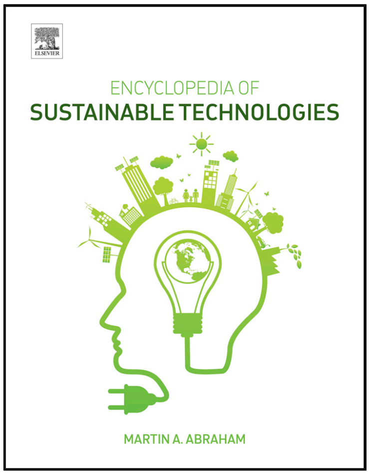

From Krozer, Y., 2017. Economics of Sustainable Technologies: Private and Public Costs and Benefits. In: Abraham, M.A. (Ed.), Encyclopedia of Sustainable Technologies. Elsevier, pp. 11–21.
ISBN: 9780128046777

Elsevier

Economics of Sustainable Technologies: Private and Public Costs and Benefits

Yoram Krozer, University of Twente, Enschede, The Netherlands; Sustainable Innovations Academy, Amsterdam, The Netherlands; and Center for Incubation, Innovation, Research and Consultancy of the Joythi Institute of Technology, Bangalore, India

Definitions

With regard to discussion about sustainable technologies, a few definitions are presented.

Environmental Qualities

This article is focused on the economics of sustainable technologies. Economics is a social science. Its primary purpose is to support the decision making involved in the transformation of environmental qualities (space, nature, energy, minerals, and others) into man-made resources (material, capital, labor, and knowledge); all of which ultimately satisfy human needs. Such transformations have negative environmental impacts that degrade environmental qualities and subsequently undermine welfare; for example, squandering of minerals, biodiversity loss, and pollution. The environmental qualities are considered common goods. While they serve individuals and society, the ownership of the environmental qualities is difficult to distribute among individuals, for various uses, without losing their specific qualities. The environmental qualities are usually defined in physical terms, such as mass, power, or other related units. Welfare, considered in a broad sense of wealth, capabilities and well-being, is commonly indicated by income, though other indicators such as human development and satisfaction are increasingly used. Efforts and sacrifices made toward welfare creation are considered costs, and their results are benefits, though many relevant activities are not montized. The resource allocations that satisfy human needs can save costs and add value to benefits; net benefit occurs when the benefits exceed the costs. The degradation of environmental qualities is a cost, as is preventing this degradation. Welfare grows when the net benefit attained has taken into consideration all costs of environmental protection and degradation. Throughout the last two centuries, it has been a subject of considerable debate whether the availability of environmental qualities can be maintained along with welfare growth. In theory, this possibility is underpinned by the condition that the development and uses of the impacts-preventing technologies evolve faster than the potential negative environmental impacts caused by unregulated income growth (Kuipers and Nentjes, 1973). Technologies, herewith, are considered tools for resource allocation which can save the costs of resource use, while simultaneously increasing the value of products in a business or society. If the total of products achieve greater value when compared with the costs it is considered productivity, which is the yardstick for economic growth. When the income-generating technologies aim to reduce environmental impacts, they can contribute to sustainable development as defined by the United Nations World Commission on Environment and Development in "Our Common Future," 1987 ("development that meets the needs of the present without compromising the ability of future generations to meet their own needs," p. 43). Such technologies are called sustainable technologies.

Environmental Impacts

The process of resource allocation is usually called production. This process delivers product qualities which can be material-intensive commodities, capital-intensive investments, labor-intensive services, and knowledge-intensive images, when measured by the share of key resource in the products. Production may cause unintended effects on other interests. Such external effects can either be beneficial or costly. Markets tend to absorb the beneficial effects, for instance access of public knowledge for private use. The costly external effects, such as pollution, are generally discharged at no or low price. The cumulated discharges, if not absorbed and neutralized in the environmental sinks, cause negative environmental impacts, which harm private and public interests. These are, for example, climate change, dirty water, and other impacts described by environmental indicators. During the last 50 years, mainstream economic studies on the environment were based on the idea of market failure due to missing markets for scarce environmental qualities. The markets are missing, it is argued, because property rights have not been established, and so a major focus of these studies have been to identify mechanisms that can correct the market failures, or get the incentives right, and at the same time to take advantage of a decentralized decision making mechanism that can achieve the environmental objectives at least costs. Authorities, being organizations with power to impose regulation and sanction noncompliance, would impose limits on pollution through permits, or by levying a tax on the external effects would install quasiprices on the environmental impacts. The prices of environmental impacts could also be created through pollution trading in which a property right to use the environment for residuals disposal is created, bought, and sold. Such a mechanism is assumed to be cost-effective. In order to assess the price of environmental impacts, some economists monetize environmental impacts as damage to society, terming them as environmental costs (Pearce and Kerry Turner, 1990). The monetizing is based on the assumption that the environmental qualities can be assessed as if they are man-made resources. This, in itself, is disputable because neither can the qualities be reproduced within the economic timeframe, nor can they be re-allocated. In addition, the monetization methods are far from perfect. Hence, production contributes to welfare if the demanded product qualities generate the net benefits after having corrected the enviromental impacts.

http://dx.doi.org/10.1016/B978-0-12-409548-9.10035-1

Encyclopedia of Sustainable Technologies, First Edition, 2017, 11–21

Sustainable Technologies

In this mainstream train of thought, authorities play a key role with respect to the sustainable technologies. When authorities impose far reaching demands for reduction of environmental impacts, they invoke more effective technologies; and when they use market-based instruments, such as taxes and pollution rights, they trigger lower costs technologies, which means more efficient impacts reduction. Empirical studies that address the implementation of sustainable technologies, however, show various deficiencies compared to this mainstream viewpoint. Herewith, only a few widely observed deficiencies are mentioned. Negative environmental impacts can grow unrecognized when the knowledge to perceive them does not permeate into policy making. For example, global climate change, being acknowledged in the 1970s, started to be regulated about 30 years later. In addition, the implementation of sustainable technologies is often obstructed by policy making aiming to protect vested interests that bear costs. Voluntary agreements with subsides and permits and waivers for compliance with standards are usual policy instruments rather than the economic instruments as recommended in the mainstream argumentation. Moreover, the taxes put on environmental impacts are rarely used for the regulatory purposes but usually for generating public income. Furthermore, the enforcement often can cause unanticipated side effects because some impacts are reduced and others enlarged, but environmental impacts assessment throughout the life cycle of technologies are rarely executed, and when done are often disputed. Even more laborious are decisions about development of the sustainable technologies. The sustainable technologies should be developed in relation to the precautions taken against environmental impacts, but this precautionary approach fails when unexpected negative side effects appear during use (e.g., nuclear power plants) or when high development costs do not deliver results (e.g., nuclear fusion). A more realistic perspective on the role of policies in development and dissemination of the sustainable technologies is presented later.

Content Outline

This section is about the costs and benefits of preventing environmental impacts by applying sustainable technologies. Consequently, each section reflects a broader context of decision making. It begins with the economist's views on the impacts in the "Economic Viewpoint" section. Decisions about costs in organizations are addressed in the "Costs" section. Transactional costs and benefits between suppliers and customers are discussed in the "Benefits" section. Market transactions with prices and qualities are introduced in the "Quality" section. Policy and stakeholders' decision making are addressed in the "Demands" section. Social decision making is discussed in the "Changes" section. All sections consist of brief introductions to a few key issues of environmental economics. For the sake of convenience, all positive effects of the sustainable technologies have been referred to as "impacts prevention." This is with regard to various issues such as pollution reduction, saving materials, efficient use of space, lower threats to biodiversity, and so on.

Economic Viewpoints

The mainstream and heterodox economic views on the use of sustainable technologies are presented.

Mainstream Viewpoint

In the mainstream, neoclassic economic viewpoint, technology is a black box. Production is the output function of capital and labor inputs, all in monetary terms. The material inputs are often neglected because their costs are considered low and knowledge is an assumed segment of labor. Producers find the lowest input costs for every output scale because inputs are considered divisible and usable. Output changes over and above the input changes of capital and labor are attributed to technology. These changes are assessed with statistical data on the historical input–output relations in the selected sectors and countries, that is, elasticities, used for extrapolations across other sectors and countries. Environmental impacts are considered negative external effects that are insufficiently priced on markets. Higher prices could emerge if individuals and societies benefit from impacts prevention. However, the sustainable technologies are perceived costly in comparison with their benefits measured by lower environmental costs, for instance, health damage caused by noise could be monetized as higher than the costs of noise prevention. The costs of sustainable technologies are expressed as the continuously increasing marginal costs function of impacts prevention or a decrease in environmental costs. The costs of production and the impacts prevention costs are considered in addition to each other as a joint production function. For assessment of the joint production function, environmental impacts indicators are found empirically by evaluating the state of the environment and the impact prevention costs are based on inquiries into the firms' production costs.

Heterodox Viewpoint

The heterodox viewpoint as found in behavioral, cost-engineering, evolutionary, institutional, and other theories is focused on the practical knowledge of production, that is, know-how, as being embedded in technologies and human capabilities. Production is comprehended as a sequence of units that process inputs into output. In the cost-engineering viewpoint, for instance, output qualities in a production unit are a factorial function of the input qualities plus one, meaning 3 inputs will generate 7 qualities, 4 inputs will generate 25, and so on. Formally, it is represented as:

$$N_o = N_i! + 1 \tag{1}$$

with N_o outputs and N_i inputs.

Outputs of a production unit form inputs form the next unit until all outputs are delivered to another production process or discharged into environment, ending in consumption. Even a simple production can generate numerous output qualities but only a few qualities are valuable because they are in demand. The qualities that are not in demand are wasted and consequently can cause environmental impacts when discharged. In this train of thought, know-how about how to maximize the valuable outputs, thereby prevent wasteful ones, reduces the environmental impacts along with higher income and lower costs of technology. Hence, environmental impacts are prevented due to know-how about how to process inputs into the valuable outputs and about how to prevent impacts of the wasteful outputs. The former is often classified as the process technology; the latter as the sustainable technology. The sustainable technology is either integrated in the process for preventing hazards and contributing to the process, or added to the process for preventing environmental impacts of hazards. From this perspective, environmental impacts are caused mainly by insufficient know-how. As the know-how is costly, these costs must be covered by the sale of products that are in demand and through lower costs of wasteful discharges.

Economic Consequences

If perfect input allocations are assumed, as it is in the mainstream viewpoint, outputs grow when lower input costs are attained. Sustainable technologies undermine the allocation process because they use costly inputs without valuable outputs unless environmental impacts are priced. The direct economic effect of using sustainable technologies is a higher cost of production. The indirect effect is reallocation of funds, such as the substitution of research and development into valuable products for additional pollution control. The consequence, in this viewpoint, is lower productivity. The justification for using the sustainable technologies is prevention of environmental impacts, which contributes to welfare. The welfare effects are expressed as lower environmental costs when the environmental impacts are monetized. The benefit of a sustainable technology in the mainstream view are lower environmental costs. If the resource allocations are far from perfect, as pinpointed in the heterodox viewpoint, the sustainable technologies—when integrated in the process—can contribute to higher value and cost-savings, and prevent environmental impacts when used as an add-on. Moreover, environmental impacts can be considered as being indicators of process deficiencies. Such indicators are useful in decision making with regard to cutting costs along with prevention of environmental impacts. In addition, the suppliers of the cost-effective sustainable technologies can increase their output when as frontrunners; they sell their technology to others because these technologies benefit the users. Actions of these innovators have a positive effect on productivity. Though the benefits of higher productivity may not always outweigh all costs of the sustainable technologies, they certainly do add to the positive welfare effects of impacts prevention. Thus, sustainable technologies have positive effects on productivity and welfare.

Environmental-Economic Debate

The productivity effects of sustainable technologies have been a subject of ongoing debate. As the productivity effects of sustainable technologies are considered to be negative within the mainstream view, the justification of their use is found primarily in their contribution to lower environmental costs. However, given the imperfect monetization of environmental impacts, negative effects on welfare are usually observed. In this train of thought some scholars assume that the sustainable technologies are insufficiently effective in protection of environmental qualities and advocate lower productivity alongside fair income distribution entailing de-growth and better environmental qualities. Within the heterodox viewpoints, there are no a priori positions in favor of or against sustainable technologies because they depend on technological and managerial performance. Empirical economic studies show hardly any impacts of sustainable technologies on productivity when compared with other factors of production, such as labor costs or market opportunities, mainly because the costs of sustainable technologies are low compared with the processing technologies. The material-intensive producers who suffer from the high costs of sustainable technology reduce environmental impacts by changing production technologies; for example, reducing greenhouse gases by substituting coal for natural gas. As know-how is generated over time, suppliers develop cheaper and more effective sustainable technologies, e.g., substitution of gas for renewable energy. Sales of the cost-effective sustainable technologies contribute productivity and use of them to welfare, labeled as “first mover effects.” The cost-effective sustainable technologies evolve into parity with conventional technologies, while retaining the benefit of lower environmental impacts, as is experienced with the renewable energy business.

Costs

Below are basic concepts in business economics, linked to cost assessments.

Total Cost Assessment

Three main cost categories are usually pinpointed in the total cost assessment of the use of sustainable technologies: direct (usual) costs, indirect (hidden) costs, and societal (liability) costs (White et al., 1992). Direct costs address the production process. These costs are recorded in management accounts. The indirect costs refer to sustainable technologies. They are partly hidden in the direct costs and partly unrelated to the specific process units. Process-integrated technologies require cost allocation between process and sustainable technologies. Add-on technologies need cost allocation when they can prevent impacts at several process units. The rules for cost allocation are normative; the conventional rule is the main impact indicated by use of material resources, or by externalities such as pollution measured in physical terms. The societal costs are when a firm is made liable for environmental impacts. These are potential costs related to insufficient impacts prevention as perceived by society, for example, potential payment for discharge of hazardous waste if insufficiently prevented. If liability is not incurred, the societal costs are intangible. The liability assessments depend on interests that are external to business, that is, whose accounts are not known to the firm's management. The external interests refer to authorities that can delay permits for production and penalize pollution, to customers that can revise their list of suppliers, to environmental organizations that boycott products, and promote competitors and so on. Management experiences with liabilities in the past make for poor predictors because policies and stakeholders demand change. Businesses often perceive high liabilities. This perception would explain the higher rate of compliance with the environmental policies than what is expected based on enforcement of policies, because the chance of persecution and penalties are low (even negligible in many countries). Liability assessments are usually about the chance of liability multiplied by potential costs of offense or damage, which is usually a very low chance times high costs, for example, in cases of oil spills in the sea. Process-integrated sustainable technologies can add to the indirect costs and save on societal costs, for example, fire retardants in materials prevent fires at additional costs, or they can save the direct costs, e.g., energy-efficient boiler. The add-on technologies often cause higher indirect costs but save on societal costs, for example, a dust filtering on boilers reduces health hazards of employees and neighbors. When liabilities are insufficient, society bears environmental impacts. These are rarely considered in the total cost assessments even if the impacts are monetized as environmental costs.

Fixed and Variable Costs

The costs of many sustainable technologies are hardly recoverable because they remain in place over a long period of time; that is, their costs are sunk, meaning investments and purchases are made and cannot be recovered. A typical depreciation period as prescribed in the rules of taxation across many countries in the world is 15–25 years for civil work, 5–10 years for electromechanical equipment, and 2–5 years for electronic equipment; civil work being the largest expense. Annually depreciating costs are capital costs and the purchase costs after subtraction of the capital costs give us book value. Many sustainable technologies have nil book value because equipment is kept after the depreciation period, for example, sewerage pipes are kept for many decades. Authorities, herewith, are often the asset owners and decision makers about liabilities. Being the owners, many authorities prolong the life time of equipment because they do need to fear liabilities. Hence, the decision making is usually biased in favor of the obsolete technologies, and incentives for adoption of the novel sustainable technologies in the public market are low. In effect, the societal costs of the obsolete sustainable technologies, meaning the potential costs of liabilities, are often underestimated. Labor, energy, chemicals, and maintenance are typically variable components that cause the operational or running costs. Sum of capital and operational costs is the total cost. The capital costs of sustainable technologies are usually above two-third of the total costs throughout their life time. The total costs exclude the societal costs, and the environmental costs after all pollution treatment.

Marginal Costs

The total costs of a sustainable technology are usually expressed as the cost of achieving performance, for example, X cost of Y impacts prevention. This performance is usually expressed for each process unit. The impacts prevention, herewith, often consists of several compounds expressed as equivalents of one compound, for instance, carbon dioxide equivalents for the greenhouse gasses. The total costs divided by the total impacts prevention is the marginal (unit) cost, also known as cost-effectiveness. It is:

$$c_r = \frac{C_t}{E_t} \tag{2}$$

where c_r is the marginal cost of impacts prevention; $C_t = C_c + C_o$ is the total cost (i.e., the sum of capital and operational costs); E_t is the equivalent of total impacts prevention.

When far reaching impacts prevention is demanded, additional sustainable technologies must be used. For instance, if the anaerobic wastewater treatment is insufficient for compliance with the demanded pollution reduction, aerobic wastewater treatment can be added to the process. When several processing units are involved various sustainable technologies can be used, which constitute an inventory of technology–process combinations. The inventory can be, for example, various energy saving technologies at different households. The costs in an inventory can be described by the marginal costs of additional impacts reduction. These are used for assessing costs of policies aimed at attaining an impact reduction target. The total cost of the inventory should be assessed consecutively for every process–technology combination in ascending order of the combinations' marginal costs. However, in practice, the average costs of several technology–process combinations are often reported, which usually provides an unrealistically low costs of the impacts prevention.

Cost Escalation

For decision making, it is convenient to assume that the lowest marginal costs of impacts prevention are found at the largest process units because decision makers can focus on the use of sustainable technologies at the large scale units. This assumption is widely used in cost-engineering: the marginal costs increase exponentially as impacts are prevented at the additional, smaller process units. Having deficient knowledge about sustainable technology at various process units, marginal costs of that technology are escalated based on a few illustrative processes.

$$\alpha = \ln\left[\frac{(c_j/c_i)}{(E_j/E_i)}\right] \tag{3}$$

where $c_{i,j}$ and $E_{i,j}$ are the marginal costs and total emission reduction, respectively, at the illustrative technology–process combinations.

The escalation factors, arrived at empirically, are 0.2–0.8; the low escalation factor meaning that marginal costs of additional impacts prevention increase slowly. The cost escalation can hold good only when one type of sustainable technology is used in the technically similar processess; for instance, anaerobic wastewater treatment in large breweries. In reality, many factors influence costs and impacts. For example, the costs of flue gas desulfurizing (one sustainable technology), at a large scale fireplace (one scale) in a coal heated power plant (one primary process) for electricity (one product), also depends on capacity utilization, fuel quality, distortion of operations, volume of vent gas, and other factors. Cost-engineering models simulate the marginal costs caused by such variables, but reliability is low when the models are irregularly verified with the empirical data. A radical departure from this method of escalating costs is the assumption that the data on marginal costs in an inventory of technology–process combinations is stochastic. Based on this assumption, the steepness of the marginal cost can be estimated in an inventory based on a few empirical data and probability distribution between them. The marginal costs at the specific combinations, however, cannot be estimated (Krozer, 2008).

Profitability

In general, investments in technologies should generate product sales that provide income after subtracting the costs of sales. If the present value of income covers the investment, profit is made. In the profitability assessments, income is discounted during the period of technology use at an interest rate that reflects the costs of capital which takes into consideration inflation, availability of savings and funding, aspirations of profit, among other factors. Investments in the use of sustainable technology do not generate income. Nonetheless, the profitability of alternatives that attain similar impacts prevention can be compared. Incremental analysis is applied, while the lowest investment alternative provides the baseline. The incremental investments and incremental annual costs are calculated, and then discounted in order to obtain the incremental net present value after subtracting investments. The highest incremental net present value is the preferable alternative, which indicates the highest profitability. When alternative sustainable technologies with varying lifespans are compared, their present values are annualized for the comparison into the uniform annual stream, often abbreviated as annuity. If not, results can be biased in favor of the technology with the shorter lifespan. The sustainable technology is usually capital-intensive, meaning the fixed costs cover the largest part of the total costs; sometimes nearly all costs, for example, waste disposal on landfills. Hence, the annualized investments are often used for comparing alternatives, but the total costs throughout the lifetime remain underestimated in such decisions.

Benefits

The benefits of sustainable technologies are discussed from the private and public perspectives.

Transaction Surplus

Technology suppliers and users may share joint interests in transactions, but their perspective on the costs and benefits differs. The suppliers' sales mirror the users' investment costs, which must be covered by the users' sales. The suppliers generate profits if the present value of income exceeds all costs that are necessary for the supplies. An adopter, a purchasing user, must generate cost-savings, in comparison with the available technologies on markets, and its installed technology during its remaining lifespan. User benefits are attained when the incremental net present value of an alternative during that lifespan is positive. The net benefits of transactions are sum of the suppliers' profits and users' benefits, also called 'Surplus' or 'Rent':

$$NPV_u = \overset{\text{Supplier perspective}}{\left[\sum_{t=1}^{n}(V_s - C_s).r_s^{-t} - I_s\right]} + \overset{\text{User perspective}}{\left[\sum_{t=1}^{n}(C_u - C_i).r_u^{-t} - \Delta I_u\right]} \tag{4}$$

where V_s is the value of sales; C_s is the cost of sales; I_s is the supplier investment; r_s is the supplier interest; t is the lifespan of the installed technology; C_u is the cost of using a new technology; C_i is the cost of using the installed technology; r_u is the users' interest; and ΔI_u is the users' incremental investment.

This holds good for the sustainable technologies, but implementation is laborious. In economic theory, technology should be replaced when the present value of its capital and operational costs during its remaining lifespan is higher than the present value of supplied alternatives during that lifespan. "Bygone is bygone investment" is a conventional teaching of economics in reference to the technology replacement, even if recently installed and profitable. However, several imperfections in the replacement of sustainable technologies are widely observed. Firstly, newly supplied sustainable technologies are generally costlier than their earlier versions because suppliers add qualities. This addition is justified by liabilities for environmental impacts. Since organizations are generally risk averse, this motivation works. The consequences are that purchases become more costly for users and the diversity of technology alternatives decrease. It is markets that generate quasispontaneously a few dominant suppliers. This is enhanced by standards of quality for all suppliers, imposed by the associated market interests and authorities to safeguard from market entry of the substandard rivals and environmental impacts. Secondly, imperfections emerge when the costs of installed technologies are sunk. Given the sunk costs, substitution for more cost-effective sustainable technologies is attractive only if it safeguards from liabilities. If this risk is low because the penalty or chance of liability is low, then there is little incentive for purchasing sustainable technologies. The sunk costs of the installed technologies impede the entry of sustainable technologies entailing the use of obsolete, ineffective sustainable technologies.

Cost–Benefit Assessment

Sustainable technologies can be costly to some private interests but beneficial to others, for example, wastewater treatment is a cost to an industry but enables tourism to generate income. Hence, the private costs and benefits across all interests involved need to be assessed for decision making about large investments. Hence, the social costs and social benefits should be known, including the intangible costs and benefits, for instance the ones of future generation. Cost–benefit assessment is a method assumed to provide objective results, for example, about infrastructural projects. The most attractive sustainable technologies are those that generate the highest net present value of the benefits; in case of project alternatives with different lifespan, it is the highest annualized net benefit. Since the assessments address the far future, it is not surprising that the data on costs and benefits are often deficient. The costs generally increase during implementation because unforeseen elements must be added entailing costs overruns post the implementation period, and benefits of the sustainable technologies of that moment are often disappointing because market demands change and cost-effective alternatives are introduced. Even if accurate calculations are made based on high quality data, assessments can be biased. Some interests perceive a project as a benefit, while others' standing (of the same) deem it as a cost, for example, tax payers and tax spenders. The standing and distributional effects differ, but often, they are not reported. Costs and benefits should be assessed from the standpoint of the final decision maker, and in consideration of distribution. Discounting is yet another bias that might occur. Firstly, the present value of costs and benefits reduce to nil in the long run, favoring projects with a short lifespan. Secondly, benefits are usually generated with a time lag, after the costs are made. This underestimates the total benefits of long lifespan assets, for example, the benefits of a nature reserve. Various techniques for monetization of environmental qualities and impacts are far from perfect but not discussed because they are indirectly related to the sustainable technologies. The general difficulty for decision making is that all methods express social conventions about environmental quality and impacts at that moment, entailing a large gap between articulation of the benefits and actions after a while when the assessments are used (Kahnemann and Knetsch, 1992).

Market Benefits

Benefits of sustainable technologies include the private benefits in the form of lower costs in production and value added in consumption (Krozer, 2015). Several types of benefits can be observed. The first type of benefits in production refers to the saving of direct costs. This can be achieved due to lower energy and material use, slower equipment depreciation, better maintenance, better management of the primary process, and so forth. The second type of benefit in production is related to policy demands for the impacts reduction. These demands generate markets of sustainable technologies that reduce impacts along with lower indirect costs and societal costs, popularly labeled as "pollution prevention pays." Sustainable technologies in consumption can also generate benefits. The third type of benefit refers to the consumer products. The environmental friendliness of products is perceived as a private benefit, for example, healthy and tasty. It is also considered to be a social benefit, for example, fair and natural. The fourth type refers to staying close to nature, which is expressed in sustainable tourism, wellness, and other outdoor activities. It reflects the growing leisure time and interest in environmental amenities. The fifth type of benefit refers to the cultural expressions of environmental qualities. This benefit is expressed on markets of art, media, and in cultural industries. All these benefits put together constitute a large market value of the sustainable technologies entailing numerous profitable activities.

Qualities

Theories on price and quality assessments of sustainable technologies are presented later.

Views on Market Prices and Qualities

In mainstream economics, market transactions determine quality assessments of products. The train of thought is that consumers purchase the preferred product qualities at higher prices than the less preferred ones. The relative prices are indications to suppliers about the consumers' preferences for the supplied product alternatives. Given the consumers' preferences, market prices generate transactions that reflect the suppliers' marginal costs and the consumers' marginal benefits. Optimal transactions are achieved unless they are distorted by imperfect competition, including cartels, criminals, and mistaken interventions by authorities. This viewpoint implies that suppliers will use the sustainable technologies if consumers are willing to pay an additional price for preventing environmental impacts entailing lower environmental costs. Low use of sustainable technologies on markets indicates low consumers' preference for environmental qualities. The heterodox argumentation is focused on the supply chain of product qualities. In the supply chains, suppliers use material, capital, labor, and knowledge resources for compounding qualities into products that are delivered to customers at sales prices that cover all costs and profits. The suppliers also dispose waste that causes environmental impacts. In each step, product qualities change, costs increase, and environmental impacts enlarge. The suppliers are also purchasers of qualities compounded by the previous suppliers, and they are consumers of technologies as expressed by depreciation of the capital goods. The final purchasers are the consumers. Consumers also use resources, for example, electricity; depreciate technologies called consumer goods, for example, cars, and they dispose consumed materials, that is, household waste. Prices are determined by the total costs and profits in supply chains, also called value chain, within the framework of the consumer's income and quality preferences. The consumers' preferences, in this viewpoint, are determined by known social conventions and individual habits. The total costs in supply chains and consumption, including costs of sustainable technologies, constitute the life cycle costs, which indicates the prices. The risks of environmental impacts also accumulate in value chains, because societal costs and unpriced environmental impacts add up in the chain. The perceived risks of impacts generate demands for sustainable technologies.

Asymmetric Information

Market prices can be assessed equally well by suppliers and customers, however, not the product's qualities. The suppliers' and customers' access to information about the qualities is asymmetric in every step of the value chain. Suppliers can get information about the customers' quality perception because the latter have an interest in supplies that are tuned to their preferences. The suppliers, however, have no interest in delivering reliable information unless they are liable for deviation from the customers' specifications. Customers have deficient information about qualities compounded into products by suppliers, as well as about sustainable technologies used for supplies, societal costs, and unpriced environmental impacts of the supplies—all of which is available to the suppliers. This asymmetry in information between suppliers and customers implies that customers have deficient information about the supplied product qualities. Given the customers' income, the supplied qualities are primarily determined by prevailing conventions, habits, morals, hypes, and other cultural expressions within supply chains. When a sense of urgency for better environmental qualities is expressed and awarded, sustainable technologies are supplied and purchased despite high costs; otherwise even cheap ones are rejected. The costly purchases are then justified by prevention of risks with regard to the cumulated societal costs in the products' life cycle. Within this framework, the suppliers aim to differentiate their deliveries from competitors. The cultural expressions of deliveries, called branding, vary from selfishness to altruism, largely depending on the social mechanisms for awarding behavior. These expressions can be divided into two quality categories: functionalities and ethical attributes. The former refers to the practical uses of products, such as durability and weight. The latter addresses social interests, such as environmental quality and fairness. Branding fosters sales of sustainable technologies that enable to resolve trade-offs within and between these quality categories. These are perceived as credible by stakeholders, and thus gain sales (Krozer, 2015).

Information Assessment

Given the asymmetric information in every step of product life cycles, chances are high that product qualities deviate from stakeholders' preferences. Various methods aimed at mitigating these deficiencies are introduced. Some methods aim to assess the suppliers' reliability. There are two approaches. The first approach is tracking record of the suppliers' outputs, for example, revenues or customer satisfaction. The second one is the suppliers' inputs, for example, successful ideas or research expenditures. Having a limited track record is usually considered to be poor quality, but the contrary is often observed because newcomers aim to satisfy customers at their best and high inputs do not guarantee good results. The content is also assessed through product tests. Some testing methods address resource uses, for example, energy analyses. Other methods assess impacts, for example, toxicity. Some assessments compare products' life cycles with one another; others use targeted performance as a basis for comparison. External expertise is often involved in such life cycle assessment. This involvement aims to mitigate biases but the choice of experts and interpretation of expertise cannot avoid biased favorites. Given the risk-avoiding behavior of organizations, it is observed that mediocre qualities are favored. The highly performing but unconventional qualities are usually neglected because they are considered to be uncertain. Evaluations do not resolve much, but do add to administration. Asymmetric information is an unsolvable issue if one strives for the symmetry between suppliers and customers. A radical departure from this objective is advocated by some scholars on entrepreneurship. They argue that the information asymmetry enables entrepreneurial action because suppliers of the novel qualities can accrue competitive advantages, due to imperfect customer knowledge about all product qualities. From this perspective, sustainable technologies are opportunities for suppliers because enable sales of services aiming at cost-effective prevention of the societal costs.

Product Circulation

Sustainable technologies can prolong the longevity of products and materials used in the economy due to better product design, maintenance, recycling, and so on, termed the "circular economy." The price of the products' lifespan, herewith, depends on three cost components: capital, operational, and societal costs. The capital costs of long-life products are lower because these products depreciate over a longer period. The lower capital costs must outweigh the additional capital costs of compounding qualities for a longer lifespan, for example, design of more durable product designs. The operational costs of long-life products are lower because they need less maintenance and repair. A longer life of products, however, impedes the entry of novelties which can be cost-effective alternatives. The societal costs and unpriced environmental impacts of long-life products are lower because less supply is needed and there are fewer disposals after consumption. The product's life cycle costs should be compared with the uniform annualized costs because the lifespans differ. Presently, the first and second cost components are in favor of the short lifespan products; this is with regard to the shortening time-to-market of new products. Hence, the circular economy largely depends on the third cost component. This one reflects liability risks. Long-life products are attractive when the societal costs are high, that is, producers risk liability. Recycling is attractive when products and materials are refurbished for sale and reuse; direct disposal is the alternative. When aiming for the lowest market price, the sale of the recycled products and materials (after subtracting the total recycling costs) must be higher than the disposal costs. With decreasing real material prices, as observed throughout the last two centuries, either the costs of recycling must decrease at a faster rate than the prices decrease, or the disposal costs must increase faster. Hence, recycling is also largely dependent on liability risks. The disposal usually concentrates materials on an area or dilutes them with the aim of reducing environmental impacts caused by the material's dissipation. High liability risks for the dissipation lead to more costly disposal, which can compensate for recycling costs. To summarize, the circular economy largely depends on liabilities for the environmental impacts caused by waste disposal.

Demands

In what follows, the effects of demand for environmental qualities on technology development are addressed.

Innovation in General

In the mainstream view, market demands induce innovations. The mechanism is that demands change relative market prices, which trigger competing businesses to develop technologies that satisfy demands at lower costs than the competitors' costs. The innovation process is comprehended as investments in subsequent phases, under uncertainties. Research generates ideas. However, it may be found out later in time that the ideas are wrong. Designers invent novelties, but deficiencies in designs can be revealed over time. These are the technology-related uncertainties in the phase of research and development. When successful, these phases deliver invention. The invention must be proven during demonstration projects, but the results can disappoint potential customers. Pilot production can deliver product qualities, but at high costs. Finally, expansion aims at sales while demands can change. These are the market-related uncertainties in the market introduction phase, also called business development. The successful process delivers innovation. The chance of success increases at every step as do the costs. Innovations emerge when suppliers generate profits and users net benefits, called innovation-rents. This demand-pull model also applies to the development of sustainable technologies. The additional uncertainty is that market prices of environmental qualities are deficient. Herewith, it is usually assumed that authorities demand reduction of environmental impacts, which trigger development of sustainable technologies; this is usually supported with subsidies (Jaffe et al., 2002). The enforcement is based on direct regulations that reduce impacts through permits, or market-based regulations through taxes, fees, liabilities, subsidies, and other instruments that put a price on the impacts. Economists generally recommend market-based instruments. These instruments would invoke more cost-effective sustainable technologies because it would be beneficial to prevent impacts beyond the maximum, as defined by permit. However, the regulations are usually based on permits and the regulatory market-based instruments are rarely enforced. It is also argued that the stakeholders' negotiations about prevention of environmental impacts would not need regulations because the negotiators would reach optimal solutions, that is, most beneficial to all interests involved independent of their initial situation. The optimal solution would be achieved if the individual negotiators are free in their private decision making and the transaction costs of all negotiators are negligible, as it is with trading on auctions. When the negotiators harbor vested interests, these negotiations usually postpone implementation at high transaction costs. Empirical findings suggest that the stakeholders' negotiations cause higher costs and less impacts reduction than regulations.

Policy Making

In practice, the aim of policy making is to define reasonably achievable targets valid for all process units of a particular business. What is reasonably achievable is based on sustainable technologies that are proven and available at that particular point in time, because they have been developed prior to regulations. This development is set in motion when environmental impacts have been acknowledged, in policymaking, as harmful; which is several decades before the regulations. For regulatory purposes, the sustainable technologies taken into consideration are those whose performance is demonstrated at a few process units assumed to be illustrative of processes in the selected business. These, so-called best available technologies, are supposed to reduce impacts below the average marginal cost of all available sustainable technologies, at that particular moment, for that specific business. The best available technologies are set as the minimum standard for impacts reduction. The advantages of such technology standards are that companies receive blueprints for compliance with the policy demands and that the regulations are easier to enforce than measurements of environmental impacts caused by every process unit. After the technology has been demonstrated, innovators must make provisions for a waiting period until the regulations are approved by political decisions, several years later. Sales are uncertain because the innovators fail if their sustainable technology performs below the standard; they also fail when the technologies overshoot the standard at additional costs because an additional impacts prevention is not rewarding. Even though markets created by the authorities' demands are large, the waiting period and uncertainty of sales are deterrents that render innovating for environmental demands generally unattractive.

Decision Making Model

Business deliberation involves the use of the best available technologies to comply with legal requirements, or innovations aiming to anticipate future requirements. The marginal costs of compliance are low when the level of control demanded by the authority is low, but they run the risk of exponentially increasing costs when additional impacts prevention is demanded. Businesses that anticipate more stringent environmental demands must spend on costly technology development or advance innovative purchases, even before the regulation is put in place and without the guarantee of its successful use when enforcement is lax. However, they stand to benefit from low costs, and even incomes and competitive advantage, when more impacts prevention is demanded. When far reaching demands are expected, the anticipation strategy is cheaper than that of having to comply with available technologies. The uncertainty about the authority's future demand for cleaner methods of production impedes innovation. This model of decision making helps underpin sound conditions for development of sustainable technologies. This development does not solely depend on policy, not even on the instruments of policy, but on the stringency of social demands, decisive enforcement, and high business capabilities. Firstly, businesses must sense an urgency for the anticipation strategy, that is, a clear need for the impacts prevention. Hence, the demands must be tangible, not far away in future. The second condition is one wherein far reaching environmental demands are envisaged. Thirdly, the need for a decisive authority that announces enforcement well in advance, so as to reduce uncertainties about innovating into sustainable technologies. Fourthly, businesses must have the freedom to develop and choose the technology they will apply to meet demands. Fifthly, businesses must be able to raise funds for innovations, which implies that substandard performers may lose competition. Finally, the sixth condition is that businesses must be able to go ahead with the innovation process, that is, they must be able to generate know-how about the policies and technologies (Krozer, 2008).

Changes

Innovations and adaptations for sustainable development are discussed later.

Sustainable Development

The World Commission on Environment and Development focused international attention on the issue of how to make global economic systems compatible with the sustainability of the planet's life support systems. This UN report led to a veritable explosion of publications in virtually all disciplines, on the topics of current and future patterns and practices of economic development. With regards to business decision making, the concept of sustainable development was refined into the managerial process so as to balance economic, social, and environmental interests; branded as the "Triple Bottom Line." This refinement is more an approach to raise consciousness, rather than an analytical one. It inspired a broadening of the accounting framework with social and ecological dimensions expressed in a wide range of sustainability indicators; as well as in managerial practices with social and environmental performance as criteria for corporate social responsibility. The assumption underlying the concept of sustainable development is that the use of sustainable technologies can reduce environmental impacts by way of substitution of material resources for capital, labor, and knowledge. Sustainable technology, herewith, is the cornerstone of sustainable development; innovating sustainable technologies is referred to as sustainable innovations. When the surplus from cost-savings generated by the lower material use and environmental impacts is allocated into value adding activities with low environmental impacts, then lives supporting environmental qualities are made available for welfare growth. Decreasing environmental impacts per income evolved globally throughout the last century. This process of decoupling income from environmental impacts is observed, but several mechanisms impede fast progress. One such impediment is when additional income generates activities that increase environmental impacts. This rebound effect can be exemplified in the case of electricity saving bulbs that can trigger more lighting hours. The rebound effects enlarge when activities are geared toward material-intensive uses entailing more impacts, and decline when material-extensive activities grow, such as with the use of services and images. A second impediment is when more expenditure is required for countering the impacts. Such defensive expenditures are generally higher than the impacts prevention, for example, the expenditures on health injuries caused by air pollution usually exceed the costs of air pollution controls. Thirdly, consumption patterns change when income generates novel expenditures or when the population composition changes; for instance, spatial mobility grows faster than income and elderly people need more medical treatment than youngsters, respectively. New consumption patterns release certain environmental impacts while aggravating others. Also, new issues emerge when environmental impacts surpass the adaptive capabilities of the environmental qualities and when new harmful impacts are observed, for example, noise and light impacts on the migration of species. The emerging issues absorb the surplus without reducing other environmental impacts.

Barriers for Sustainable Innovations

Sustainable innovations reduce environmental impacts at a social net benefit when they substitute the installed technologies. However, this substitution is obstructed when suppliers' networks are vested because they operate as a system. The replacement of the system for an apparently superior one poses the risk that suppliers have to be tuned into each other. This replacement involves additional transaction costs and takes on the risk that the system's performance is deficient during a period of time. The costs and risks of a change-over to a new system reinforce decisions in favor of the vested networks, entailing a costly lock-in to a dominant system. These market-based barriers of entry for sustainable innovators increase when authorities appoint a network to uphold performance standards, as expressed in prevailing regulations. In addition, progress is obstructed by policy interventions that support rivals which cause large environmental impacts. These interventions are subsidies for use of scarce and polluting resources, for example, use of fossil fuels and water, concession for squandering minerals and space, entitlement for delays or exemptions of implementation, and others. All these provide advantages to the vested interests because their costs are reduced compared to the costs of sustainable innovations. The social costs of these interventions are substantial. Introduction of a sustainable innovation abroad is even more challenging because the innovators confront other performance standards and must overcome protectionist interventions, such as quality standards tuned to the context of local vested networks.

Adaptations of Sustainable Innovations

The performance of sustainable innovations is improved during their dissemination across various adopters. The dissemination, usually termed as diffusion, evolves during a period of time when many adaptations are made in supply and use. These adaptations throughout the diffusion period are known as learning. Several types of adaptations are observed. The first type is when suppliers execute research and development cost-effectively entailing better and cheaper inventions. The second type of adaptation is when the manufacturing costs of innovative products decrease because products, due to process standardization, are made in series. Herewith, the unit costs decrease as the fixed costs of manufacturing are covered by a larger output. The third type is when better quality products are delivered at a lower cost on account of improved operations. Users also adapt their performance. The fourth type covers better purchases of the manufactured products due to lower transaction costs and better purchase results. In this case, supplies are better tuned to the user system, which is often based on the users' recommendations made to suppliers. The fifth type of adaptation is when users improve their operation with purchased equipment. Adaptations are often formalized as a cost function of time as represented here:

$$C_t = C_1 - N_t^{-at} \tag{5}$$

where C_t is the marginal cost of cumulative production, sales, or use; C_1 is the initial marginal cost; N is the cumulative units; t is the year; and a is the factor learning.

The technological change, herewith, is expressed as an annual percentage of its cost-effectiveness. For instance, 20% more cost-effective supplies of solar panels means that the sales price decreases by 20% every year; or that its effect increases by that percentage of the given price.

Enhancing Sustainable Innovation

Having acknowledged the need for sustainable innovations, the emerging debate is about how to enhance them. Comprehension of the factors that drive innovations has changed throughout the last 50 years (Grübler et al., 2002). In the mainstream view, markets spontaneously prevent exhaustion of resources. This would happen because the large use of scarce resources generates high prices, which in turn would induce backstop technologies to substitute the scarce resources for less scarce ones. In this train of thought, innovations are induced by factors external to technology development, called exogenous factors. From this perspective, sustainable innovations can be considered as backstop technology for environmental impacts due to quasiprices imposed by the policy and social demands. Observations are that scarcities of natural resources do not automatically induce technological alternatives but sometimes to the contrary, they invoke more exploitation when prices rise. The evolutionary viewpoint is that technological changes are generated by the goal-oriented search for solutions and the selection of superior ones. These are driven by development of know-how. Know-how is generated at any resource scarcity and prices of materials though high prices enhance this development. In this view, know-how that generates innovations determines resource prices, rather than the other way around. Technological change is driven by internal technology factors, known as endogenous factors. Sustainable innovations emerge from the know-how on resolving environmental impacts. The endogenous factors are also pinpointed in the behavioral viewpoint, though focused on entrepreneurial capabilities in developing markets and technologies. The capabilities are generated through the exchange of know-how and the creation of arrangements forged to overcome barriers posed by vested interests. Thus, sustainable innovations emerge when societies sense an urgency to resolve environmental impacts, and entrepreneurs can overcome rent-seeking behavior of vested interests and policy entitlements for continuation of the dominant system. The debate remains inconclusive and observations signal mixed practices that strengthen and impede each other.

Conclusion

Progress in sustainable innovations is driven by the growing number of knowledge workers. In the last century, their share has grown from nil to a quarter of all labor in many countries. Types of innovators have also diversified. Hence, the mainstream idea of technology development in subsequent phases is challenged by innovations derived from knowledge interactions between scholars and practitioners; referred to as knowledge spillover. The use of know-how for innovations is comprehended as innovation networks with the participation of various types of sustainable innovators. Herewith, consumers generate the distributed sustainable technologies for energy, water, and recycling, referred to as "User Innovations." Artists and designers introduce sustainable technologies in clothing, housing, and creative industries, branded as the "Experience Economy." Small and medium size enterprises introduce sustainable foods, tourism, mobility, and so on, labeled as ecological and fair. Nongovernmental organizations develop nature, sports, and the media. Sustainable innovators in finance and insurance emerge as ethical investors. All of this is in addition to the traditional sustainable technology manufacturers and engineers. Welfare grows when more know-how is allocated in sustainable innovations because these generate lower environmental impacts along with a higher income. The relations between income and environmental qualities are being increasingly determined by sustainable innovators. Economics has no definite conclusion about sustainability. Nonetheless, it does underpin that sustainability is a feasible option for humankind, thanks to progress in sustainable innovations. Two conclusive messages can be drawn out from this development. The first is that innovation-driven welfare growth and environmental qualities are positively interlinked, they are worth pursuing despite frictions between social and private interests. These frictions are particularly forceful when innovators are suppressed by political oppression, and when entitlements to rent-seeking interests that harm environmental qualities are given. The second message is that the diversity of innovators pursuing private and social interests is the driving factor for sustainable development; not individual discoveries, engineering excellence, management performance, entrepreneurial spirits, or public money and regulations. Welfare can grow and environmental qualities can be secured when social capabilities are fostered through education, knowledge interactions, and perverse incentives are abolished.

Acknowledgments

I am grateful to Haynes C. Goddard for advisory contribution on sustainable development; Andries Nentjes and an unknown referee for comments; Allan White for being referee and Shonali Chenzira for editing.

See also: Environmental Management Systems—History and New Tendencies.

References

Grübler, A., Nakicenovic, N., Nordhaus, W.D., 2002. Technological change and the environment, resources for the future. Washington, DC.
Jaffe, A.B., Newell, R.G., Stavins, R.N., 2002. Environmental policy and technological change. Environmental and Resource Economics 22, 41–69.
Kahnemann, D., Knetsch, J.L., 1992. Valuing goods, the purchase of moral satisfaction. Journal of Environmental Economics and Management 22, 57–70.
Krozer, Y., 2008. Innovations and the environment, 1st edn. Springer, London.
Krozer, Y., 2015. Theories and practices on innovating for sustainable development, 1st edn. Springer, Heidelberg, New York.
Kuipers, S.K., Nentjes, A., 1973. Pollution in a neo-classical world: The classics rehabilitated? The Economist 121 (1), 52–67.
Pearce, D., Kerry Turner, R., 1990. Economics of natural resources and the environment, 1st edn. Harvester Wheatsheaf, Harlow.
White, A., Becker, M., Goldstein, J., 1992. Total cost assessment. EPA, Washington, DC.