

Author & Year	Application area, Country & Sample	Input variables	Output variables	Methodology	Conclusion
Arocena and Waddams Price, 2002	33 Spanish electricity generator (1984-1997)	Capital Labour Fuel	Undesirable – SO2 NOX Particulates Desirable – Annual net power produce	HE, Malmquist productivity index	Public coal powered generation plants were more efficient than those in the private sector under cost of service regulation.
Boyd and McClelland, 1999	146 Manufacturing plants-integrated paper mills, United States (1988 – 1992)	Capital stock Production worker Electricity cost Fuel cost Material cost	Undesirable – Air pollutant (Sox,TSS) Water pollutant (BOD, TSS) Toxics (Chlorine, Methane, Sulfuric acid) Desirable – Output value	DEA, HE	Win-win potential for inputs and pollution to be simultaneously reduces by 2% to 8% without reducing productivity.
Boyd et al., 2002	63 Glass industries, United States (1987 – 1990)	Labour Capital Stock Energy cost Material cost	Undesirable – Nitrogen oxide Desirable – Value of shipment	DDF, Malmquist Productivity Index	Technical change has contributed industry growth in productivity and environmental performance, and that efficiency made this productivity growth somewhat more rapid than would have occurred with the underlying technical improvements alone.
Brannlund et al., 1998	41 Pulp and paper industries, Sweden (1986 – 1990)	Labour Wood Fibre Electricity	Undesirable – BOD Chemical Oxygen Demand Suspended Solid Desirable – Production of pulp	Linear programming model of technology	This industry would have had up to 6% higher profit in 1989 if emissions trading had been used instead of individual permits to achieve the same total emission target.
Burnett and Hansen, 2008	Electric utility industry, United States : 84 Phase One plants (1990 – 1995) 164 Non Phase One plants (1990 – 1995)	Capital Fuel Cost Operating Cost	Undesirable – SO2 Desirable – Kilowatt-hour	DEA	Lower polluting plants are relatively more efficient, both cross-sectionally and longitudinally. The support for the porter hypothesis is reinforced by evidence consistent with the use of new and innovative fuel blending technologies to reduce SO2.

Choi et al., 2012	30 provinces, China (2001 – 2010)	Capital Labour Energy	Undesirable – CO2 Desirable – GDP	DEA,SBM	The economically well-developed east area evidences better CO2 emission efficiency than the other two regions, whereas the west area, with the lowest level of economic development, evidences the lowest CO2 emission efficiency.
Chung et al., 1997	39 Paper and pulp industries, Sweden (1986 – 1990)	Labour Wood fibre Energy Capital	Undesirable – BOD Chemical oxygen demand Suspended solid Desirable – Production	DDF, MLPI	This technique (DDF) provides individual plant-specific information on productivity and its sources without requiring data on prices of inputs and outputs.
Domazlicky and Weber,2004	Inorganic chemical industry, US (1988 – 1993)	Labor Capital	Undesirable – Toxic air emissions Toxic water emissions Toxic land emissions Toxic underground emissions Desirable – Value added	DDF	Accounting for toxic chemical releases, productivity grows at an annual rate of between 2.4% and 6.9%. No evidence that environmental protection measures reduce productivity growth.
Färe et al., 1989a	30 pulp and paper mill in US (1976)	Capital Labour Energy	Undesirable – BOD TSS SO2 Particulates Desirable – Output of paper	HE	Performance rankings turned out to be very sensitive to whether or not undesirable outputs were included.
Färe et al., 2005	209 electric utilities in US (before 1993 and after 1997)	Labor Generating capacity fuel	Undesirable – SO2 Desirable – Electricity generated	DEA, quadratic DDF	Policy makers could benefit from knowing how much of the emission reductions could be met from enhanced efficiency and what the shadow cost is of reducing emissions further to meet the target.
Färe et al., 2006	US agricultural sector (1960 – 1996)	Land Labour Capital Material inputs	Undesirable – Leaching Runoff Desirable – Crops	DDF	The pollution costs from the runoff and leaching of pesticides are 6% of crop and animal revenues and are highest in the Midwest and lowest in the Western states.

Färe et al., 2007	92 coal-fired power plants (1995)	Capital Employees Heat content of the coal, oil, and natural gas	Undesirable – SO ₂ NO _x Desirable – Net electrical generation	DDF	The maximum good output production associated with the environment production function is slightly higher than the maximum good output production of the environmental directional distance function.
Ke and Hu, 2011	15 OECD countries (1995 – 2003)	Labour Capital	Undesirable – CO ₂ Desirable – GDP	DDF, MLPI	Developed economies have higher productivity if CO ₂ emission is not considered in the Malmquist index. Since developed economies face stricter CO ₂ abatement obligations, they have lower productivity than developing nations if the CO ₂ abatement is taken into account in the Malmquist Luenberger index.
Kumar Mandal, 2006	20 cement industry, India (2000 – 2005)	Capital Energy Labor Raw material	Undesirable – CO ₂ Desirable – Cement products	DEA	Energy efficiency estimates are biased if only desirable output is considered. Environmental regulation has a reinforcing effect on energy use efficiency.
Kumar Mandal and Madeshwaran, 2010	20 cement industry, India (2000 – 2005)	Capital Energy Labor Raw material	Undesirable – CO ₂ Desirable – Cement products	DDF	There is enough potential for the industry to improve its environmental efficiency with efficiency being varied across states. Indian cement industry, if faced with environmental regulation, has the potential to expand desirable output and contract undesirable output with given inputs.
Lee et al., 2002	8 coal-burning & 9 oil-burning plants of the Korea Electric Power Corporation (1990–1995)	Nameplate Capacity Fuel heat Labor	Undesirable – SO NO _x Desirable – Electricity generation	Shadow price, DDF	The shadow prices of pollutants depend upon the employed efficiency rule and whether or not the production/environment inefficiency is taken into account, under the condition of ceteris paribus.
Lozano and Gutierrez, 2008	28 states in US (1990 - 2004)	Population	Undesirable – Energy consumption Greenhouse gas Desirable – GDP	DEA, DDF	Reasonable GDP growth rates are compatible with significant reductions in GHG emission levels and higher level of GDP could be attained if GHG consumption were reduced instead of increased.

Lu and Lo, 2007	31 Regions, China (2001)	Capital stock Labour	Undesirable – SO2 Industrial soot Industrial dust Desirable – GDP	DEA, monotone decreasing transformation	The regional development disparities in China not only arise because of economic imbalance, but they still exist after taking into consideration the environmental deductions.
Picazo-Tadeo et al., 2005	35 Spanish ceramic tile producers (1995)	Clay, kaolin, feldspar & limestones Labour Capital	Undesirable – Watery muds Used oil Desirable – Ceramic pavements	DDF	When firms face environmental rules preventing free disposal of bads, their potential to increase desirable output by behaving efficiently is largely affected.
Picazo-Tadeo et al., 2012	55 Olive industry, Spanish (2010)	Erosion Pesticide risk Energy	Undesirable – CO2 Desirable – Net income	DDF	Eco-inefficient management is a widespread practice among olive farmers. A win-win strategy in which environmental pressures are reduced at the same time as net income is increased is feasible in Andalusian olive growing.
Riccardi et al., 2012	21 world cement industry (2005 – 2008)	Capacity Energy Labor Clinker Import clinker Raw materials	Undesirable – CO2 Desirable – Cement products	DEA, DDF	The inclusion or the exclusion of undesirable output (CO2) influence efficiency levels as well as the investments in new technologies and the utilization of alternative fuels and raw materials in the cement and clinker production processes.
Scheel, 2001	13 Selected European economies (1997)	Labour	Undesirable – NOx Desirable – GDP	DEA, output oriented BCC model	Additive inverse yield equivalent efficiency classifications, while the multiplicative inverse or a weak disposability assumption yield smaller sets of efficient DMUs.
Seiford and Zhu, 2002	30 Paper mills production, United States (1989)	Fiber Energy Capital Labour	Undesirable – BOD TSS Particulate SOx Desirable – Paper produced	DEA, linear monotone decreasing transformation	Using the classification invariance property, the standard DEA model can be used to improve the performance via increasing the desirable outputs and decreasing the undesirable outputs.

Song et al., 2012a	4 main regions (1998 – 2008)	Labor Capital Energy	Undesirable – Industrial waste gas Industrial waste water Industrial solid waste Desirable – GDP	Hierarchical cluster analysis	A downtrend in efficiency is found for all four regions with efficiency value the biggest for the East, bigger for the Northeast, less for the West and the least for the Central.
Song et al., 2012b	Domestic production efficiency (1995 – 2009)	Fix asset investment Industry employment population	Undesirable – SO2 Desirable – GDP	DEA-SBM	The new model's computing conclusions are highly related to the efficiency assessment of the DEA-SBM model, and it has a greater focus on the affects of undesirable outputs on production efficiency than the latter, which means that this new model has a greater extensive value for application and provides a better quantitative theoretical basis for environmental policy analysis.
Taskin and Zaim, 2001	49 countries (1977, 80,85,90)	Labor Capital	Undesirable – CO2 Desirable – GDP	Non parametric non stochastic production frontier	After accounting for the effect of changes in per capita income level on environmental efficiency, there remains some variation in environmental efficiency that can be captured by trade related variables
Telle and Larsson, 2007	4 Industries, Norway (1992 – 2002) : 144 Pulp and paper 70 Primary aluminum 105 Ferro alloy	Labour Capital Intermediate input	Undesirable – Greenhouse gas Acid Desirable – Output	Malmquist productivity index, Malmquist index	When using a measure of productivity growth that accounts for emissions, a positive and significant relationship between regulatory stringency and productivity growth have been found.
Tone and Tsutsui, 2011	30 electric utilities, US (1996 – 2000)	Total generation capacity Fuel consumption	Undesirable – SO2 NOx Desirable – Nonfossil power generation Fossil power generation	Hybrid efficiency measure	The utilities had improved their overall management and environmental efficiency between 1996 and 2000.
Tyteca, 1997	48 Fossil-fired electric utilities, United States (1991)	Installed capacity Coal Oil Gas Labour	Undesirable – SO2 NOx CO2 Desirable – Electricity generation	DEA	If a single appraisal of the polluting effects of the discharges is to be accounted for, then a simple model or the simplest version of the DEA model that do not include the effects of input use, might be preferred.

Watanabe and Tanaka, 2007	219 provinces in China (1994-2002)	Labour Capital Material	Undesirable – SO2 Desirable – Industrial value added	DDF	Omitting undesirable output (sulfur dioxide) results in biased estimates of industrial efficiency.
Wang et al., 2012	28 provinces, China (2001 – 2007)	Capital Laour Energy	Undesirable – CO2 Desirable – GDP	DDF	When desirable outputs are adjusted to the optimal level, some provinces have still the possibility to further reduce CO2 emission. About half of the provinces is found to be in the status of high incoordination between environment and economy.
Wang et al., 2012b	30 regions, China (2000 – 2009)	Capital Laour	Undesirable – CO2 SO2 Desirable – GDP	DEA	East China has the highest and the most balanced energy and emission performance. The energy and emission performance of China remained stable during 2000-2003, decreased slightly during 2004-2006, and has continuously increased since 2007.
Weber and Domazlicky, 2001	48 states in US (1988-1994)	Labour Capital	Undesirable – Total emission Desirable – State manufacturing output	DDF	Measuring economy-wide productivity growth using a source-of-growth or a cost-function approach found a negative impact of environmental regulation and PAC expenditures on measured productivity growth.
Wu et al., 2012	28 provinces, China (1997 – 2008)	Capital Labor Energy	Undesirable – CO2 Desirable – Value added	DEA	The energy efficiency improvement in China's industrial sector was mainly driven by technological improvement.
Yoruk and Zaim, 2008	28 OECD countries (1983-1998)	Capital Labour	Undesirable – CO2 NOx Organic water pollutant Desirable – GDP	DEA, distance function(environmental performance index)	Some industrialized and well-developed countries are ranked among the worst in terms of their environmental efficiency. International regulations are reported to have a positive effect on environmental performance.
Zaim and Taskin, 2000b	25 OECD countries (1980, 1985, 1990)	Labour Capital stock	Undesirable – CO2 Desirable – GDP	DEA	If the disposability for CO2 emissions were strictly restricted as the result of an environmental regulation, 10% reduction in CO2 emissions is feasible for only nine out of 25 OECD countries while 1% reduction is feasible for 16 countries.

Zha and Zhou, 2009	28 provinces in China (1995-2005)	Capital Energy Labour	Undesirable – Industrial waste solid Industrial waste water Industrial Sulfur dioxide Desirable – Industrial gross output	DEA, DDF	There exist significant differences in environmental efficiency scores across provinces. The central and western regions are less environmentally efficient during the time series versus the east.
Zhang et al., 2008	30 Industrial systems provinces, China (2005)	Water resource Raw mining resource Energy	Undesirable – Chemical Oxygen Demand Nitrogen SO2 Soot Dust Industrial solid waste Desirable – Value added of industry	DEA	Provinces with higher level GDP per capita will have higher eco-efficiency.
Zhang, 2009	30 provinces in China (2004)	Labour Capital	Undesirable – Waste gas emission Desirable – Industrial output	DEA , DDF	Both environmental and technical efficiencies have the potential to be greatly improved in China, which may provide some advice for policy makers.
Zhou and Ang, 2008a	8 world regions and OECD country (2002-2004)	Energy consumption	Undesirable – CO2 Desirable – GDP	DEA, malmquist productivity index, Shephard output distance function	Production-theoretical decomposition analysis (PDA) can decompose a change of aggregate CO2 emissions over time into seven contributing factors. The factors can be obtained by DEA.
Zhou et al., 2006	30 OECD countries (1998 – 2002)	Total primary energy supply Population	Undesirable – CO2 Desirable – GDP	Slacks-based environmental performance	Two slack based efficiency measures for modeling environmental performance could reasonably incorporate all the input excesses and output shortfalls in a standardized efficiency score.
Zhou et al., 2008	8 world regions : OECD, Middle East, Former USSR, Non-OECD Europe, China, Asia, Latin America, Africa (2002)	Total energy consumption	Undesirable – CO2 Desirable – GDP	DEA	In some circumstances it may be difficult to compare some DMUs only by the proposed EPI because of the weaker discriminating power of radial DEA efficiency measures.

Zhou et al., 2007	26 OECD countries (1995 – 1997)	Labour Primary energy consumption	Undesirable – CO2 SO NO COX Desirable – GDP	Non-radial DEA, non-radial malmquist environmental performance index	Non-radial DEA-based model has a higher discriminating power than radial ones in environmental performance comparison.
Zofio and Prieto, 2001	14 manufacturing industries of OECD countries (1990, 1995)	Labour Net stock	Undesirable – CO2 Desirable – Manufactured production	DEA, output distance function, hyperbolic output distance function	The calculation of lower and upper limits for each observation enables to calculate the cost of any regulation given that it is greater than the lower limits.