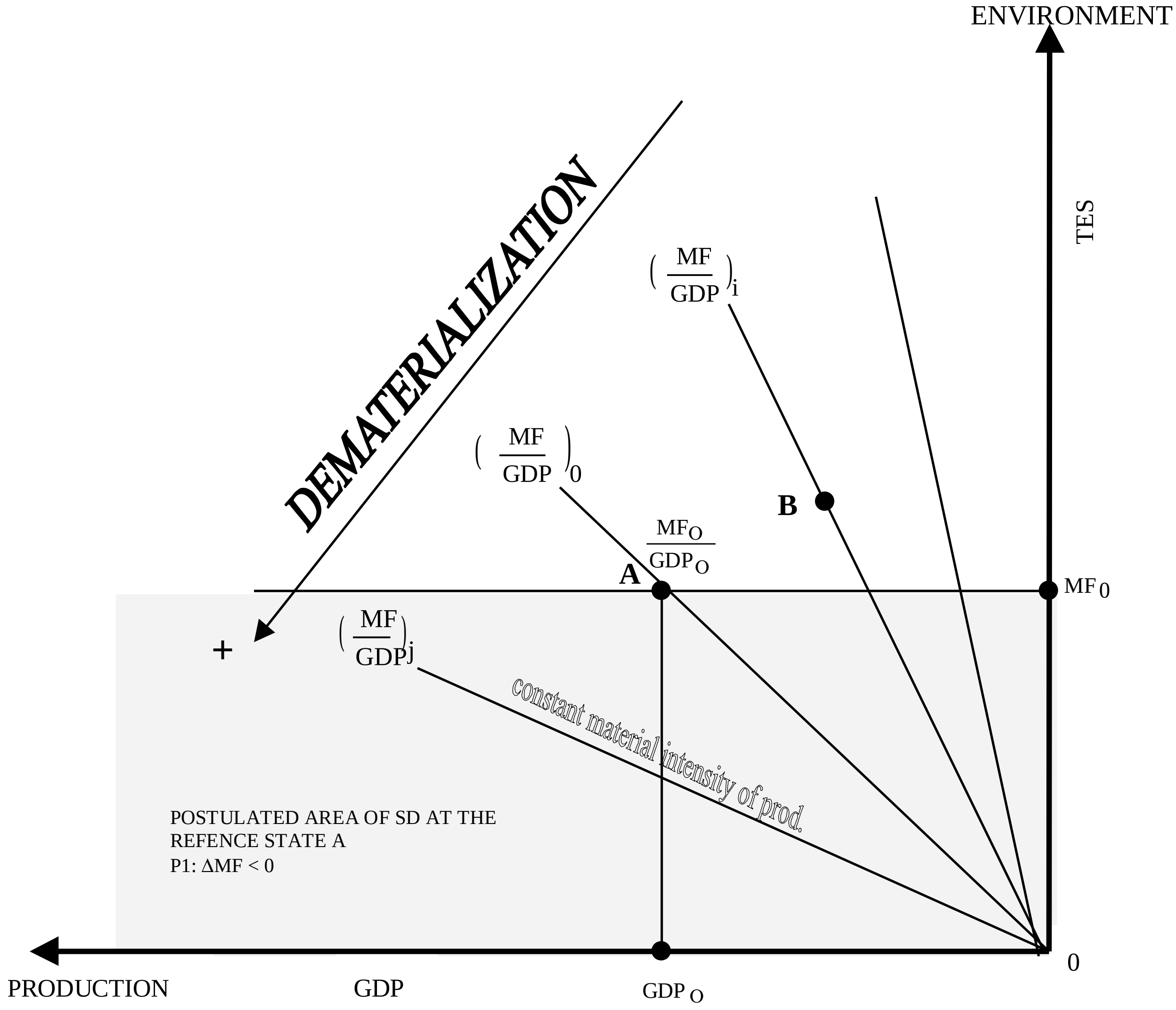

Figure 1. Graphical illustration of dematerialization of production and the shaded feasibility area of SD at the reference state A. The state B is on the unsustainability region.

5.1.2. Sustainable Economic Growth

The total use of natural resources, and thus the total environmental stress caused by production, has increased in many countries from the 1970s to 90s despite of demonstrated dematerialization processes (Hoffrén 1999b, Sun 1996). It appears that there are other processes going on at the same time with dematerialization, that counter-balance the dematerialization effect. One of them is a fast economic growth itself with its excessive contribution to the total environmental stress, called here the growth effect or Gth-effect for short.

The growth effect is defined as the total change of TES, or in quantitative terms

Gth -effect = **D(**MF**)** (9)

The simultaneous occurrence of the dematerialization effect and the growth effect generates a complementary third theoretical term, which is called the gross rebound effect and termed GRbd-effect. It represents the change of the TES in excess of the dematerialization effect. The reasons of rebound phenomenon are not well known nor researched. It may even be, at least to some extend, that the dematerialization process gives birth to counter-acting rebound effects. Some other researchers use the term rebound differently to mean an intrinsic part of the excess of the change, which can be attributed to specific and known counter-acting causes. By the term of Gross rebound it is aimed to recognize the difference of definitions. From eq. (7), (8) and (9) we get a definition to the gross rebound effect in (10):

GRbd-effect = Gth-effect **-** Dem-effect (10)

In an empirically measurable form we get

GRbd-effect = = **D(**MF**) - D(**MF/GDP**)** (10a)

Under sustainability conditions the economic growth is inevitably both possible and desirable. The more effective the dematerialization process is the faster economic growth may be without causing a deviation from a sustainable track of development. The sustainable economic growth is defined as the maximum growth not leading to any positive growth effect, i.e. with the condition of **D(**MF**)** = 0 in eq. (9). From there we get the definition of the sustainable economic growth (SE-growth) in (11).

SE-growth = **- D(**MF/GDP**)** / (MF/GDP) (11)

It asserts that under the sustainability conditions the cumulative economic growth between the base year and the end year cannot exceed the relative improvement of the material intensity during that time, or if annual figures are used, the economic growth rate cannot exceed the rate of dematerialization of production.

From another point of view the change of the material intensity of production may be interpreted as an implication of technological development. Decreasing the intensity is possible only through technological development and thus these two factors are causally related with each other. With this interpretation in mind the eq. (11) tells that the faster the technological development the faster economic growth will still be acceptable within the regime of sustainability. Limits imposed by sustainability may be in contradiction with real growth policies of a country and the world. The rebound effect is in any case counteracting benefits from technological development. If the growth effect is positive, it indicates that the real growth rate is on the unsustainable region. In that case the economic policy for sustainability would call for either to slow down the economic growth rate or to accelerate the pace of the technological development.

If the economic growth rate is a fixed and inflexible target, the pace of the technological development - sustainable technological development - becomes of primary interest in maintaining sustainability. The definition linking the sustainable technological development (ST-dev.) to the targeted economic growth **D(**GDP**)** is given in eq. (11a):

$$\text{ST-dev.} = (\text{MF/GDP})\mathbf{D}(\text{GDP}) \qquad (11a)$$

The faster economic growth is aimed at the faster pace of the development of technology is needed in order to maintain sustainability conditions.

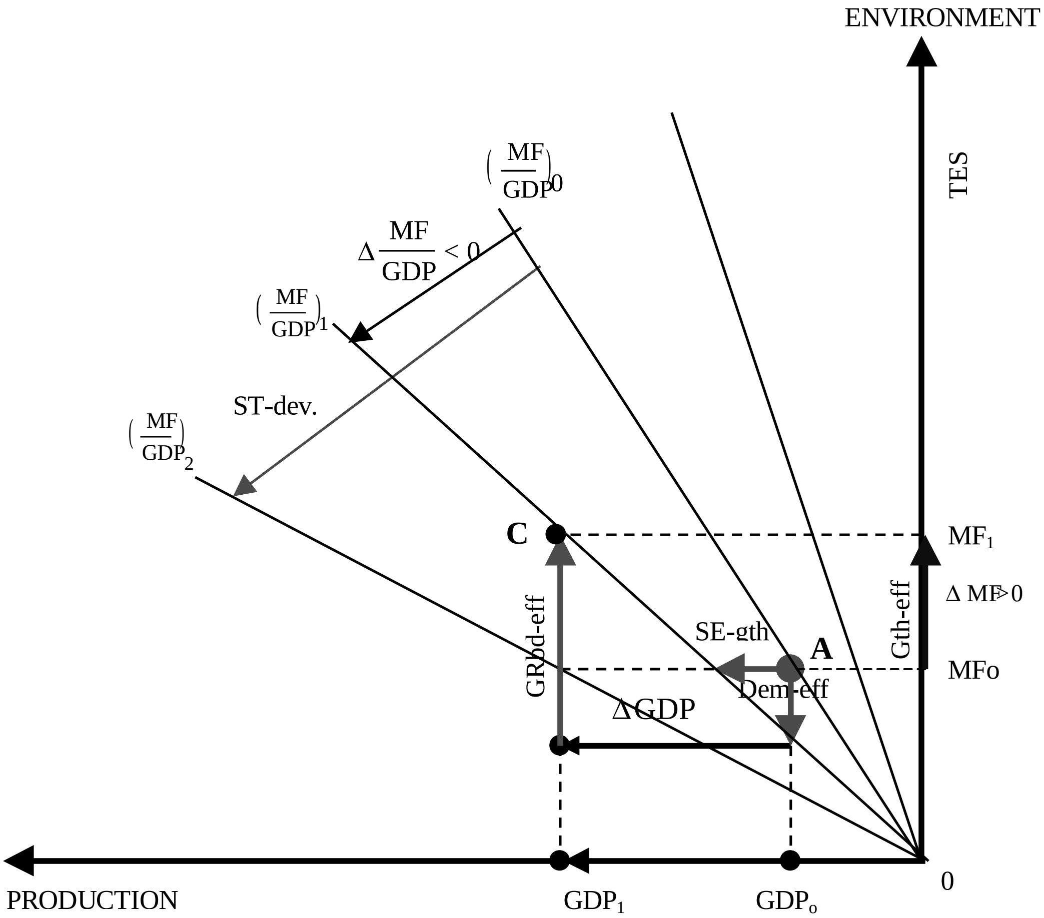

Figure 2. Graphical illustration of the basic concepts of the theoretical framework of sustainability. In the course from A to C the economic growth (ΔGDP) exceeds the sustainable economic growth (SE-GTH) and dematerialization of production is insufficient and Dem-eff inadequate to maintain sustainable development. Unsustainability is indicated by the positive values of Gth-eff.

5.2. Employment and Automation Dilemma

At first sight the relation of the ecological sustainability to employment is opaque and obscure. The effect of automation may be assumed supportive to sustainability, because of a more efficient use of natural resources it seems to offer. The identity relation of the total environmental stress with employment in (5) reveals new aspects of the issue. Redefining **D(**MF**)** in employment form we get:

D(MF**)**=(MF/EMP)(EMP/POP)**D(**POP**)**+(MF/EMP)**D(**EMP/POP**)**+**D(**MF/EMP**)** (12)

The growth of the population, **D(**POP**)**>0, will remain an unavoidable fact for a long time to come. And maintaining the employment level of population as high as possible is an uncompromising policy of any government, i.e. **D(**EMP/POP**)**>0. The only factor in the right hand side of the equation that might bring a decreasing effect on environmental stress is the material flow handled per employed worker or **D(**MF/EMP**)**<0. It then becomes a key factor in advancing sustainability. However, the present economic development with automation of production goes in the opposite direction.

The quantity of (MF/EMP) is related to automation in a way that the ratio is increasing with advancing automation. The very process of automation means that a smaller number of workers will manage and handle larger and larger volumes of material flow because of more and more efficient production systems and machines. Accordingly the consequence of this under increasing employment is, that the total environmental stress is increasing. For the change of the ratio (MF/EMP) we get from above:

$$\mathbf{D}(MF/EMP)/(MF/EMP) < -[(EMP/POP)\mathbf{D}(POP)+\mathbf{D}(EMP/POP)] \qquad (12a)$$

The value of the right hand side is negative, where as the advancing automation keeps the left side positive. This is a sustainability dilemma in mathematical form not solvable by any direct way. One has to turn to analyze a structural shift of the economy for a solution.

5.3. Structural Shift of the Economy as a Sustainability Solution

The structural shift offers a solution to the employment and automation dilemma. It provides a way to decrease the ratio (MF/EMP) even with increasing employment and automation. The necessary condition for it is a multi sector economy where some sectors deviate from each other in their material intensity of supply. The material flow per employed worker in the dominant main industry is assumed to be much larger than in some other sector of the economy. If the less intensive sector is increasing its share of the total employment the ratio (MF/EMP) of the whole economy is to decrease. A shift of the employment from the materially more intensive sectors to a materially less intensive one becomes the solution of the sustainability dilemma of the previous chapter. Lets have a look at the equation (5) once more. Now we know that the ratio (MF_o/EMP_o) is going to increase in the dominant industry sector (denoted by the subscript o) with advancing automation, i.e. the condition $\mathbf{D}(MF_o/EMP_o) > 0$ holds. On the other hand there is a possibility of shifting the total employment share from that sector to a materially less intensive sector by amount of $\mathbf{D}(W_o) < 0$. The change of the ratio of the whole economy **D(**MF/EMP**)** is then from (5)

$$\mathbf{D}(MF/EMP) = (MF_o/EMP_o)x\mathbf{D}(W_o) + W_o x\mathbf{D}(MF_o/EMP_o) - (MF_n/EMP_n)x\mathbf{D}(W_o) \quad (13)$$

The structural shift value $\mathbf{D}(W_o)$, which would be adequate to counterbalance the automation advance follows from the condition of $\mathbf{D}(MF/EMP) < 0$:

$$\mathbf{D}(W_o)/W_o < -\frac{\mathbf{D}(MF_o/EMP_o)}{MF_o/EMP_o - MF_n/EMP_n} \quad (14)$$

The formula gives the sufficient minimum structural shift in terms of the relative change of the prevailing industry's share of employment $\mathbf{D}(W_o)/W_o$. The greater the difference between the intensive and the less intensive sectors, the smaller the shift that is capable of balancing an assumed advance in automation, and vice versa. The equation (14) shows that the shift from the industrial to service economy is in concordance with the ecological sustainability ethos.

5.4. Immaterialization of Consumption

The ultimate goal of human productive activity is not producing and consuming ever more material goods, but providing human welfare for which the material production is only as a means to the end. The environmental stress accounting must be extended to the final demand of welfare. In equation (6) a concept of the material intensity of welfare was presented and defined as the ratio between the material flow and the welfare provided, (MF/WF), on the demand side. The equation relates the TES with welfare production and its material intensity. By difference operation we get the following condition of advancing sustainability:

$$\mathbf{D}(MF) = (MF/WF)\mathbf{D}(WF) + \mathbf{D}(MF/WF) < 0 \quad (15)$$

According to the postulate P2 the welfare is to be increasing. From this it follows that decreasing material intensity of welfare, i.e. $\mathbf{D}(MF/WF) < 0$, is a sine qua non to sustainability advance. A process leading to a decreasing material intensity of welfare is named immaterialization of consumption.

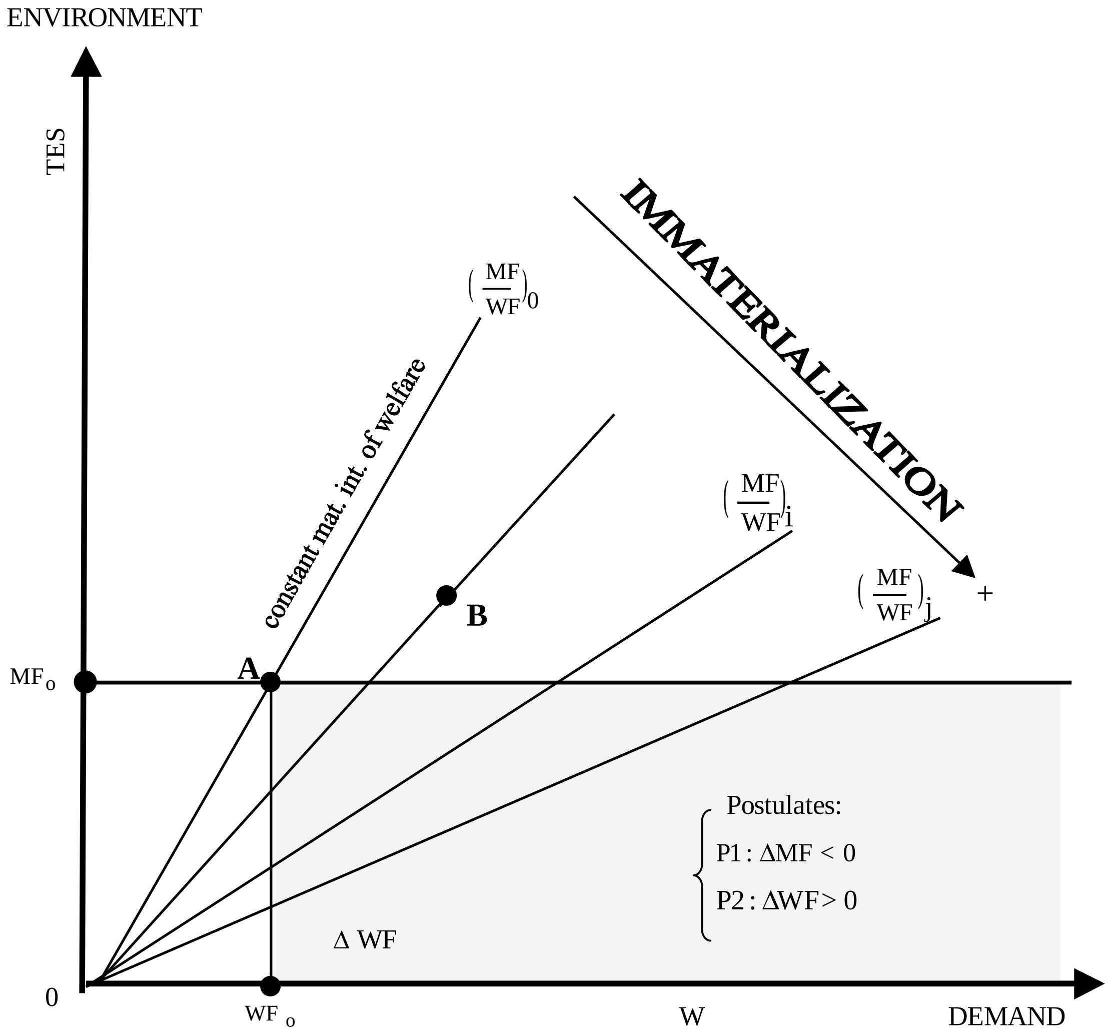

Figure 3. Graphical illustration of immaterialization of consumption and the shaded feasibility area of SD at the reference state A. The state B is on the unsustainability region.

5.4.1. Immateralization Effect and Sustainable Welfare growth

In an analogous way with the dematerialization effect it is now possible to define the immaterialization effect on the demand side. It means a fictive decrease of TES on the base year due to the change of the material intensity of welfare, i.e. Imm-effect = **D(**MF/WF**)** in per unit value of TES. And respectively it is possible to define an indicator of the concept of the sustainable welfare growth as the maximum growth of welfare given the pace of immaterialization, i.e. SW-growth = **- D(**MF/WF**)**/ **(**MF/WF**).** Also a new concept of consumption rebound effect and change of life style may be defined and empirically studied.

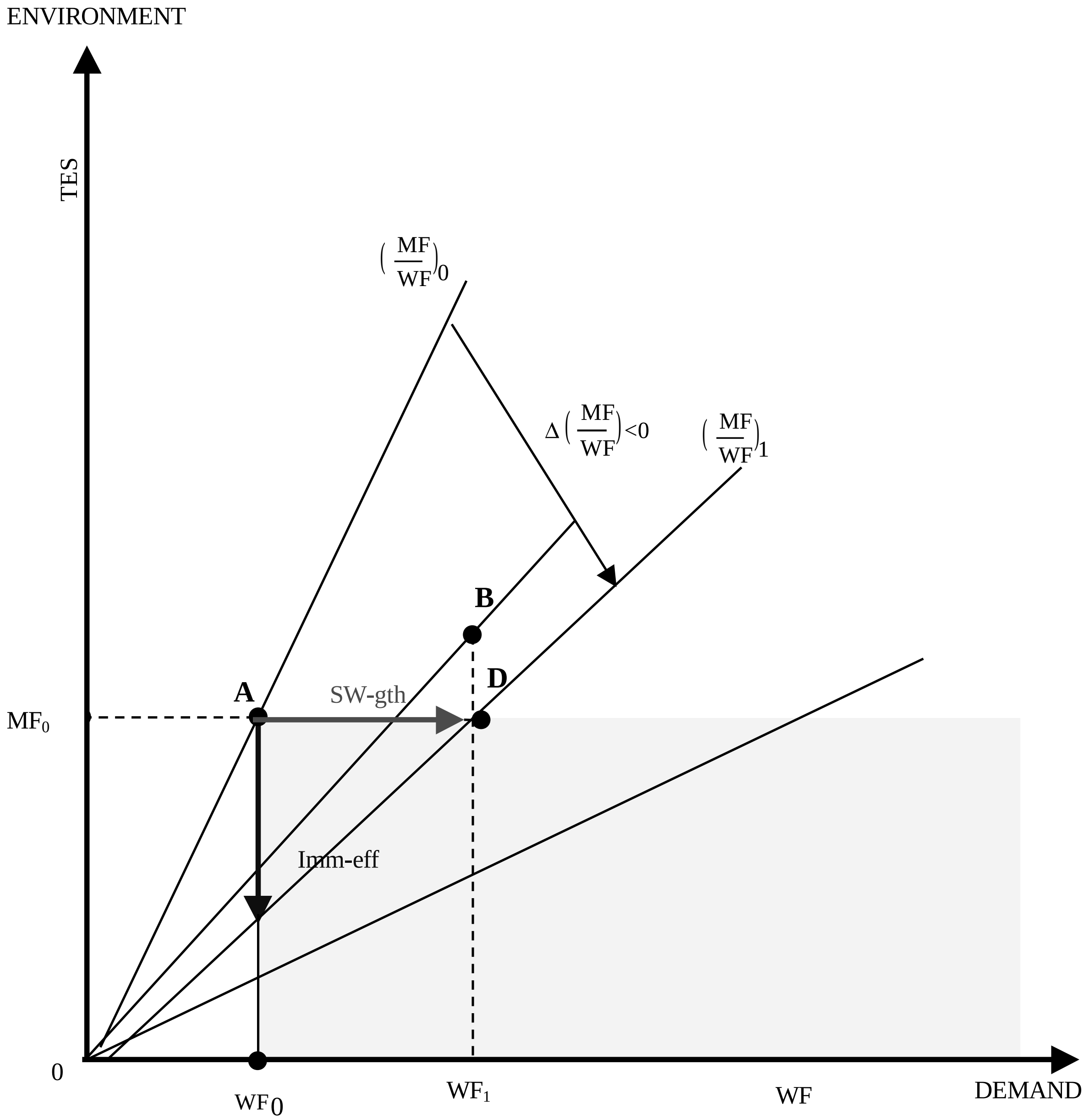

Figure 4. Graphical illustration of the basic concepts of the immaterialization of consumption, when Δ(MF/WF) is given. Sustainable growth of welfare at point A is SW-gth and immaterization effect on TES is Imm-eff.

5.5. Welfare Productivity

From the welfare identity in eq. (6a) and the postulate P2 a necessary condition of advancing sustainability is derived in eq. (15a)

D(WF**)** = (WF/GDP)**D(**GDP**)** + **D(**WF/GDP**)** > 0 (15a)

The sustainability conditions of eq. (15) and (15a) define a feasible region of sustainability advancement of the economic growth and welfare productivity growth. In general there are three different feasible sub-regions of sustainability advancement. In one sub-region sustainability conditions are maintained with a strong growth of the welfare productivity and even with negative economic growth. In another region high economic growth dominates, and the third sub-region is characterized by variability between the economic growth and welfare productivity growth rates. The actual choice of these values determines the pace of decrease of the material intensity of the welfare, i.e. the pace of immaterialization of consumption.

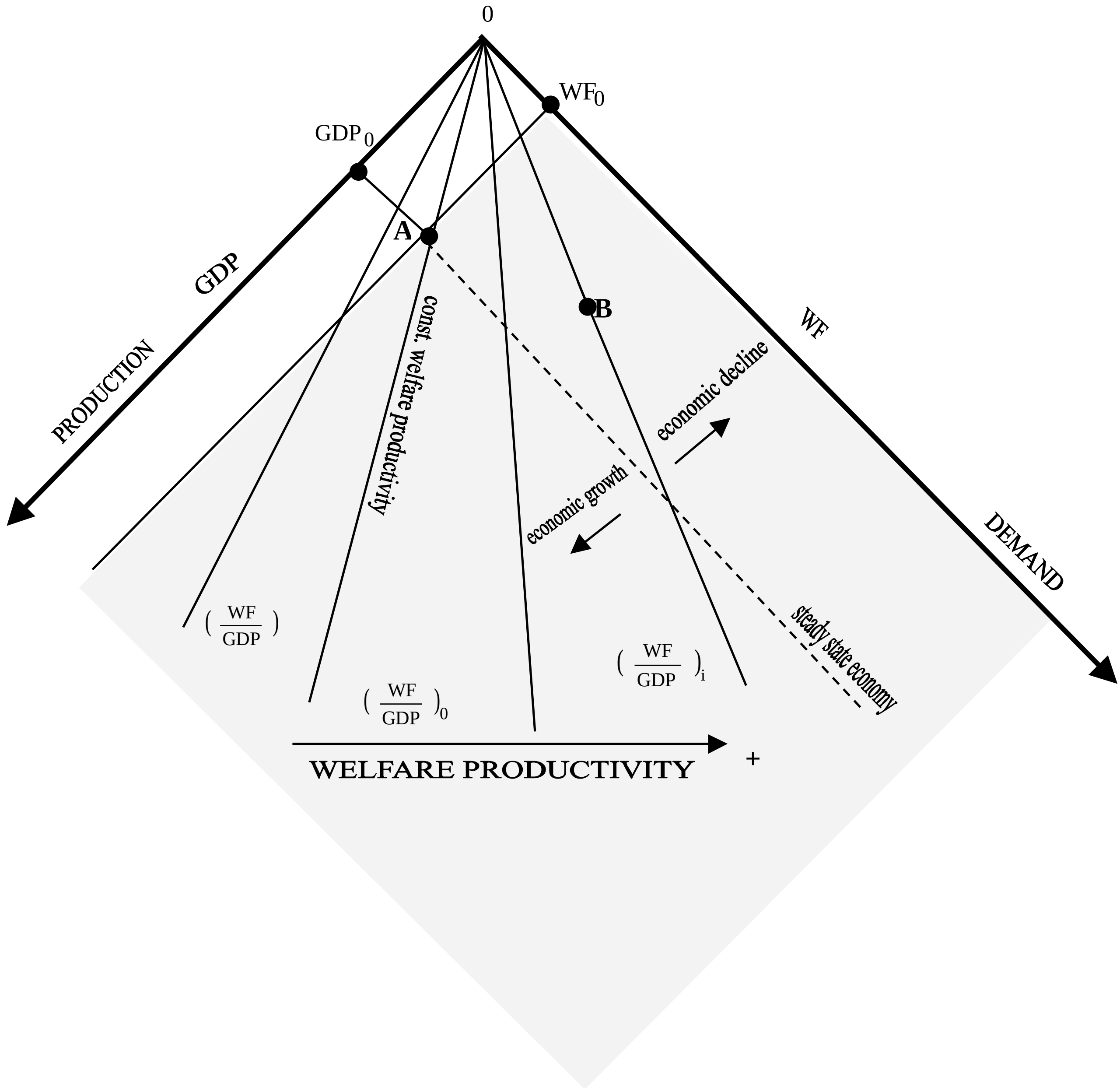

Figure 5. Graphical illustration of the welfare productivity dimension of sustainability analysis. Economic growth is not a necessary condition of sustainable development nor is it a preventing condition. A steady-state economy may well be an alternative to sustainable development. The point B on the shaded area corresponds to the state B in Figure 1, Figure 3 and Figure 4 and accordingly it represents unsustainable course from A. The shaded area is a region of necessary but not sufficient condition of SD.

6. EMPIRICAL ANALYSES

In the empirical analyses, mainly the total material flow is used to indicate the total environmental stress. Another option would be to use a measure of the total energy for the purpose, because energy is inseparable from material processes whether it be extraction, production, consumption, or rejection and waste treatment – all these material phenomena are associated with energy-flow changes from higher to lower quality according to the entropy law. In this study electric energy data are used for illustration in one part of the study, where sector data are.

The aim of the empirical analyses is to show how the theoretical formulas are applied. The second purpose is to demonstrate the explanatory power of the theory through numerical results. The empirical results will not be generally conclusive but explanatory in nature, because only the data from of a country (Finland) are used. The sources of the data are Finland Yearbooks of Industrial Statistics in 1970-1997, Statistical Yearbooks of Finland in 1970-1997, Energy Statistics 1997 and material flow databases from Statistics Finland (Hoffrén 1999a, 1999b).

The results demonstrate possible advances or non-advances of the ecological sustainability in the case country during the observation period. The analyses could also be extended for writing scenarios of sustainability for the future and formulating sustainability policy; this, however, was not done in this study.

It is worth of repeating here that the results give only necessary conditions of advancing ecological sustainability. If any of the conditions is unmet, the ecological sustainability is not advancing. But on the other hand, if all the conditions are met, the advance of sustainability is not guaranteed. The conditions define a demarcation line between the region where sustainability advance is not possible to achieve and the region where it may be possible.

6.1. TES Data

The data of the total material flow (MF) representing the total environmental stress (TES), is depicted in Figure 6. In the empirical study the quantitative values of the variables are expressed in the dimensionless numerical per-unit values with a given base-year value as the measurement unit. For the total environmental stress the unit of measure is the value of the total material flow in 1960, i.e. unit of TES = 172.6 Mt/a in all the following relevant figures.

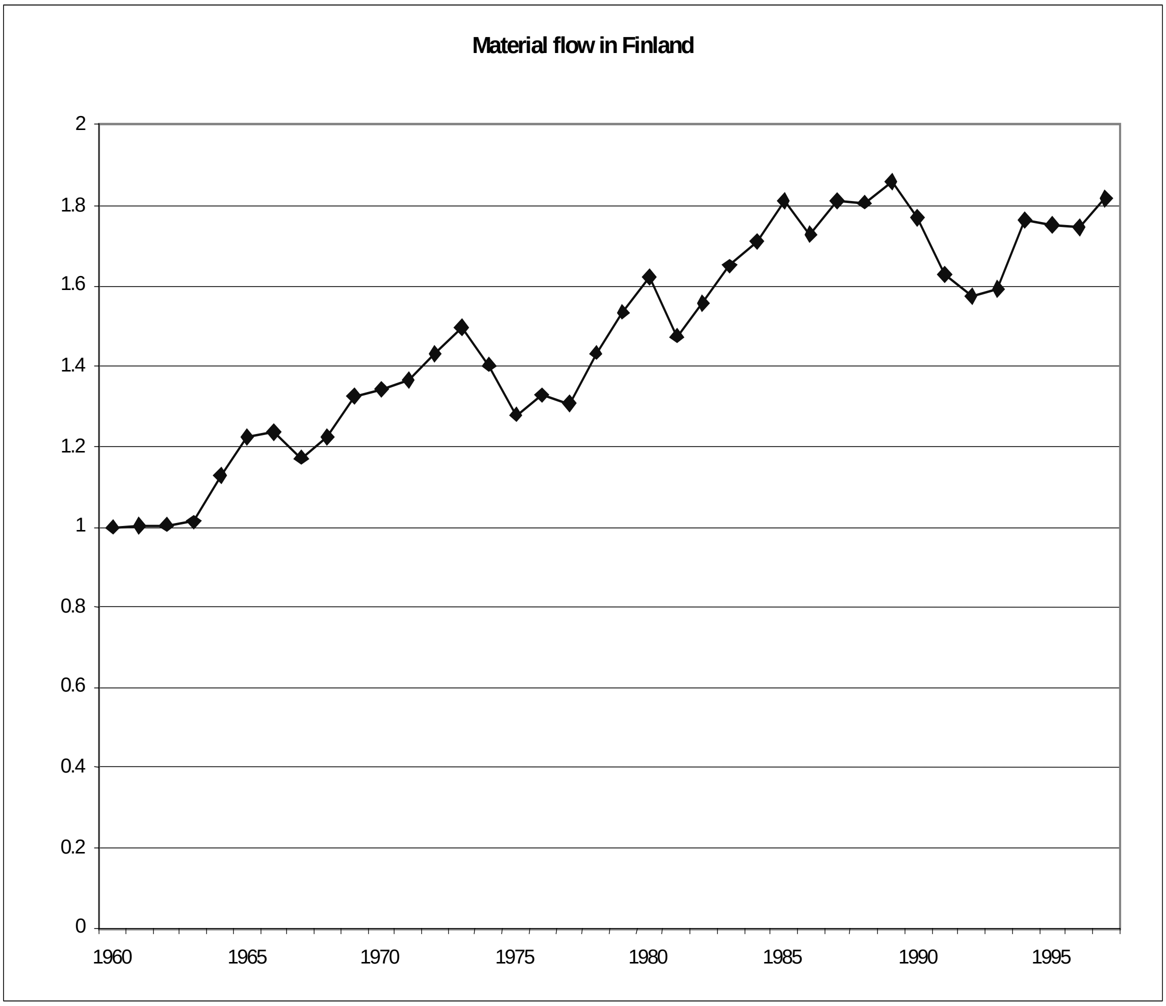

Figure 6. Data of the total material flow (MF) representing the total environmental stress (TES) in per-unit value (base year 1960, unit value 0= 172.6 Mt/a).

Per-capita figures of the direct material input, hidden material flow, and total material flow are depicted in Figure 7 in order to illustrate additional aspects of total environmental stress.

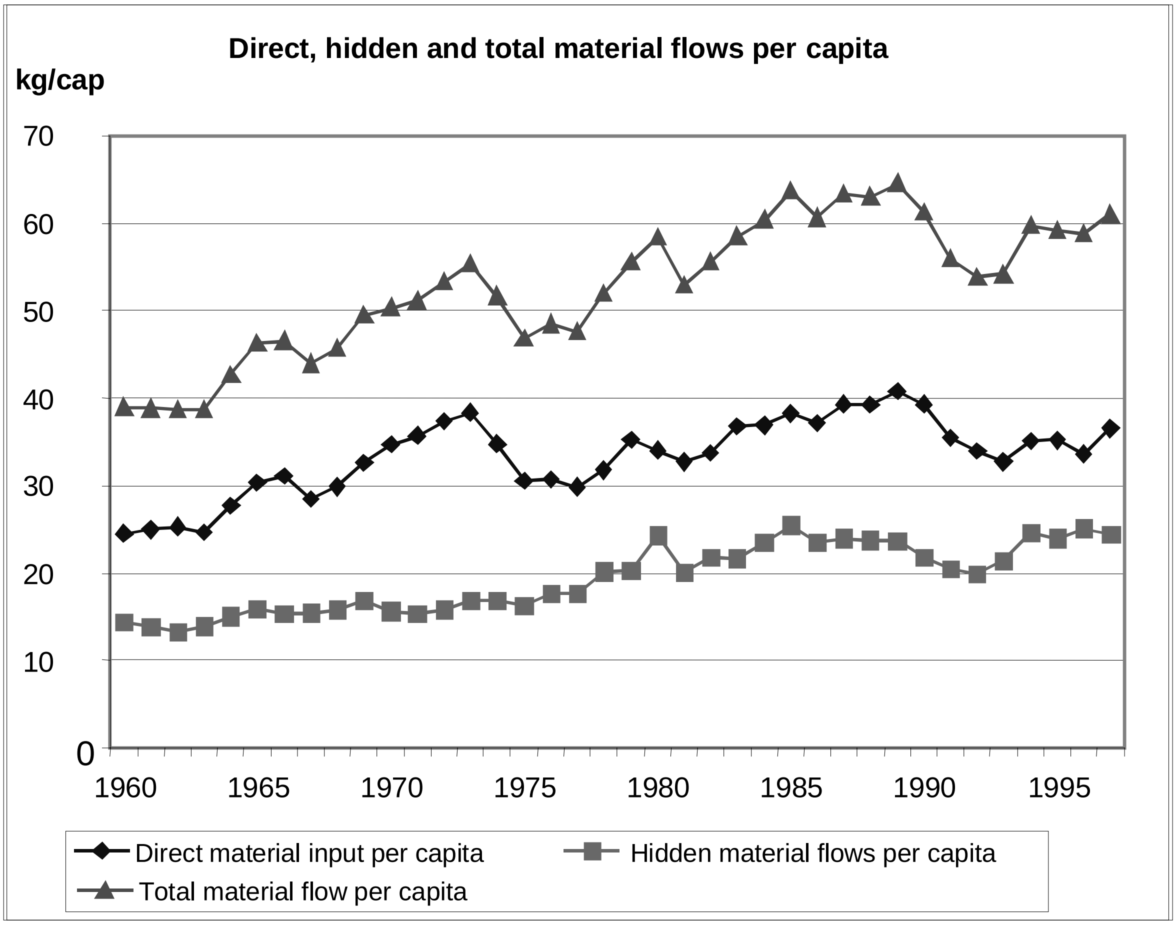

Figure 7. Per capita total material flow, direct material input, and hidden material flows in Finland from 1960 to 1997. Hidden material flows refer to the side flows and remains in the basic extraction of material (e.g. the unused stone material in mining).

As the Figure 6 and 7 show, environmental stress has been increasing. The oil crises in the 1970s and the economic recession in the early 1990s had, however, a decreasing effect on material flows. In the long run, the total material flow has been increasing at an average rate of 1.7 %/a (the direct material flow at 1.5 %/a and the hidden material flow at a faster rate, i.e. 2 %/a).

Exploration of the empirical data above reveals that the sustainability condition of equation (2) of the theory was not entirely met by the Finnish economy from 1950 to 1997. An empirical analysis is needed to get a more complete picture of the sustainability situation and of possible deviations from it.

6.2. Dematerialization and Sustainable Economic Growth

The dematerialization of production is one of the key processes for advancing sustainability. In order to determine numerical estimates of the total dematerialization, gross rebound and growth effects on the total environmental stress and to calculate the rate of sustainable economic growth the data of GDP and MF/GDP for the production master equation (3) are also required. They are provided in Figure 8 and Figure 9.

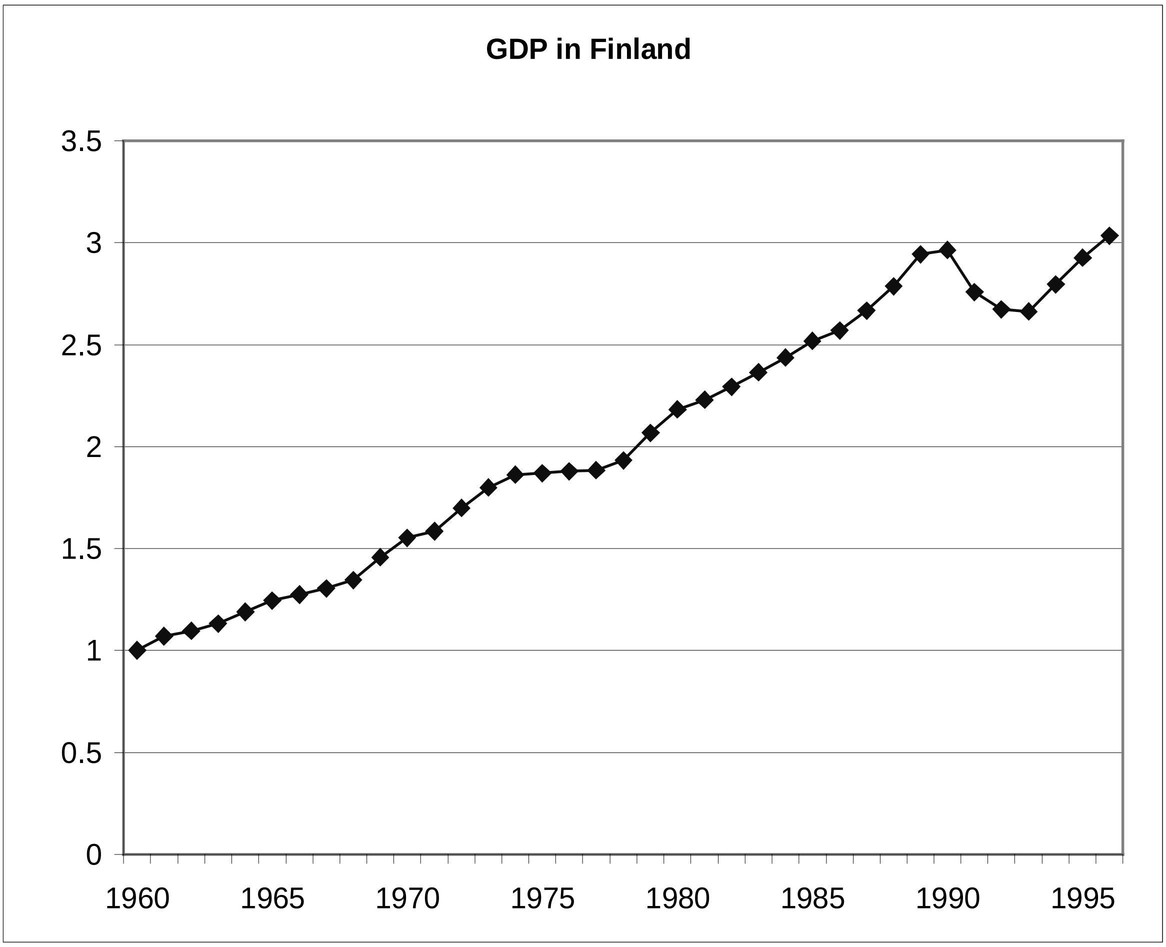

Figure 8. Data in per-unit value of the gross domestic product in Finland from 1960 to 1996 (base year 1960, unit value = $151.2*10^9$ FIM/a)

The GDP has been increasing almost monotonically since the 1960s with some recent exceptions in the 1990s. The theory offers a possibility to analyse, if continuous economic growth realized has, at the same time, also advanced sustainability or has been in contradiction to it.

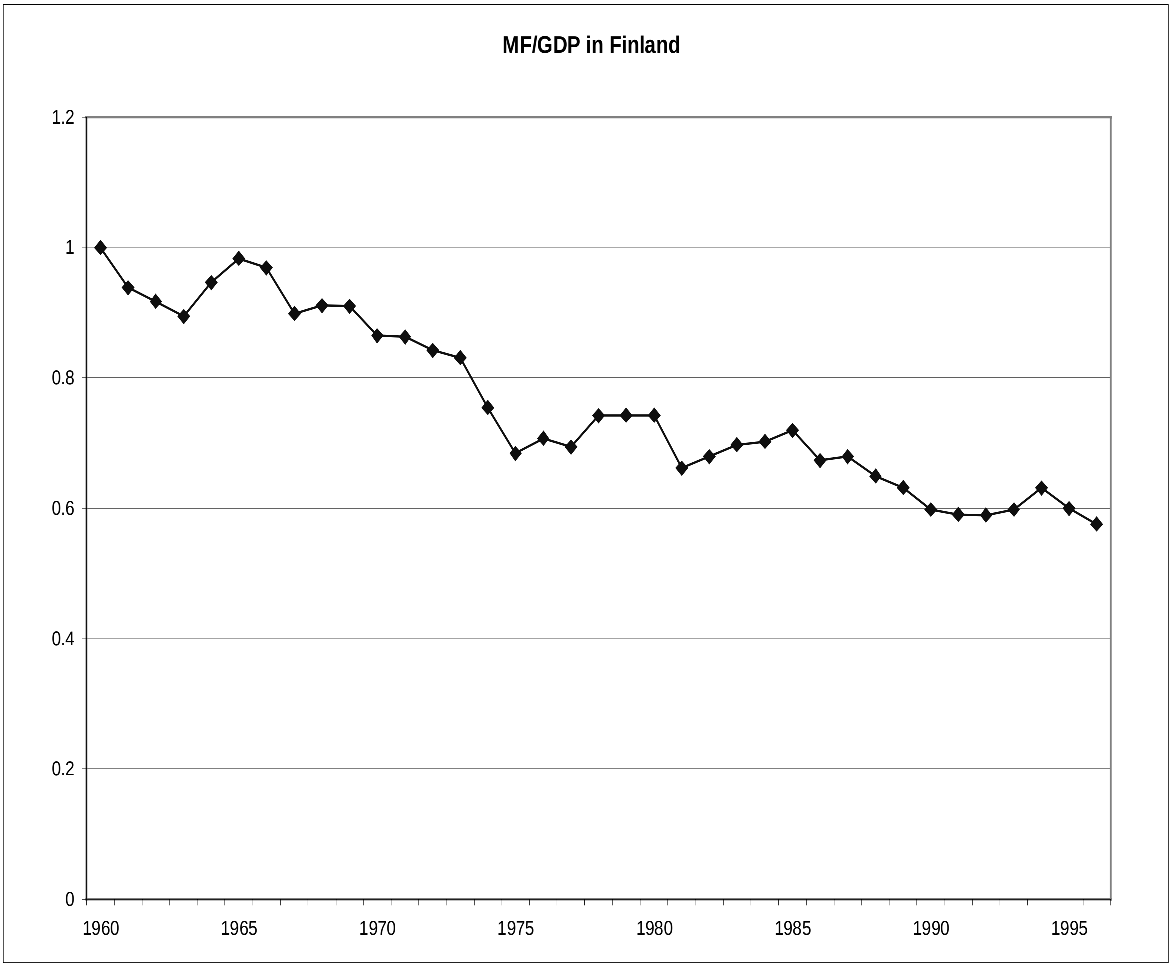

Figure 9. Data of the material intensity of GDP, (MF/GDP), in Finland from 1960 to 1996 (base year 1960, unit value = 1.14 kg/FIM)

The material-intensity figures in Figure 9 show that some dematerialization processes of production for advancing sustainability have been benefiting the Finnish economy since 1960.

Equations (8a), (9) and (10) of the theory define the dematerialization process in the form of three effects on total environmental stress: total dematerialization effect (Dem-effect), growth effect (Gth-effect), and gross rebound effect (GRbd-effect). The calculated empirical results of these effects are given in the figures 10, 11 and 12. According to the equations the figures are cumulative values from the base year to the end year and in per-unit form with the unit of TES = 172.6 Mt/a of material flow.

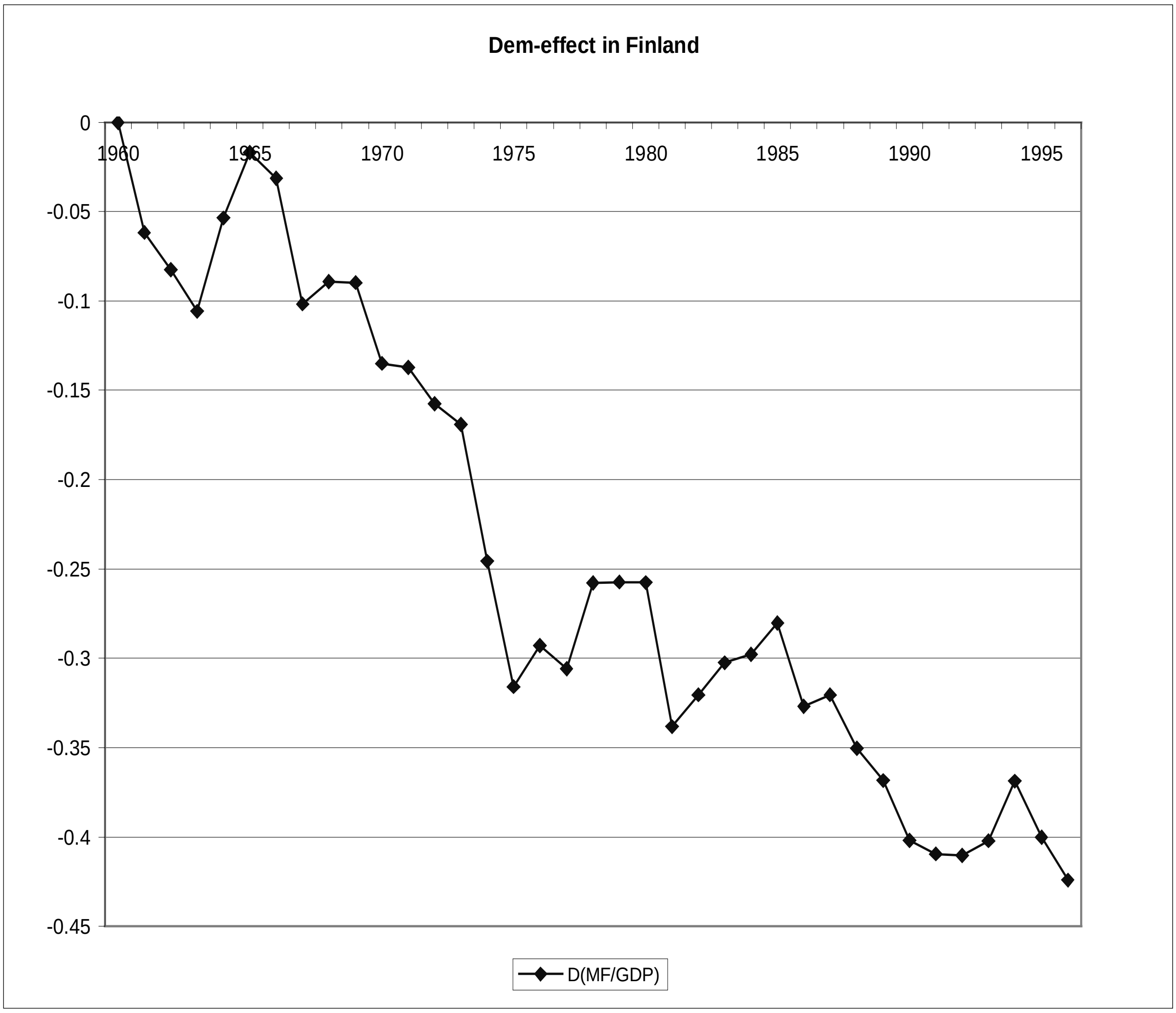

Figure 10. Cumulative total dematerilisation effect on TES in Finland from 1960 to 1996 (base year 1960, unit of the horizontal scale = 172.6 Mt/a). Positive values indicate contribution to deviation from sustainability, and negative values fulfillment of the necessary condition of sustainability.

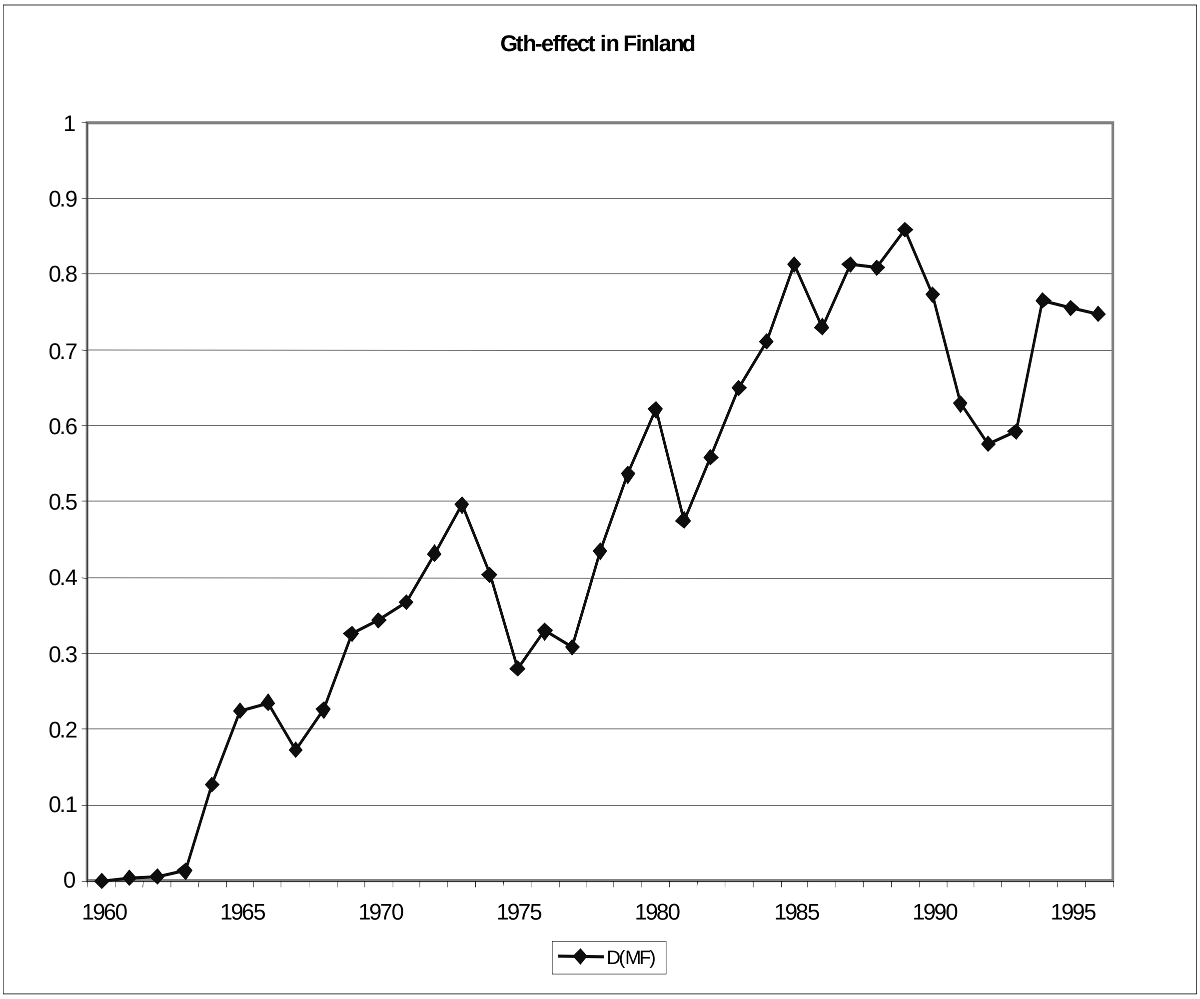

Figure 11. Cumulative growth effect on TES in Finland from 1960 to 1996 (base year 1960, unit of the horizontal scale = 172.6 Mt/a). Positive values indicate to contribution to deviation from sustainability.

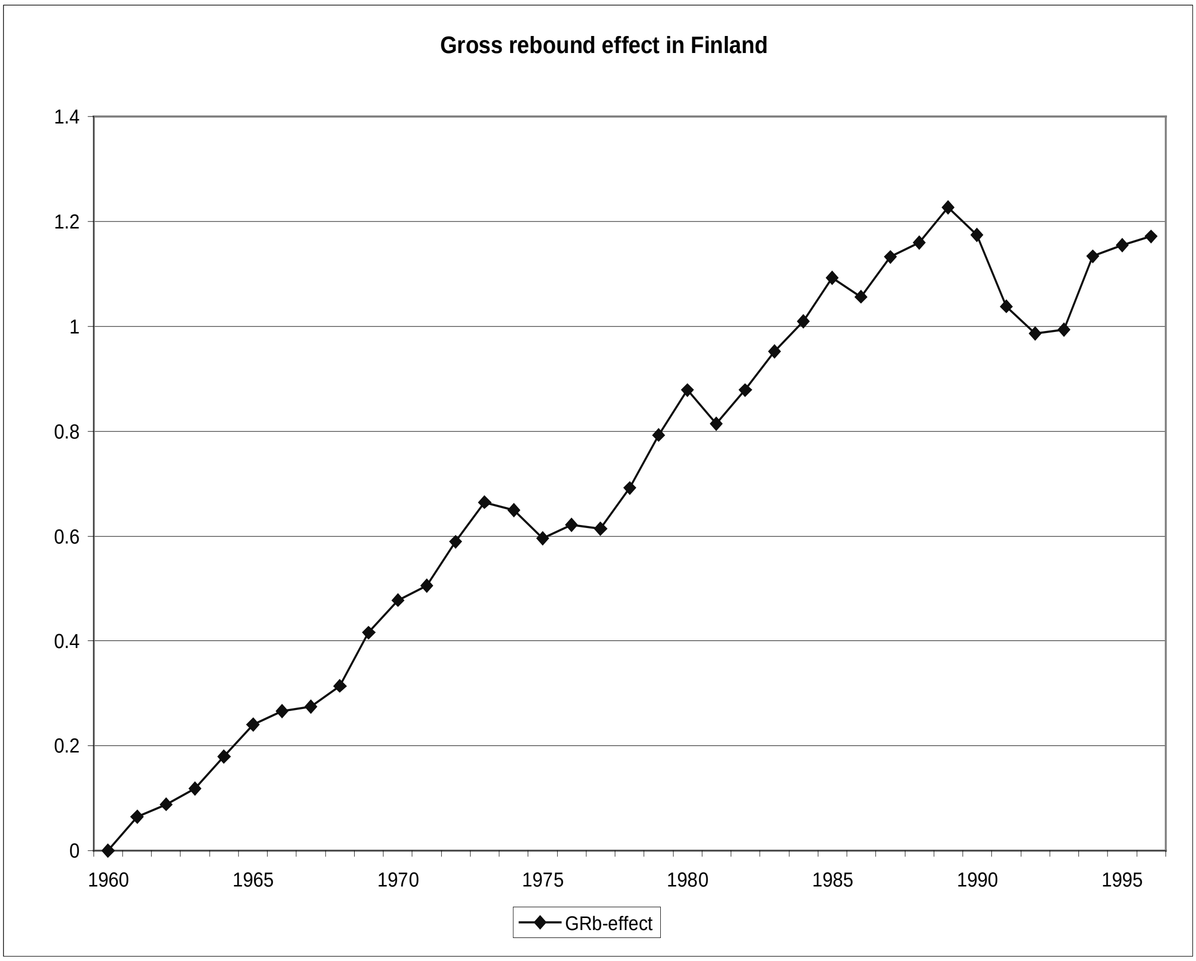

Figure 12. Cumulative gross rebound-effect on TES in Finland from 1960 to 1996 (base year 1960, unit of the horizontal scale = 172.6 Mt/a). Positive values indicate the contribution to deviation from sustainability.

During the 36-year period, the dematerialisation effect in Figure 10 has been accumulating to about 42 % of the unit value of TES. This corresponds to an average rate of improvement of material efficiency and development of technology of about 1.5 %/a from 1960 to 1996. Without this process of getting more from less in production, the increase in the use of material resources would have been considerably higher. The dematerialization process has, however, been insufficient to compensate for the adverse contribution of economic growth and gross rebound to sustainability. This is observed from the strong positive growth effect in Figure 11. A counter-effect called gross-rebound appeared at an average growth rate of 2.2 %/a (see Figure 12).

The sustainable economic growth concept provides another way to demonstrate how well the necessary condition of sustainability is or is not met. According to the theory, the ecologically sustainable economic growth rate depends on the rate of change of the material intensity, which can be seen in Figure 9. On the other hand, the material intensity of the economy indicates the quality level of production technology, and a decreasing intensity indicates technological development. This interpretation of the material intensity associates the dematerialisation process as a whole with technological development.

The sustainable annual economic growth rates in Finland from 1975 to 1996, which were calculated according to the theoretical formula (11), are presented in Figure 13A.

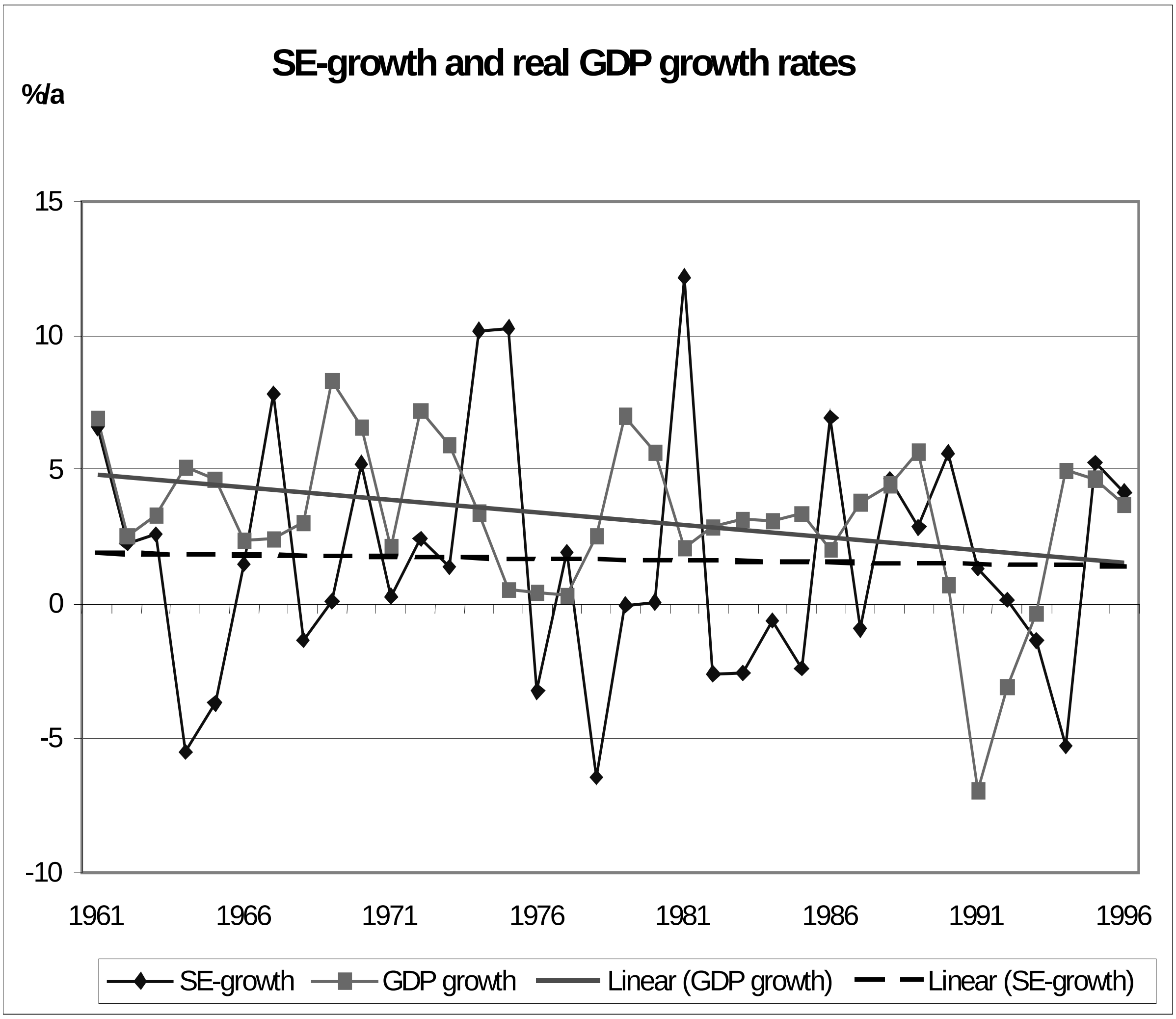

Figure 13A. The calculated annual sustainable economic growth rate and its linear trend in comparison with the observed real growth rate and its linear trend in Finland from 1960 to 1996. The sustainability condition is met only in random occasions, where the real growth rate remains below the sustainable rate.

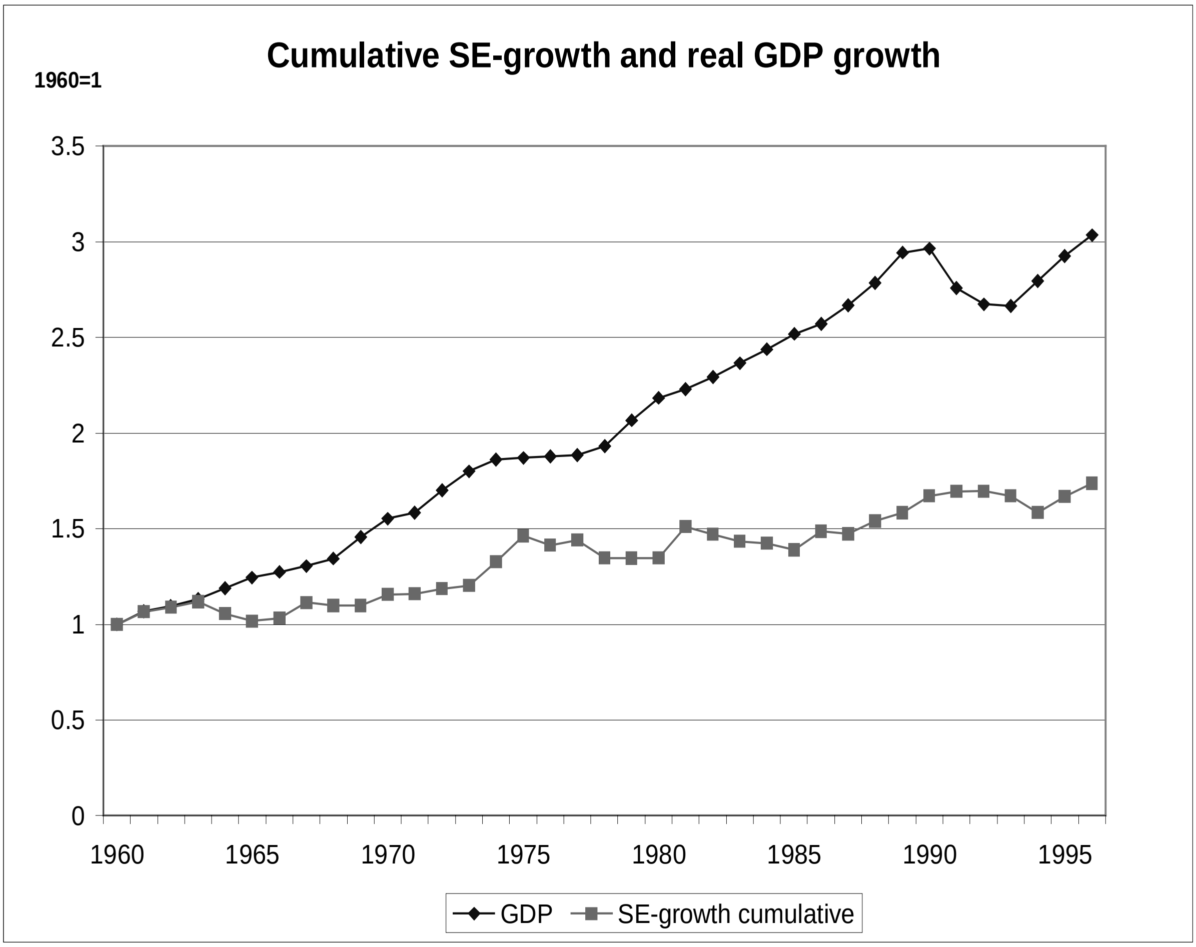

Figure 13B. The calculated cumulative sustainable economic growth in comparison with the observed real growth in Finland from 1960 to 1996 (base year 1960, unit = $151.2*10^9$ FIM/a). The difference between the curves demonstrates an increasing debt to sustainability.

Comparing real economic growth with sustainable growth potential in Figure 13A, we observe that there are few intervals where the sustainability condition is not violated, while for most of the period sustainability does not advance. The recession in the early 1990s contributed to ecological sustainability, but since then the trend has reversed itself. Most recently the growth has again turned towards advancing sustainability again, and this time not only with slowing down the real growth but also by increasing the economy's potential for sustainable growth.

6.3. Welfare Dilemma

The welfare dilemma of chapter 5.2 calls for a way to measure welfare independently of the GDP. There are numerous attempts to define and measure it in different ways.

The UNDP's human development index is one attaining increasing acceptance since the 1990 (see Human Development Report 1990, 1993, 1994, 1996). In this study it is used to analyse immaterialization processes, and the welfare productivity of GDP from 1960 to 1995 is determined accordingly. The use of HDI in measuring welfare has some special problems (e.g. the maximum value it can attain is 100) but in this paper we do not discuss this or other problems of welfare indices. The results of the empirical analysis (based on the Eq. (4) of the theory) are presented in Figure 14 and Figure 15.

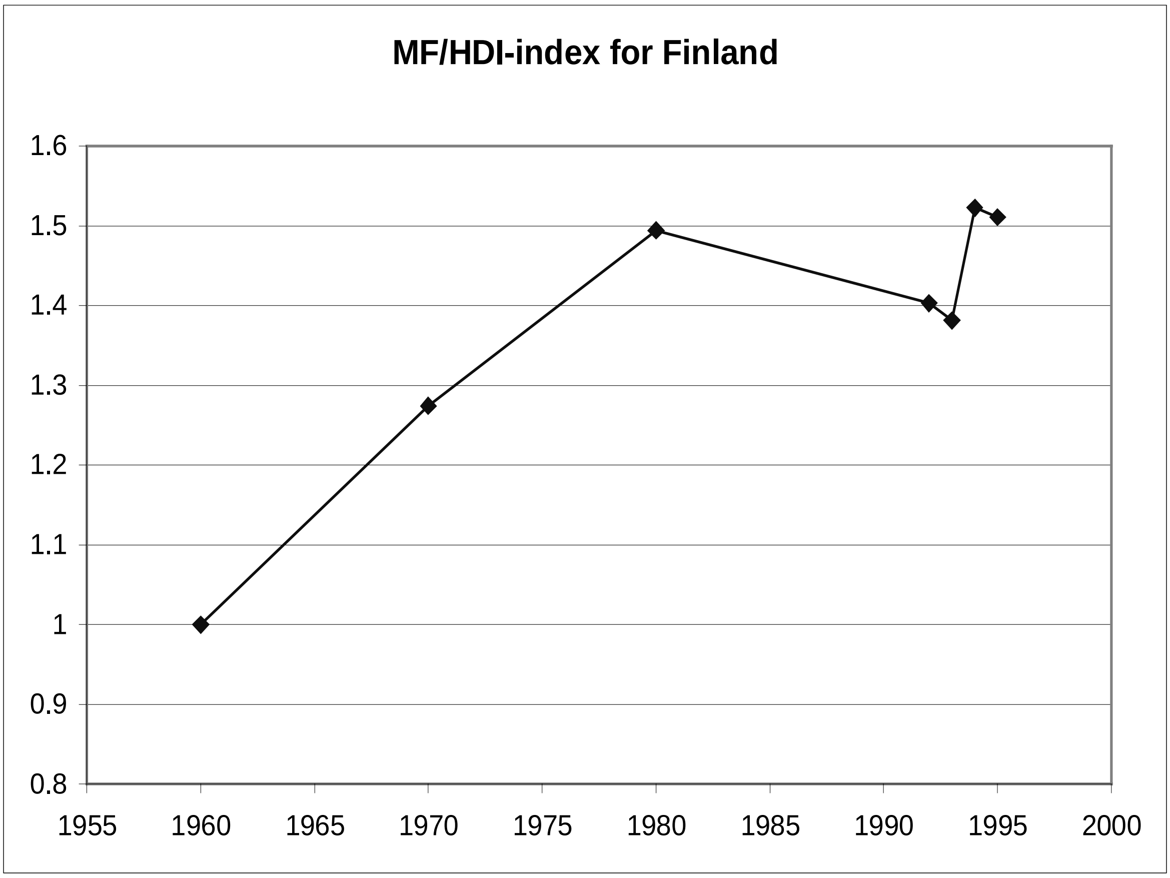

Figure 14. Data of the material intensity of welfare, i.e. the total material flow (MF) divided by the Human Development Index (HDI), in Finland from 1960 to 1995. (base year 1960, unit value = 212.8 Mt per HDI-unit)

Figure 14 shows that the material intensity of welfare has been increasing by the year 1980 but between 1980 and 1994 some temporary immaterialization process of consumption was in effect. The material intensity of welfare, measured by (MF/HDI), increased by about 50 % from 1960 to 1995. This reveals that sustainability was not advanced, but that the eco-efficiency of welfare production in Finland decreased instead.

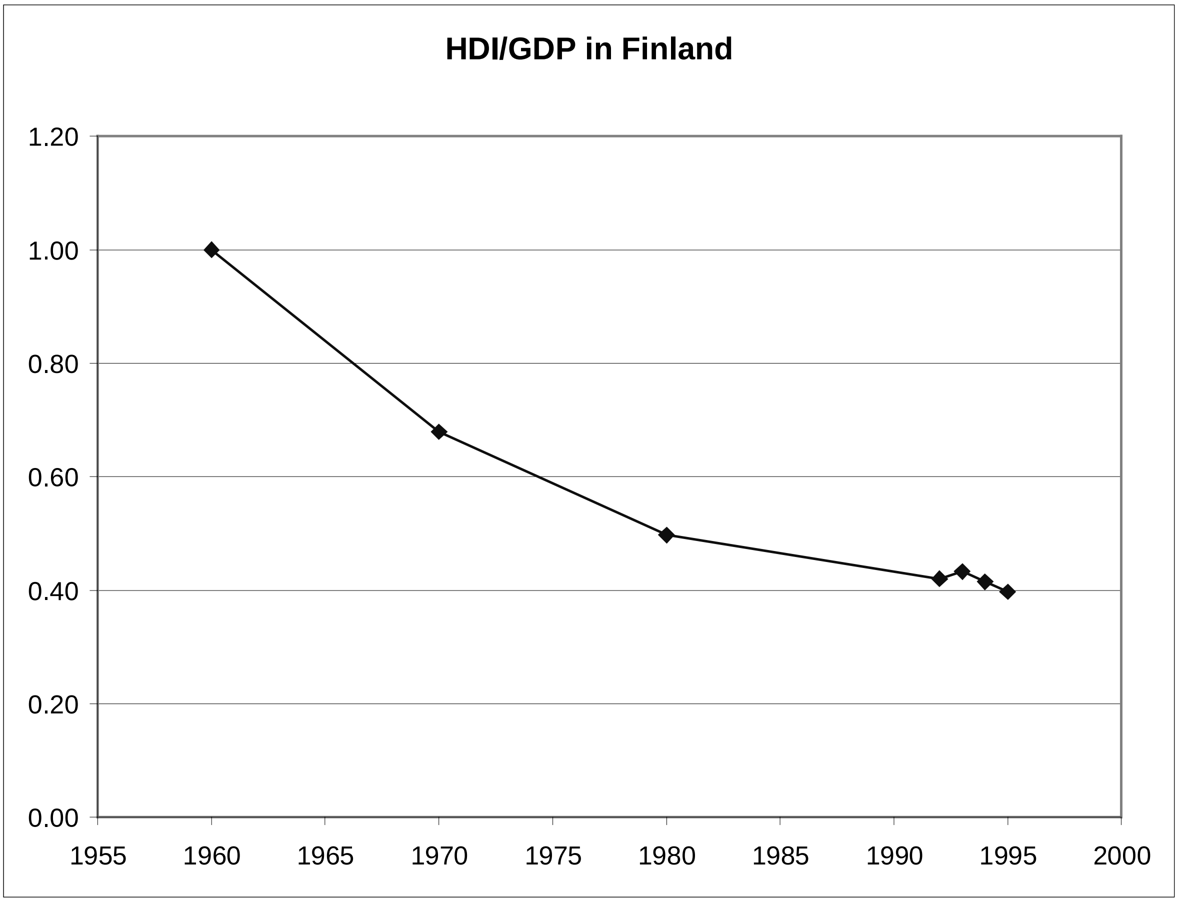

Figure 15. Data of the welfare productivity of GDP, which is measured using the HDI/GDP ratio (base year 1960, unit of the horizontal scale = 5.35 HDI-unit/MFIM/a

In the official economic policies the GDP growth is regarded as the ultimate end of social activity. The sustainability analysis regards economic growth only as a better or worse means to an ultimate goal expressed in the welfare concept. It is thus only natural to inquire about the efficiency of the means to the end, i.e. about the efficiency of the economic growth policies adopted, and to give priority to welfare productivity growth policies instead of plain economic growth.

Figure 15 shows that the welfare productivity of GDP in Finland has decreased dramatically, about 60 %, since 1960. The economic growth has not been supporting welfare productivity but has instead hindered it. It is believed that this dilemma is pertinent for present economic growth in all countries and for global growth as well. According to Eq. 12 an increasing trend of welfare productivity is a necessary condition for advancing sustainable development. In Finland this condition has not been met. Sustainable development requires that governments substitute plain growth policies with welfare productivity policies.

It is interesting to notice that while some dematerialization has taken place in the Finnish economy, and thus the condition of equation (8) has been fulfilled, the other condition of equation (12) has not been met. This implies that the theory is not about sufficient conditions, but only about necessary conditions for advancing ecological sustainability. Also, this theory is not a phenomenological theory capable of describing how to behave sustainable, but it provides the constraints and boundaries beyond which sustainability will certainly not advance.

Turning the welfare productivity of GDP from its present decreasing course shown in Figure 15 into an increase would be the only proper sustainable growth policy, and governments should make it a priority over plain economic growth. The course of the material intensity of welfare, as in Figure 14, determines the minimum rate of welfare productivity growth needed to regain immaterialization process of consumption (a decreasing course in Figure 15). The welfare productivity growth required to counter-balance the realized increase of material intensity would have been about 1.2 %/a on average in the observation time span. It remained, however, unrealized. The analysis shows that economic growth can no longer be regarded as a sole and adequate measure of true development. If new measures in policy formulations are not taken, the result may be further decreases in welfare and worsening sustainability problems.

The theoretical analysis and the empirical demonstrations show that when material intensity is examined from two sides, i.e. from the production side and the consumption side of society, the social-economic dimensions of sustainability are more easily covered. The theory provides an inevitable basic conceptualization for sustainability discourse based on environmental, economic and social points of view. The explanatory possibilities it offers were not taken into account sufficiently in previous sustainability approaches.

6.4. Employment and Automation Dilemma: The Case of Finland

The role of automation and its social consequences has not adequately been discussed in the sustainability literature. The dematerialization of production in Figure 9 can, to some extent, be linked to automation. However, dematerialization does not explain all aspects of automation. A more thorough understanding is offered by the equation (5) of the theory, which relates automation and employment to the sustainability problematique. The employment data required for the empirical analyses are presented in Figure 16.

Figure 16. Data of the ratio of employed workers to the total population (EMP/POP) in Finland from 1975 to 1996 (base year 1975, unit of the horizontal scale = 0.473 employed persons per capita)

The ratio of employed persons to the total population has been about 47 %, but during the economic recession in the 1990s it decreased below 40 %. This has resulted in high levels of unemployment. The unemployment problem has been incorporated in the development of environmental policies in two ways. Firstly, new fiscal measures have been planned through environmental taxes with the aim to reduce some other taxes and costs related to labor. This approach was thought to increase employment and to support labor-intensive technologies. Secondly, the severity of the unemployment situation has had an adverse effect on making environmental solutions a priority over plain economic growth and export policies. These aims and policies are reflected in the empirical figures of the material throughput per worker as in Figure 17.

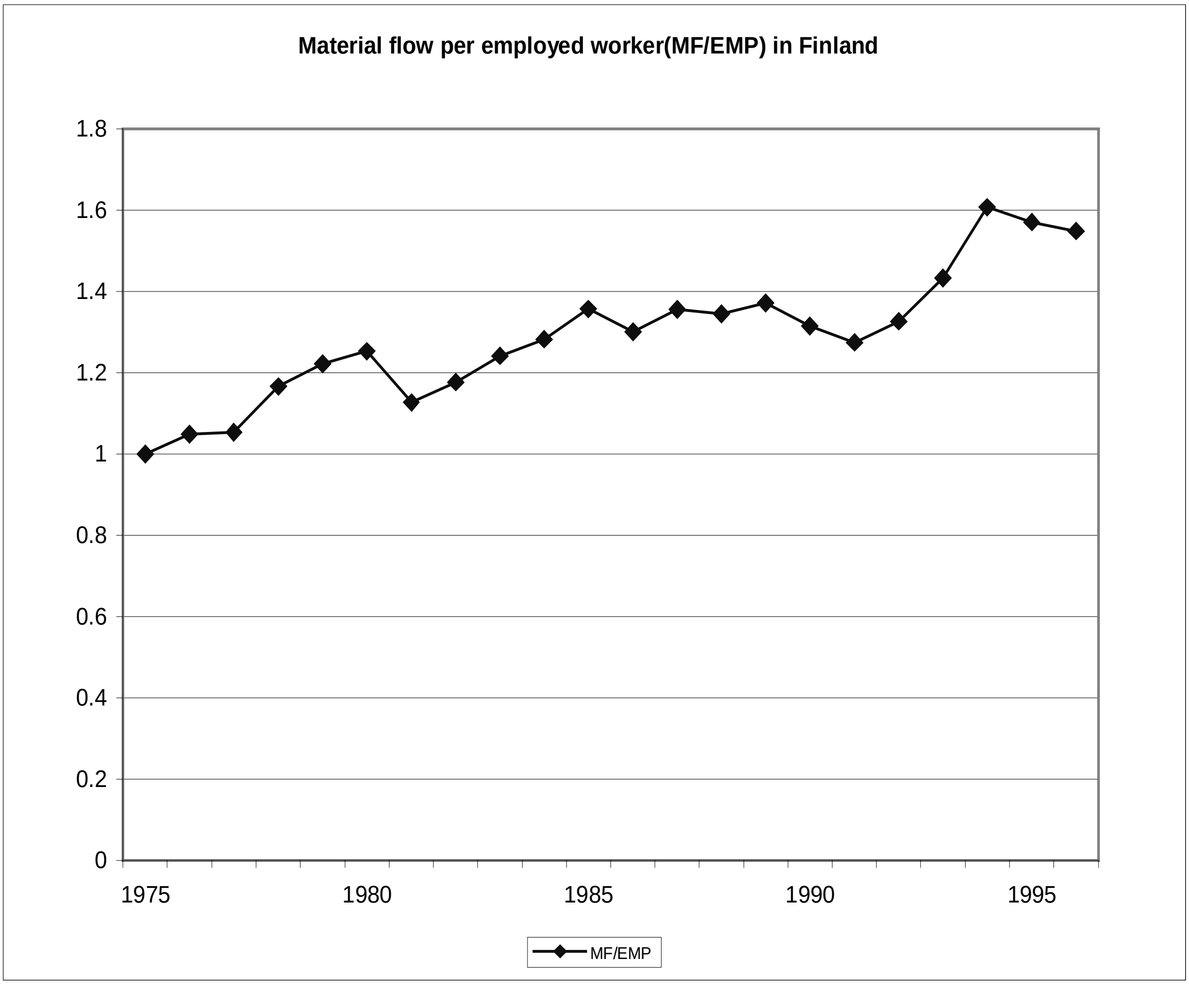

Figure 17. Data of the material flow per employed worker (MF/EMP) in Finland from 1975 to 1996 (base year 1975, unit of the horizontal scale = 98.9 t/a/worker)

In Finland, the material flow per employed worker has increased about 60 % from 1975 to 1996. This reveals advancing automation of production presented in equation (6 a), i.e. one worker handles larger material flows with the help of automated machines. There is a trend-like increase in the figures, with variations up and down, up until the end of the 1980s. Since 1990 the figures experienced a rapid increase, which is linked to the worsening unemployment during the same time. The turn reflecs, however, a substantial labour productivity growth in the economy, i.e. getting more from less labour in production.

To increase unemployment cannot be a sound policy to advancing sustainability nor can be halting development of production automation. The empirical findings presented so far have only made the dilemma between these different goals visible. The theory can show a partial solution to the dilemma with a structural shift of the economy.

6.5. Structural Shift as a Sustainability: The Case of Finland

In order to analyse the structural shift of the economy and its implications for sustainability, the sectoral data of material use are needed. Unfortunately, sectoral data of material use are not available. In the structural shift analysis the electricity consumption is used as the measure of TES. The economy is thought to consist of two sectors, one of high material intensity and the other of low intensity. The sectors approximately correspond to the industry and the service sector. Figure 18 provides data of the sector labour force shares (for the weight variables, W_o and $(1-W_o)$, in Eq. 6).

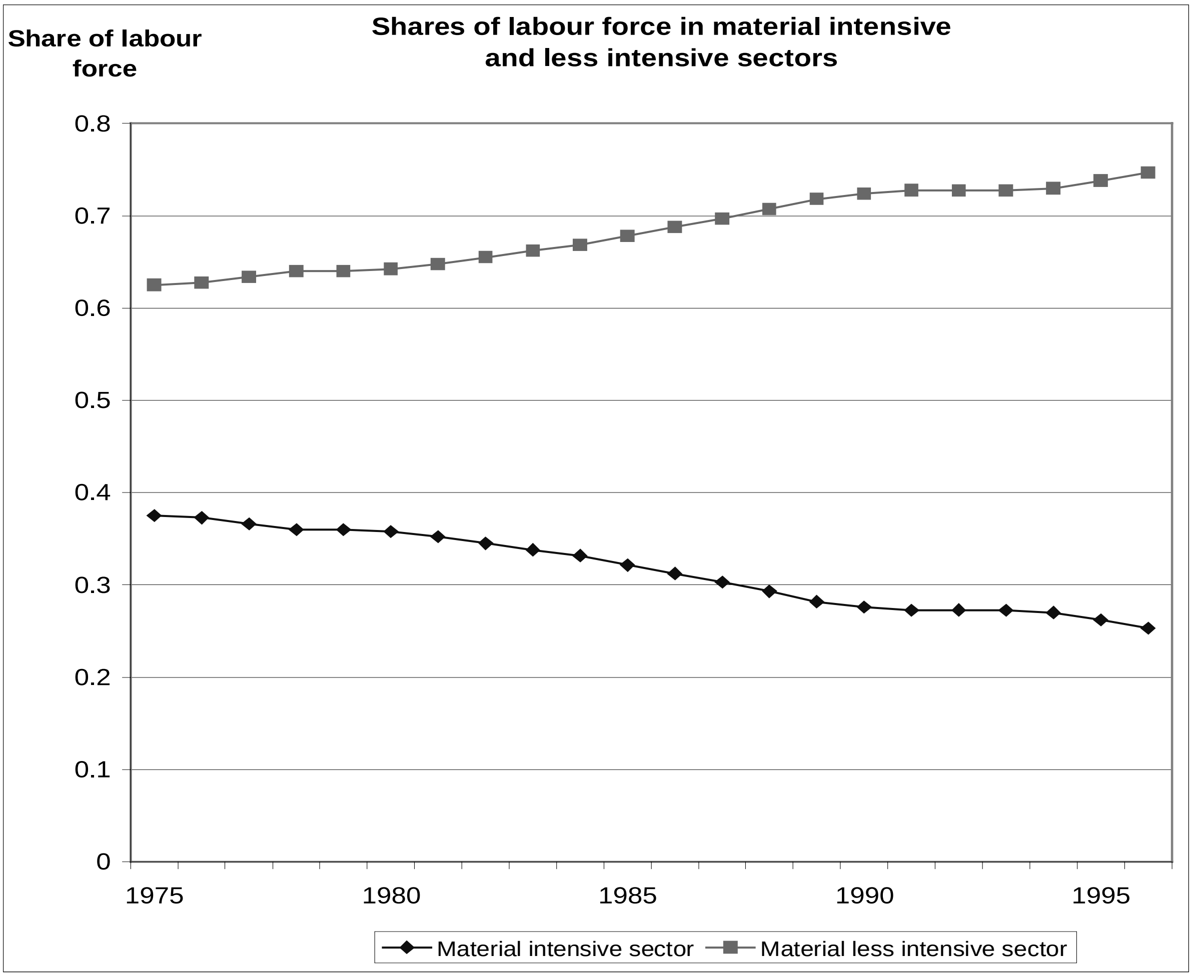

Figure 18. Rough data of labor-force share in the material-intensive sector (W_o) and in the less material-intensive $(1-W_o)$ sector in Finland from 1975 to 1996. The material intensive and less intensive sectors are presented in Appendix 1.

The figures above indicate that a structural shift indeed took place in the Finnish economy between 1975 and 1996. Whether it been strong enough to counter-balance the increase of total environmental stress from automation and employment is examined using Eq. 14 of the theory. The Figure 19 provides the data of the shift of employment from one sector to the other. The structural shift values needed to counter-balance the increase of the total environmental stress or material flow due to automation and employment dilemma in Figure 19 are calculated using Eq. 14.

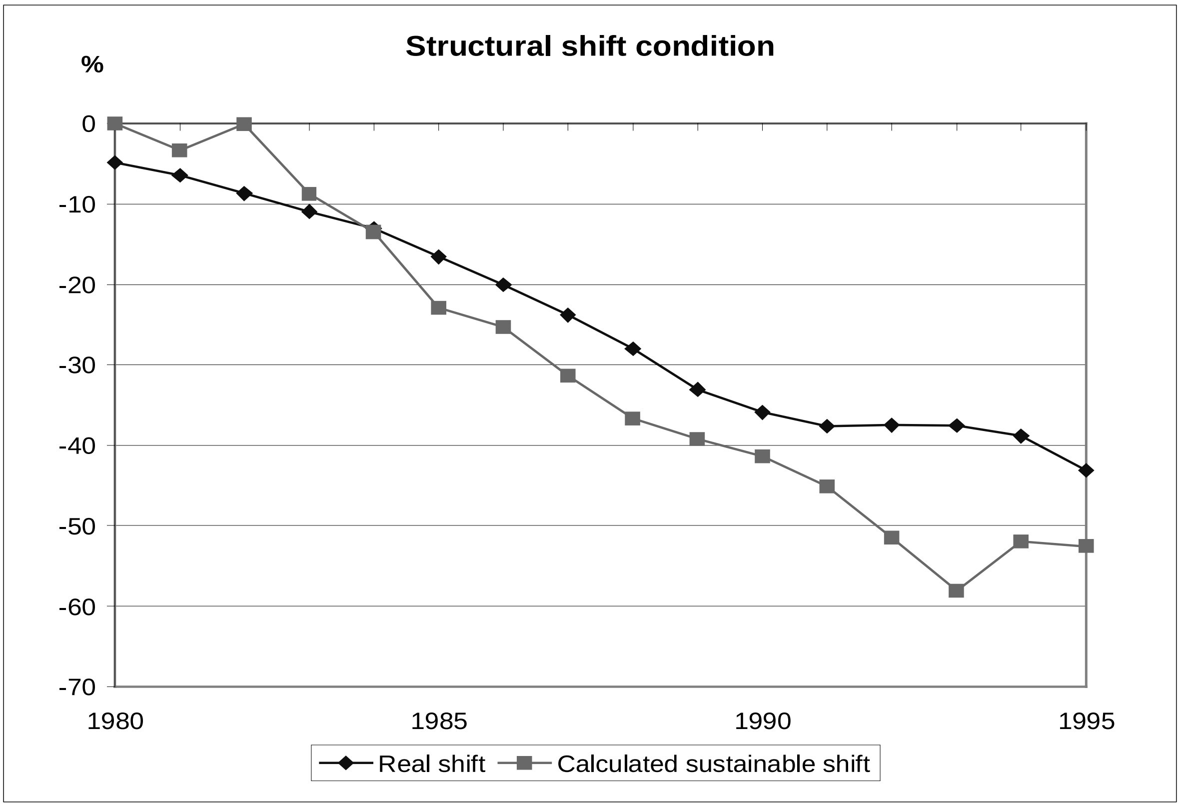

Figure 19. Data of the cumulative real structural shift in Finland from 1975 to 1997, and the sustainable shift as calculated using Eq. 14. (per cent of the labor-force share of the materially-intensive sector for base year 1975). When the real shift is above the curve of the calculated sustainable shift, it implies deviation from sustainability.

The results indicate that the necessary condition of advancement of sustainability was realized in the Finnish economy during the early 1980s but not during the late 1980s and 1990s. The structural shift has been inadequate to compensate for the increase in total environmental stress caused by employment policy and automation advance.

7. CONCLUSIONS

New fundamental principles of sustainable development have been discussed in this paper. The sustainability approach presented is diachronic, statistical and macro-oriented, whereas synchronic issues concerning decomposition are not discussed. A new theoretical framework of necessary conditions for advancing sustainability is formulated by relating the total environmental stress to the indicators and variables of the economic, technological and social development. Empirical analyses of one country's data (Finland) were conducted to demonstrate the applicability of the theory. The explanatory power of the theory was demonstrated through important new concepts and formulas as well as through the empirical analyses using mainly the total material flow as a measure for total environmental stress.

Results show that the theory works well in evaluating the ecological sustainability. According to the theory the case country (Finland) has not given the advancement of sustainability a real priority among the objectives of the society, such as economic growth, automation or employment. Sustainability is, de facto, a global ethos, where each country has a joint role to play together with all others. The theory needs to be supplemented with a global decomposition theory enabling us to conduct synchronic analyses in addition to the diachronic analyses now available. The per-unit value method developed will be an inevitable tool in making a theory, which can be applied more generally.

REFERENCES

Ayres, Robert U. (1978). Resources, Environment and Economics. Applications of the Material/Energy Balance Principle. New York.

Bishop, Richard C. (1978). Endangered Species and Uncertainty: The Economics of a Safe Minimum Standard. American Economic Review Vol. 60, 10-18.

Bishop, Richard C. (1993). Economic Efficiency, Sustainability and Biodiversity. Ambio. Vol. 22. No. 2-3, 69-73.

Boskin, Michael J. (1979). Economics and Human Welfare. Academic Press, New York.

Botkin, David B. (1990). Discordant Harmonies. A New Ecology for the Twenty-First Century. Oxford University Press, Oxford.

Carlson, Rachel (1962). Silent Spring. Houghton Mifflin, Boston MA.

Cassier, Ernst (1946). Language and Myth. Dover Publications, New York.

Cassier, Ernst (1985). The Philosophy of Symbolic Forms. Yale University Press, New Haven and London.

Christensen, P.P. (1989). Historical Roots of Ecological Economics - Biophysical vs. Allocative Approaches. Ecological Economics. Vol. 1. No. 1, 17-36.

Ciriacy-Wantrup, Siegfried V. (1952). Resource Conservation. Economics and Policy. University of California Press, Berkeley.

Common, Michael (1995). Sustainability and Policy: Limits to Economics. Cambridge University Press. Cambridge.

Common, Michael & Perrings, Charles (1992). Towards an Ecological Economics of Sustainability. Ecological Economics. Vol. 6, No. 1, 7-34.

Daly, Herman (1990). Toward Some Operational Principles of Sustainable Development. Ecological Economics. 2, 1-7.

Daly, Herman (1992). Steady-state Economics, Second Edition with New Essays. Earthscan, London.

Daly, Herman (1996). Beyond Growth. The Economics of Sustainable Development. Beacon Press, Boston, Massachusetts.

Daly, Herman & Cobb, John B. (1989). For the Common Good. Green Print, London.

Dieren, Wouter van (1995). Taking Nature into Account: Toward a Sustainable National Income. A Report to the Club of Rome. New York Copernicus, New York.

Echrlich, Paul & Echrlich, Anne (1990). The Population Explosion. Hutchinson, London.

Ekins, Paul (1997). The Kuznets Curve for the Environment and Economic Growth: Examining the Evidence. Environment and Planning A. Vol. 29, 805-830.

El-Serafy, Salah (1989). The Proper Calculation of Income from Depletable Natural Resources. In Ahmad, Y., El-Serafy, S. & Lutz, E. (Eds.) Environmental Accounting for Sustainable Development. A UNDP-World Bank Symposium. Word Bank, Washington D.C.

Energy Statistics 1997, Statistics Finland, Helsinki.

Federation of Engineers (WFEO, UPADI, FEANI) (1972). Declaration of Engineers to the UN Conference on the Human Environment. Stockholm, June 12th 1972.

Femia, Aldo, Hinterberger, Friedrich & Luks, Fred (1999). Ecological Economic Policy for Sustainable Development. Potentials and Domains of Intervention for Delinking Approaches. SERI Working Paper No. 1. Sustainable Europe Research Institute, Wien.

Femia, Aldo, Hinterberger, Friedrich & Renn, Sandra (1999). Economic Growth with less Material Input? De-composing the Empirical Trend of De-linking. Paper prepared for the Symposium “Energetic and material Metabolism” at the Conference on "Nature, Society and History. Long Term Dynamics of Social Metabolism" Wien, September 30th – October 2nd, 1999.

Finland Yearbooks of Industrial Statistics 1970-1997, Statistics Finland, Helsinki.

Giarini, Orio (1980). Dialogue on Wealth and Welfare. Pergamon Press, Oxford.

Hanley, Nick, Shogren, Jason F. & White, Ben (1997). Environmental Economics in Theory and Practice. MacMillan. Houndmills. Basingstoke. Hampshire.

Hartwick, J.M. (1977). Intergenerational Equity and the Investing of Rents from Exhaustible Resources. American Economic Review. Vol. 67, No. 5, 972-974.

Hartwick, J.M. (1978). Substitution among Exhaustible Resources and Intergenerational Equity. Review of Economic Studies. Vol. 45, 347-354.

Hirsch, Fred (1977). Social Limits to Growth. Routledge and Kegan Paul, London.

Hoffrén, Jukka (1999a). Material Flow Accounting as a Measure of the Total Consumption of Natural Resources. The Finnish Environment 287. Ministry of the Environment, Eurostat, Helsinki.

Hoffrén, Jukka (1999b). Economy as Generator of Wellbeing and Environmental Damage - Measuring the Finnish Eco-efficiency. Statistics Finland, Research Reports 226, Helsinki.

Hotelling, Harold (1931). The Economics of Exhaustible Resources. Journal of Political Economy. Vol 39, 137-175.

Howarth, Richard B. & Norgaard, Richard B. (1992). Environmental Valuation under Sustainable Development. American Economic Review. Vol. 82, No. 2, 473-477.

Human Development Report 1990, United Nations Development Programme, William H. Draper, 1990.

Human Development Report 1992, United Nations Development Programme 1992.

Human Development Report 1993, United Nations Development Programme 1993.

Human Development Report 1994, United Nations Development Programme 1994.

Human Development Report 1996, United Nations Development Programme 1996.

Human Development Report 1998, United Nations Development Programme 1998. http://www.undp.org/hdro/98hdi.htm.

IUCN (1980). World Conservation Strategy: Living Resource Conservation for Sustainable Development. Morges, Switzerland

Jokinen, Pekka & Malaska, Pentti & Kaivo-oja, Jari (1998). Environment in an "Information Society": Transition Stage Towards Sustainable Development? Futures. Vol. 30, No. 6, 485-498.

Kasanen, Eero (1982). Mathematical Models of Exploitation of Natural Resources, (diss.) Turku School of Economics Serie A: 1982/6

Klaasen, G. and Opschor, H. (1991). Economics of Sustainability or the Sustainability of Economics. Ecological Economics, 4, 83-92.

Lemma, Aklilu & Malaska, Pentti (eds.) (1989). Africa Beyond Famine: A Report to the Club of Rome. Tycooly Publishing, London.

Malaska, Pentti (1971). Future Prospects of Technical Man. Insinöörien kustannus, Helsinki.

Malaska, Pentti (1987). Environmental Problems of Modern Societies. International Journal of Technology Management. Vol. 2, No. 2, 263-278.

Malaska, Pentti (1997a). Ecosystem and Technosystem - a Problematic Relation. In Internet address: http://www.tukkk.fi/tutu/ecotec.htm.

Malaska, Pentti (1997b). Sustainable Development as Post-Modern Culture. In Lars Rydén (Ed.) Foundations of Sustainable Development. Session 9. A Sustainable Baltic Region. Uppsala University. Ditt Tryckeri. Uppsala, pp. 45-50.

Malaska, Pentti, Luukkanen, Jyrki & Kaivo-oja Jari (1999). Decomposition Method in Sustainability Analysis. FUTU-publication 3/99, Finland Futures Research Centre. Turku School of Economics and Business Administration. Turku.

Max-Neef, Manfred (1995). Economic Growth and Quality of Life: A Threshold Hypothesis. Ecological Economics, 15, 115-118.

Material Flow Accounting. Experience of Statistical Institutes in Europe. Eurostat - Statistical Office of the European Communities. Directorate B: Economic statistics and economic and monetary convergence. Quarterly accounts and environmental accounts - unit. Luxembourg, December 1997.

Meadows et al. (1972.). The Limits to Growth. Report to the Club of Rome Universe Books, New York. A.

Pearce, David (1993). Economic Values and the Natural World. Earthscan, London.

Pearce, David W. & Turner, R. Kerry (1990). Economics of Natural Resources and the Environment. Harvester Wheatsheaf. Hertfordshire.

Pearce, David & Atkinson, Giles (1995). Measuring Sustainable Development. In D. W. Bromley, The Handbook of Environmental Economics. Blackwell Handbooks in Economics, Blackwell, Oxford & Cambridge, 166-181.

Pezzey, John (1992). Sustainable Development Concepts, An Economic Analysis. World Bank Environmental Paper Number 2. World Bank, Washington, D.C.

Pezzey, Jack (1994). The Optimal Sustainable Depletion of Non-renewable Resources. Paper to EAERE conference, Dublin.

Sadik, Nafis (1991). The State of the World Population 1991. UNFPA (UN Fund for Population Activities), New York.

SCEP - Report of the Study of Critical Environmental Problems (1970). Man's Impact on the Global Environment, The MIT Press Cambridge USA.

Scitovsky, Tibor (1979). The Joyless Economy. Oxford University Press, London.

Solow, Robert (1974). The Economics of Resources or the Resources of Economics. American Economic Review, Vol. 64, 1-14.

Spangenberg, Joachim H. (1995). Towards Sustainable Europe, Wuppertal Institute for Climate, Environment and Energy, Wuppertal.

Statistical Yearbooks of Finland 1970-1997. Statistics Finland, Helsinki.

Stockhammer et al. (1997). The Index of Sustainable Economic Welfare (ISEW) as an Alternative to GDP in Measuring Economic Welfare. Ecological Economics, Vol. 21, 19-34.

Sun, JiWu (1996). Quantitative analysis of Energy Consumption Efficiency and Saving in the World, 1973-90. Publication of the Turku School of Economics and Business Administration, Series A-4:1996. Turku.

Tisdell, Clement A. (1990). Economics and the Debate about Preservation of Species, Crop Varieties and Genetic Diversity. Ecological Economics, 2, 77-90.

Turner, R. Kerry (1993). Resource Conservation and Pollution Control: On Overview. In R.K. Turner (ed.) Sustainable Environmental Economics and Management. Belhaven Press, London, 1-25.

United Nations (1993). Agenda 21: Programme of Action for Sustainable Development. United Nations, New York.

United Nations (1995). World Summit of Social Development, Copenhagen. United Nations, New York.

Van Pelt, M.J.F. (1993). Ecologically Sustainable Development and Project Appraisal in Developing Countries. Ecological Economics, Vol 7, No. 1, 19-42.

Wall, Göran (1986). Exergy - a Useful Concept. Physical Resource Theory Group, Göteborg.

WCED (The World Commission on Environment and Development) (1987). Our Common Future. (The Brundtland report). Oxford University Press, New York.

Weizsäcker von, Ernst, Lovins, Amory B. & Lovins, L. Hunter (1997). Factor Four. The New Report to the Club of Rome. Earthscan, London.

APPENDIX 1

Material-intensive sectors:

Agriculture, forestry, logging
Mining and quarrying
Manufacturing of food, beverage and tobacco
Manufacturing textiles and textile products
Manufacturing of wood and wood products
Manufacturing of pulp, paper and paper products
Manufacturing coke and petroleum products
Manufacturing of chemicals, chemical products
Manufacturing of rubber and plastic products
Manufacturing of other non-metallic minerals
Manufacturing of basic metals
Manufacturing of fabricated metal products
Electricity, gas & water supply
Transport and storage

Less material-intensive sectors:

Publishing and printing
Manufacturing of machinery and equipment
Manufacturing of electrical and optical instruments
Manufacturing of transport equipment
Other manufacturing
Construction
Wholesale & retail trade
Hotels and restaurants
Post- & telecommunication
Financial intermediation
Real estate, renting & business services
Education
Health and social work
Other community, society & personal services
Public sector services including
Transport, storage and communication
Real estate, renting & business services
Public administration & defence
Education
Health and social work

ABSTRACT

In the article fundamental principles of sustainable development are discussed first from general points of view. Sustainable development is seen as a late-modern idea of progress, i.e. an ethos for improvement of human partnership within the earth's life support system in the current late-industrial times and the future. Secondly a macro-oriented conceptual framework of conditions necessary for advancement of ecological sustainability of the economy and society is formulated and analyzed. The theoretical framework presented is a set of logical identities, which define relationships between the total environmental stress (TES) and basic indicators of economic, technological and social development. The framework, called the Total Environmental Stress Approach of FFRC, provides necessary but not sufficient conditions for advancing ecological sustainability.

PREVIOUS PUBLICATIONS:

3/99 Malaska, Luukkanen & Kaivo-oja (1999) *Decomposition Method in Sustainability Analysis.*

2/99 Malaska, Pentti & Holstius, Karin (1999) *Visionary Management.*

1/99 Malaska, Pentti (1999) *Sustainable Development Analysis.*

4/98 Kaivo-oja, Rubin & Keskinen (1998) *Proaktiivisia toimijoita vai koekaniineita Euroopan tietoyhteiskuntalaboratoriossa?*

3/98 Malaska, Pentti (1998) *Sociocultural Transients of Work in the Late-industrial Period – USA and Finland as the Empirical Cases.*

2/98 Malaska, Pentti (1998) *Prospektiivinen analyysimetodi Suomen trendiskenaarioiden laatimiseksi.*

1/98 Keskinen, Auli (1998) *Participatory Democracy and Civil Society – Transforming Societal Decision Making in the Information Age.*

7/97 Becker, Theodore & Slaton, Christa Daryl (1997) *Transforming Modern Representative Democracy via Advanced Telecommunications.*

6/97 Masini, Eleonora Barbieri (1997) *Futures Studies and the Trends towards Unity and Diversity.*

5/97 Kaivo-oja, Jokinen & Malaska (1997) *Kestävän kehityksen tietoyhteiskunta: teoreettisia ja käsitteellisiä näkökulmia.*

4/97 Kamppinen, Matti (1997) *Teknologian riskit ja tulevaisuus.*

3/97 Mettler, Peter H. (1997) *Sustainable Technology – Sustainability of What?*

2/97 Kamppinen, Matti (1997) *Cultural Models of Risk – The Multiple Meanings of Living in the World of Dangerous Possibilities.*

1/97 Malaska, Pentti (1997) *Sustainable Development as Post-Modern Culture.*