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Original Research

Assessing the Green Growth Trajectory through Resource and Impact Decoupling Indices: The Case of Poland

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Abstract

This paper uses the most appropriate measures and data sources to map the likely growth delinking of Polish economy for the period 1990-2016. Evidences of green growth exist and were assessed both qualitatively and quantitatively. This paper also examines the likely policy implications by means of cross-correlation analysis. The results indicate that Poland can be conceptualized as a successful paradigm prescribed by the ecological modernization theory since growth is not associated with human pressure on natural resources and does not produce detrimental environmental impacts.

Keywords: green growth, decoupling, de-linking, cross-correlation, Poland

Introduction

The received wisdom in the scholarly literature perceives economic growth and the environment as antagonistic domains [1]. The rationale behind such a claim unfolds as follows. To accomplish and sustain environmental quality, through prudent management and conservation, requires resources, the scarcity of which is *prima-facie*. Then, if a society decides to divert scarce resources from the production of goods and services, it will eventually need to sacrifice some growth possibilities. In turn, growth produces waste that further deteriorates environmental quality. Simply put, it is a clear vicious cycle, which only slows down by accepting the inexorable trade-off between growth and environmental quality. The range of approaches that focus on such an inherent and irrevocable conflict are known as the "the treadmill of production" (TP) [2]. Gould et al. [3] provide a detail account concerning the theoretical underpinning and the conceptual development of "the treadmill of production".

Lately, however, there has been a burgeoning strand of the literature, which argues that economic growth may evolve in a disengaged pattern, imposing little or no damage at all to the environment. Such a

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contention originates from one of the leading theories in environmental sociology, namely the "ecological modernization" [4]. In brief, ecological modernization stresses that it is not always the case that the "economic rationale" dominates the "ecological rationale". Evidence for such a claim can be traced, *inter alia*, on the emergence of environmental protection and conservation policies, the rise of green movements and NGOs and the spread of environmentally friendly technologies. All those are landmarks that epitomize the "institutionalization of the environment" as Mol [5] argues. In addition, at least in the advanced industrial societies, the last thirty years there has been a notable shift towards "post-materialist values" [6]. Therefore, the increasing emphasis put on "buzzwords" such as recycling, the increase of resource efficiency and circular economy reflects the cultural shift associated with ecological modernization [7, 8]. In brief, the main themes behind the ecological modernization's optimism are the technological improvements and environmental governance [9].

The concept of decoupling refers to the breaking of the trade-off between economic growth and the resulting environmental pressures associated with producing economic goods and services [10]. The UNEP's International Resource Panel (IRP) distinguishes between the two types of decoupling, namely the resource one and the impact one [11]. In particular, when economic growth proportionally reduces input use then we have resource decoupling, whereas when it reduces the negative environmental impacts we have impact decoupling. Resource decoupling improves resource efficiency and in so doing, helps the alleviation of a (likely) resource scarcity and the resulting (resource) price volatility. Likewise, impact decoupling reduces the cost of externalities and hence improves social welfare. In the case where resource decoupling coexists with impact decoupling the process in known as a "double decoupling" [11]. Decoupling can be classified as absolute if economic growth increases at a higher rate than the decline of the environmental impact [12]. Likewise, if economic growth rises at a higher level than the increase of environmental impact, the situation is termed relative or weak decoupling [13].

The analysis of de-linking growth and environment often focuses at a national level, see Conrad and Cassar [14] and Liang et al. [15]. However, other options are possible. Li et al. [16] examine the link between agricultural growth and pollution in a specific Chinese region. This is an example of sectoral or regional analysis. Some other times a cross-country analysis attracts the scientific interest. Wu et al. [17], for example, compare different groups of countries (developed vs developing) to examine whether growth and energy consumption follow similar paths of change. Also, Chovancová and Vavrek [18] present a European cross-country comparison of resource and impact decoupling for the energy sector.

A special case of decoupling may result in a situation termed green growth. The latter characterizes country where the long-run increases in the gross domestic product coexist with the enhancement of natural capital and the improvement of environmental quality [19]. The rigorous conditions whether and how a country could achieve a "green" optimal growth path is explored by Smulders et al. [20]. However, Ward et al. [21] argue that decoupling may not be possible concerning the material and energy use. Also, Hickel and Kallis [22] are skeptical whether green growth is possible at a global scale.

The empirical application of this paper uses Poland as a case study. Poland has made remarkable progress in reducing the environmental impacts of economic growth as well as surpassing the requirements of the Kyoto agreements [23]. Specifically, over 2000-2012 the GHG emissions rose just by 1% compared to the 56% rise in GDP, whereas the carbon intensity (CO_2 emissions divided by energy consumed domestically) has fallen by 5% against the 54% increase in GDP between 2006 and 2015 [24]. In an assessment of decoupling using consumption-based environmental indicators, Poland is classified as absolute decoupler among the EU-28. Specifically in the period 2004-2011, Poland is a peculiar case since it has achieved a 40% increase in GDP while accomplishing an 80% reduction in the weighted indicator of environmental impacts [25]. At the same time, Poland remains an important polluter not only due to its persistence to use coal in the energy sector but also due to intensive investments in road network, which substantially facilitate vehicles'' transport and hence contribute to greenhouse gases emissions. In particular, concerning the particulate matter (PM10), Poland is among the worst cases in Europe, see Carratù et al. [26]. Fugiel et al. [27] list Poland among the worst cases regarding the release of GHG for the mining and quarrying sectors in Europe. Taking into account the majority of pollutants, Poland is classified among the dominant European polluters along with Germany, Italy, Germany, UK and Spain see Kolasa-Więcek and Suszanowicz [28]

Beyond descriptive analysis, we intend to trace the decoupling of Poland's economy during a period of 27 years after the transition to the market economy by means of the state-of-the-art indicators provided by the literature. Moreover, we attempt to relate the decoupling trajectory in Poland to major institutional events that occurred in order to draw policy implications.

The structure of the paper is as follows. The next section, namely the Material and Methods, presents the measurement of decoupling and the data used. Section 3 discusses the results, while Section 4 examines the policy implications. The brief conclusions are given in Section 5.

Material and Methods

The Measurement of Decoupling

Elaborating on socio-economic phenomena requires simple and continuous measures to assess and map their evolution [29]. Such measures enable the comparison between regions/countries or across time for the same regional unit. This section draws on a recent axiomatic approach to decoupling indices proposed by Tarabusi and Guarini [12]. The exposition equally applies to resource and impact decoupling indices.

Assume a region or a country at a time, t, and consider a proxy of economic prosperity, G_t, i.e. Gross Domestic Product (GDP), and the level of human pressure on the environment, E_t. The ratio of these two gives the environmental intensity of growth, $T_t = \frac{E_t}{G_t}$ [30], for which the rate of change is given by:

$$\delta = \Delta T = \frac{T_t - T_{t-1}}{T_{t-1}} \quad (1)$$

In turn define $\varepsilon = \frac{(E_t - E_{t-1})}{E_{t-1}} = \frac{E_t}{E_{t-1}} - 1$ and $\gamma = \frac{(G_t - G_{t-1})}{G_{t-1}} = \frac{G_t}{G_{t-1}} - 1$. By inserting these into (1) yields $\delta = \frac{\varepsilon + 1}{\gamma + 1} - 1$.

Two are the main versions of (1) that can be found in the scholarly literature. The first one is due to OECD, which proposes the following formula [31]:

$$D_o = 1 - \frac{E_t / G_t}{E_{t-1} / G_{t-1}} = -\delta \quad (2)$$

Empirical applications of (2) can be found in Conrad and Cassar [14] and Yu et al. [32]. The second one put forward by Tapio [33], which reads as:

$$D_e = \frac{\varepsilon}{\gamma} \quad (3)$$

D_e has a straightforward interpretation as the elasticity of environmental pressure with respect to economic growth. It is found in Zhou et al. [34], Zhang et al. [35] and Tang et al. [36].

According to Tarabusi and Guarini [12] the main problems associated with D_e are: a) unstable estimates when growth is close to zero; b) inability to distinguish between green growth and brown de-growth and c) inability to differentiate green growth since it is unclear whether high or low scores of the index are preferred. On the contrary, D_o is not limited by the previous problems but display some different shortcomings. These are: a) metric inhomogeneity, which means that different values in the inputs may not yield different values in the index; b) similar values for absolute and relative decoupling; and c) non-cumulativeness, the metric violates such property, which requires that the value for a specific period equals the sum of values for the sub-periods.

Tarabusi and Guarini [12] attempt to overcome these disadvantages by proposing the following index:

$$D_P = \frac{1}{c} \log \frac{2 + \tanh c\hat{\gamma} - \tanh c\hat{\varepsilon}}{2 - \tanh c\hat{\gamma} + \tanh c\hat{\varepsilon}} \quad (4)$$

...where the tanh, stands for the hyperbolic tangent, while $\hat{\varepsilon}$ = log (1 + ε) and $\hat{\gamma}$ = log (1 + γ). In line with Tarabusi and Guarini [12], the value of the parameter c is taken to be one. Note that the D_p does not suffer from any of the problems associated with the other indices while it has all the desired properties [12].

In what follows, we use the concept of ecological deficit to capture the human pressure on inputs and to construct the resource-decoupling index for Poland. Likewise, the amount of Greenhouse Gases (GHG) emissions released is taken as a proxy for the analogous human pressure on the environment, which will allow us to construct the impact-decoupling index.

Data Used: Ecological Deficit and Greenhouse Gases Emissions

The estimation of the resource-decoupling index was based on the concept of Ecological Deficit/Reserve. The latter is the ratio of Ecological Footprint (EF) over the Biocapacity (BC). EF is a measure of how much area of biologically productive land and water (BPLW) a country requires for sustaining its lifestyle and consumption pattern [37]. BPLW refers to the land and water (both marine and inland waters) that supports significant photosynthetic activity and the accumulation of biomass used by humans. EF represents a way of quantifying the total human pressure on the natural environment [38]. The total pressure refers to the amount of resources directly or indirectly consumed and to the resources needed to absorb the generated waste.

The biocapacity (BC) of a country represents its ability to renew the resources consumed by its inhabitants. Biocapacity may fluctuate from year to year due to climate and human management. BC refers to the capacity of ecosystems to regenerate what people demand from those areas. BC, as well as EF, are measured with an accounting unit known as "global hectares" (gha). The latter is necessary since there are considerable regional variations in land productivity, which without harmonization would have produced biased results. Therefore, both EF and BC scaled with the appropriate yield and equivalence factors are converted to world average biologically productive land called "global hectares" [39].

Because trade is global, a country's Footprint includes land or sea from all over the world. Without further specification, EF generally refers to the Ecological Footprint of consumption (EF_C). The link between EF_C and the Ecological Footprint of Production EF_P is:

$$EF_C = EF_P + \underbrace{\left(EF_I - EF_X\right)}_{Net-Trade} \tag{5}$$

...where EF_I is the ecological footprint of imports and EF_X stands for the ecological footprint of exports. The difference between the BC and EF_C of a region (or country) defines the concept of ecological deficit (EDF) when $BC<EF_C$. On the contrary, the case that $BC>EF_C$ defines the concept of ecological reserve (ER). The incidence of an EDF implies that the region is importing biocapacity through trade or liquidating regional ecological assets, or emitting wastes into the global commons. Sometimes EDF and ER are defined as ratios [40]. Then:

$$\begin{cases} BC > EF_C \Rightarrow \dfrac{EF_c}{BC} < 1 \quad reserve \\ BC < EF_C \Rightarrow \dfrac{EF_c}{BC} > 1 \quad deficit \end{cases} \tag{6}$$

Data concerning the EF_C and the BC were derived from the Global Footprint Network [41]. Likewise, for the estimation of the impact decoupling index we used GHG data drawn from OECD [42]. GDP and the GDP_{PC} data were derived from the OECD as well. Table 1 presents the summary statistics of the data used.

From the p-values of the Anderson-Darling Statistic in Table 1 we cannot reject the normality assumption of the variables EDF, GPP_{PC} and GDP but we can reject the normality of GHG emissions.

Case Study Poland

Since 1989, Poland has moved from a centrally planned economy to a parliamentary democracy with a market-oriented economy. That explains why the available economic data starts from 1990. The collapse of the economy during the transformation period in the early 1990s was followed by stable development, perhaps best evidenced by the average exports growth rate, which in the period 1994-2008 reached over 13% per year. In the last 30 years, Poland's exports have increased more than tenfold in real terms. Despite the uninterrupted development of the Polish economy as measured by GDP growth (in the period 2004-2015 Poland's cumulative growth amounted to 59.4%, which was the second best result in the EU), no increase in air emissions has been observed, let alone the emissions of some pollutants, namely the carbon dioxide, have actually declined [43]. That was possible mainly through technological changes in Polish industry [44, 45]

An important step towards systemic changes concerning resource decoupling is the "Roadmap for the transition to a circular economy" adopted by the Polish government in September 2019 [46]. The document contains a set of measures, including legislative ones, which aim to implement a new economic model based on sustainable industrial production and consumption as well as appropriate management of renewable raw materials. Greenhouse gas (GHG) emissions in Poland have been relatively stable since 2010 and range from 10.2 in 2014 to 10.9 tonnes per capita in 2017, which comes close to the OECD average of 10.6 tonnes per capita in 2017. According to the last available data, the largest share of greenhouse gas emission in Poland is carbon dioxide (81.3%), whereas the sector most responsible for greenhouse gas emission is the energy one (82.7%) [47]. World-Bank [48] advises Poland to invest in cleaner energy and transport and to review the tax/subsidy schemes in energy in order to reduce its dependence on fossil fuels. Moreover, the increasing

Table 1. Summary statistics of the basic indicators examined.

	EDF	GHG	GDP_{pc}	GDP
N of cases	27	27	27	27
Minimum	2.127	279.259	10,140.860	2.108E+011
Maximum	2.482	349.101	27,361.784	5.734E+011
Median	2.248	302.800	16,755.782	3.490E+011
Arithmetic Mean	2.284	309.097	17,801.241	3.720E+011
Standard Deviation	0.118	22.149	5,495.853	1.159E+011
CV	0.052	0.072	0.309	0.312
Anderson-Darling Statistic	0.765	1.294	0.497	0.503
p-value	0.041	<0.01	>0.15	>0.15
Pearson Correlation with GDP_{pc}	0.021	-0.753	1	na

energy demand and the aging energy infrastructure force the Polish energy sector to go through significant transformations [49]. The replacement of these plants presents an opportunity to reduce air pollution and carbon emissions by shifting to cleaner sources. Thus, perspectives for green growth are there, the pace depends on the implementation of targeted measures.

Results and Discussion

Assessing the Type and the Degree of Decoupling

The starting point to examine the likely decoupling of a country is to map the evolution of the economic growth and the human pressure on the environment. Fig. 1 does that in the case of Poland for the period 1990-2016. The time-span of the analysis was dictated by the data availability.

Since there are substantial differences in the scales and the units used to measure the Gross Domestic Product (GDP), the Ecological Deficit (EDF) and the GHG emissions, it is not particularly meaningful to include them in a single diagram. However, what is interesting is to examine their relative evolution. To this end, all data were divided by their initial value, so what is included in the relevant Fig. 1 is the specific pattern of how these phenomena have evolved in the period 1990-2016.

Fig. 1 portrays a general picture of decoupling economy for the period 1990-2016. However, we need some specific criteria to assess and characterize the degree of decoupling and the likely incidence of green growth. To this end, by merging the rationales of Yu et al. [32] and Tarabusi and Guarini [12] we compile the decoupling criteria in the Table 2.

Table 2. Decoupling Criteria.

Type of Decoupling	Condition
Absolute decoupling or green growth	$\gamma>0>\varepsilon$
Relative decoupling	$\gamma>\varepsilon>0$
Coupling or brown growth	$\varepsilon>\gamma>0$
Brown de-growth	$\varepsilon>0>\gamma$

Applying the above criteria for the entire period, by setting the starting point to 1990 and the end-point to 2016, Fig. 1 points to the case of green growth if the impact-decoupling is concerned since the 2016 GHG emissions point lies below the parallel line to horizontal axis drawn at 100. By the same reasoning, Fig. 1 depicts the case of relative decoupling if the resource decoupling is taken into account. However, it is noteworthy to stress that assessing the performance of a specific period depends not only on the initial and final scores of the involved variables, but also the chosen time step is crucial, especially for multimodal distributions. If the time step had been 5 or 10 years, then presumably another table would have been produced, reaching a different assessment. Hence, for the sake of transparency and avoiding the perils of aggregations, Table 3 adopts the annual step to report the results. In doing so, it is possible to map the evolution path of country's decoupling.

From Table 3 it is evident that the green growth characterizes the majority of the years (14/26 or 53,8%)

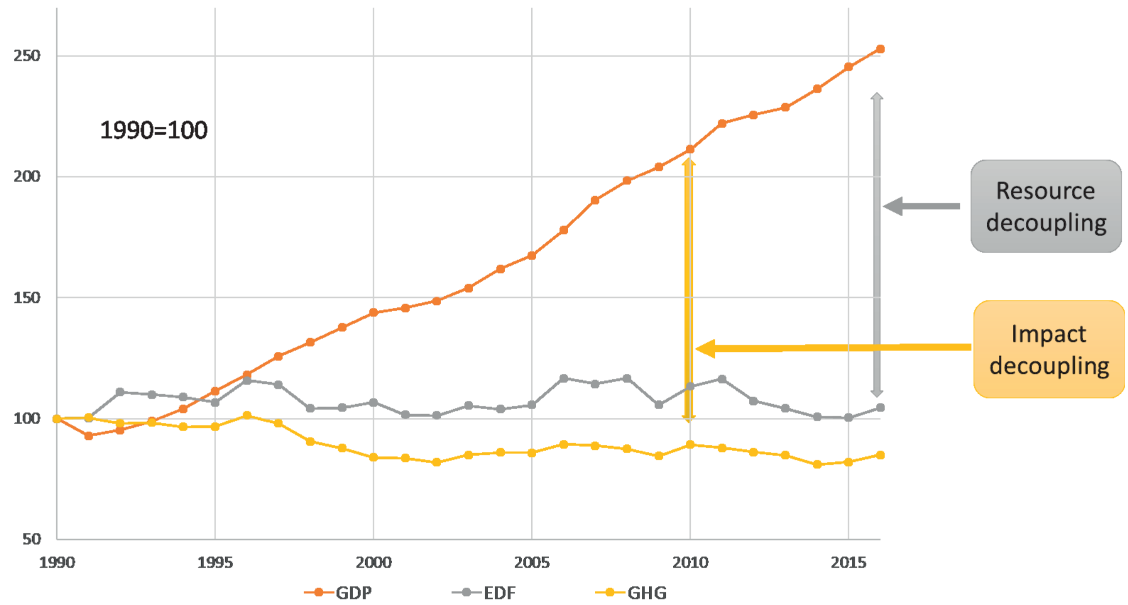


Fig. 1. Poland's growth-environment decoupling over 1990-2016.

Table 3. The Poland's path to green growth for the period 1990-2016.

	Decoupling type		
Period	Resources	Impact	Double
1990-1991	Brown degrowth	Brown degrowth	
1991-1992	Coupling	Green growth	
1992-1993	Green growth	Relative decoupling	
1993-1994	Green growth	Green growth	YES
1994-1995	Green growth	Relative decoupling	
1995-1996	Coupling	Relative decoupling	
1996-1997	Green growth	Green growth	YES
1997-1998	Green growth	Green growth	YES
1998-1999	Relative decoupling	Green growth	
1999-2000	Relative decoupling	Green growth	
2000-2001	Green growth	Green growth	YES
2001-2002	Green growth	Green growth	YES
2002-2003	Coupling	Coupling	
2003-2004	Green growth	Relative decoupling	
2004-2005	Relative decoupling	Green growth	
2005-2006	Coupling	Relative decoupling	
2006-2007	Green growth	Green growth	YES
2007-2008	Relative decoupling	Relative decoupling	
2008-2009	Green growth	Green growth	YES
2009-2010	Coupling	Coupling	
2010-2011	Relative decoupling	Relative decoupling	
2011-2012	Green growth	Green growth	YES
2012-2013	Green growth	Green growth	YES
2013-2014	Green growth	Green growth	YES
2014-2015	Green growth	Relative decoupling	
2015-2016	Coupling	Coupling	

either using the resource-decoupling or the impact-decoupling index. Although both criteria result in the same total score, the composition of this score is different. The incidence of double green growth (resource and impact) is present in 10 cases, that is 38.5%. This is a remarkable accomplishment since it is often suggested as a key element for achieving sustainable development [50].

In turn, the analysis moves on to the estimation of the decoupling indices presented in section 2.1 in order to empirically assess their suitability in characterizing decoupling. Table 4 gives the estimates for the resource-decoupling index.

Table 4 shows that different indices produce different rankings of the decoupling between growth and ecological deficit in the examined period. This is also evident from the last three columns in Table 4, where the pairwise differences in the rankings produced by these indices are presented. However, the scientific validity of such a claim can demonstrated with the use of a similarity index [51]. A well-known similarity index is the Ruzicka similarity index (RSI) (or Weighted Jaccard) which reads as:

$$RSI = \frac{\sum_i \min\{x_i, y_i\}}{\sum_i \max\{x_i, y_i\}} \tag{7}$$

In line with Warrens [52] we apply (7) to the normalized data from Table 3. If two vectors are

Table 4. Indices for the resource decoupling (growth- ecological deficit) for Poland (1991-2016).

							Rank Difference		
Period	Do	Rank	Dε	Rank	Dp	Rank	Do-Dε	Do-Dp	Dε-Dp
1990-1991	-0.0786	25	-0.0415	12	-0.0143	25	13	0	-13
1991-1992	-0.0791	26	4.2250	1	-0.0144	26	25	0	-25
1992-1993	0.0448	11	-0.2429	17	0.0086	11	-6	0	6
1993-1994	0.0588	10	-0.1704	15	0.0114	10	-5	0	5
1994-1995	0.0844	4	-0.2980	20	0.0166	4	-16	0	16
1995-1996	-0.0231	22	1.4040	4	-0.0043	22	18	0	-18
1996-1997	0.0747	6	-0.2319	16	0.0147	6	-10	0	10
1997-1998	0.1269	1	-1.8761	22	0.0256	1	-21	0	21
1998-1999	0.0409	13	0.0772	11	0.0079	13	2	0	-2
1999-2000	0.0238	15	0.4532	10	0.0046	15	5	0	-5
2000-2001	0.0591	9	-3.7939	25	0.0115	9	-16	0	16
2001-2002	0.0230	16	-0.1506	14	0.0044	16	2	0	-2
2002-2003	-0.0048	20	1.1410	6	-0.0009	20	14	0	-14
2003-2004	0.0630	8	-0.2900	19	0.0123	8	-11	0	11
2004-2005	0.0170	19	0.4961	8	0.0032	19	11	0	-11
2005-2006	-0.0395	24	1.6782	3	-0.0073	24	21	0	-21
2006-2007	0.0843	5	-0.2819	18	0.0166	5	-13	0	13
2007-2008	0.0206	18	0.4951	9	0.0039	18	9	0	-9
2008-2009	0.1193	2	-3.3491	24	0.0240	2	-22	0	22
2009-2010	-0.0343	23	1.9840	2	-0.0063	23	21	0	-21
2010-2011	0.0210	17	0.5596	7	0.0040	17	10	0	-10
2011-2012	0.0927	3	-4.8594	26	0.0183	3	-23	0	23
2012-2013	0.0428	12	-2.1186	23	0.0083	12	-11	0	11
2013-2014	0.0650	7	-1.0243	21	0.0127	7	-14	0	14
2014-2015	0.0388	14	-0.0482	13	0.0075	14	1	0	-1
2015-2016	-0.0100	21	1.3359	5	-0.0019	21	16	0	-16

the same, then we have the maximum similarity, $RSI\ (x, y) = 1$. The results are: $RSI\ (D_0, D_\varepsilon) = 0.318$, $RSI\ (D_0, D_p) = 1$ and $RSI\ (D_\varepsilon, D_p) = 0.318$, which suggest that there is hardly any agreement between $D_0\&D_\varepsilon$ and $D_p\&D_\varepsilon$ while there is complete similarity between D_0 and D_p. As shown by [12] D_ε suffers from serious defects, especially when the γ and ε are close to zero. As a result, the merit of using D_ε is extremely constrained in our case study, since the values of γ are close to zero. By contrast, while the D_0 is not immune to problems, it is a much better index than D_ε. First, D_0 is a consistent index because negative values of the index indicate coupling, while positive values correspond to the cases of relative decoupling and green growth. Furthermore, D_0 seems to be a "monotonic" index since the majority of green growth cases have higher values than the relative decoupling cases. The only exceptions are the periods 1998-1999 and 1999-2000, which although are classified as relative decoupling, they possess higher rankings positions than some green growth cases (i.e., 2014-2015 and 2001-2002). Suffice to say the difficulty of D_0 to clearly distinguish the relative coupling from green growth has been previously proven by Tarabusi and Guarini [12].

Finally, the use of the theoretically appropriate index, namely D_p, produces identical ranking results with the D_0. Therefore, the inability to distinguish between green growth and relative decoupling is also valid for D_p. In turn, the analysis moves to the impact decoupling and the corresponding indices are presented in Table 5.

Table 5. Indices for impact decoupling (growth –greenhouse gas emissions) for Poland (1990-2016).

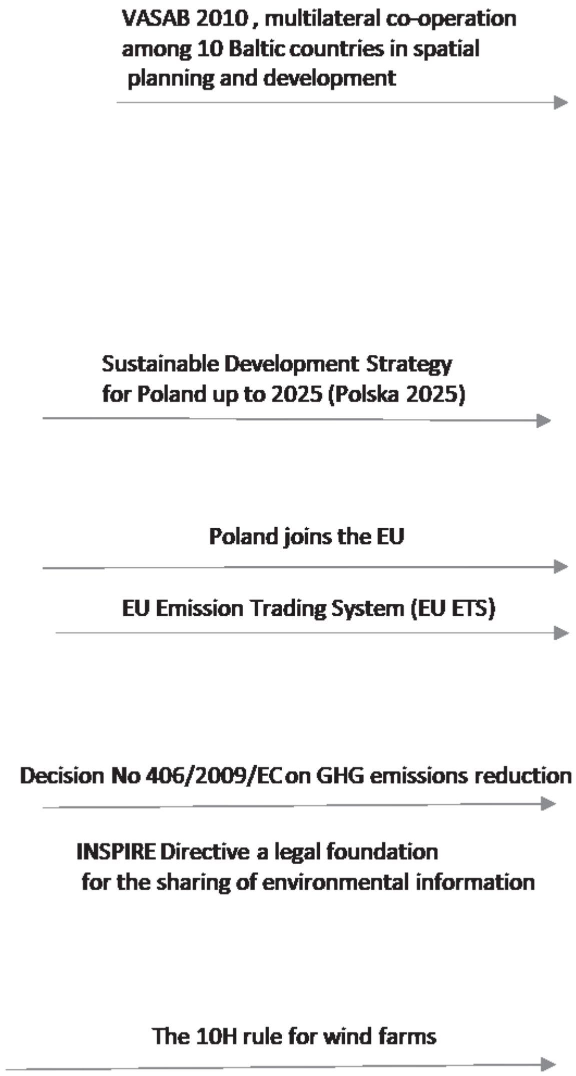
							Rank Difference		
Period	Do	Rank	Dε	Rank	Dp	Rank	Do-Dε	Do-Dp	Dε-Dp
1990-1991	-0.080	26	-0.060	11	-0.015	26	15	0	-15
1991-1992	0.048	12	-0.962	20	0.009	12	-8	0	8
1992-1993	0.033	17	0.082	8	0.006	17	9	0	-9
1993-1994	0.066	7	-0.321	15	0.013	7	-8	0	8
1994-1995	0.064	8	0.010	9	0.013	8	-1	0	1
1995-1996	0.013	22	0.781	4	0.002	22	18	0	-18
1996-1997	0.091	2	-0.497	17	0.018	2	-15	0	15
1997-1998	0.117	1	-1.655	26	0.023	1	-25	0	25
1998-1999	0.073	5	-0.641	18	0.014	5	-13	0	13
1999-2000	0.085	3	-0.957	19	0.017	3	-16	0	16
2000-2001	0.016	21	-0.263	13	0.003	21	8	0	-8
2001-2002	0.040	13	-1.023	21	0.008	13	-8	0	8
2002-2003	-0.002	23	1.045	3	0.000	23	20	0	-20
2003-2004	0.037	14	0.240	7	0.007	14	7	0	-7
2004-2005	0.035	16	-0.047	10	0.007	16	6	0	-6
2005-2006	0.021	20	0.645	5	0.004	20	15	0	-15
2006-2007	0.071	6	-0.082	12	0.014	6	-6	0	6
2007-2008	0.055	11	-0.361	16	0.011	11	-5	0	5
2008-2009	0.060	10	-1.190	23	0.012	10	-13	0	13
2009-2010	-0.018	25	1.524	1	-0.003	25	24	0	-24
2010-2011	0.061	9	-0.279	14	0.012	9	-5	0	5
2011-2012	0.036	15	-1.281	24	0.007	15	-9	0	9
2012-2013	0.029	18	-1.097	22	0.006	18	-4	0	4
2013-2014	0.076	4	-1.355	25	0.015	4	-21	0	21
2014-2015	0.025	19	0.322	6	0.005	19	13	0	-13
2015-2016	-0.006	24	1.213	2	-0.001	24	22	0	-22

Following the same procedure as previously, we obtain RSI (D_0, D_ε) = 0.349, RSI (D_0, D_p) = 1 and RSI (D_ε, D_p) = 0.349. These results are qualitatively identical to the ones in Table 4, hence no further comments are necessary. Presumably, the latter is also evident in the last three columns of Table 5, which display the relative differences in the resulting rankings. As in the previous case, the D_ε is very unreliable, since it is not possible to distinguish the cases based on the index's sign and/or value. Likewise, D_0 and D_p produce identical rankings but fail to separate green growth and relative decoupling. Nevertheless, the illusion that the D_0 and D_p may be "monotonic" indices, as it was implied in the case of resource decoupling, breaks down in the case of impact decoupling. The overriding issue that emerges from the comparison of Tables 4 and 5 is a repeat of the well-known aphorism "the choice of measure matters" [53].

An Attempt to Interpret the Trajectory of Poland's Decoupling

There are different reasons why an economy might decouple. One of them may be associated with the economic structural changes realized in that period. The latter may comprise increasing economic efficiency, or increasing efficiency in the waste management or both. For example, moving from resource-intensive low added-value economic activities, such as agriculture and mining to less resource-intensive economic activities in the service sectors, which create higher added value [54].

Table 6. Main environmental policies and the double decoupling incidences for the period 1990-2016.



period	Double decoupling
1990-1991	
1991-1992	
1992-1993	
1993-1994	yes
1994-1995	
1995-1996	
1996-1997	yes
1997-1998	yes
1998-1999	
1999-2000	
2000-2001	yes
2001-2002	yes
2002-2003	
2003-2004	
2004-2005	
2005-2006	
2006-2007	yes
2007-2008	
2008-2009	yes
2009-2010	
2010-2011	
2011-2012	yes
2012-2013	yes
2013-2014	yes
2014-2015	
2015-2016	

Another cause for decoupling may be the rationale of "pollution haven hypothesis", where the burden (polluting activities) is transferred to third countries that they follow less strict environmental policy [55]. So decoupling in such a case simply means that a country shifts from domestic production of goods to purchasing imported goods. By doing so, the use of resources and emissions are declining in the importing country but increasing in the exporting one.

However, Longhofer and Jorgenson [56] argue that it is rather difficult to identify a general mechanism that drives decoupling. In particular, behind decoupling there is often an intertwining set of heterogeneous agents, regulatory policies, endowments and organizational structures that vary considerably across countries. The links between these factors cannot trivially be transformed to policy advice.

In order to facilitate our understanding in Table 6, we insert on the timeline of Poland's trajectory to green growth (in particular the green growth cases that simultaneously identified by the resource and impact indices), the major European and national environmental regulations that might have influenced such a path.

According to Canales [57] the use of timeline is very common as a historical method/narrative. Notwithstanding, no causality links are implied, only educated guesses can be put forwards about the likely links.

The main policies inserted in the timeline are the following. First, the mechanism for the dissemination of environmental information in the region of the 10 Baltic countries agreed on 1992 (known as VASAB 2010) [58]. Second, the long term strategy for sustainable development (known as Polska 2025) [59]. Third, the EU membership in 2004 [60]. Fourth, the launch of the EU emission trading scheme in 2005 [61]. All the above reflect various elements of Poland's commitment towards sustainable development.

Perhaps, the double decoupling of the period 2012-2014 could be attributed to the pressure exercised by two events in 2009: the European

Parliament Decision No 406/2009/EC to reduce GHG emission and commitment of Polish government to report environmental information, and hence being accountable, in terms of INSPIRE directive [62].

Yet, in 2016 the Polish government introduced the 10H rule, which provides that the minimum distance between the wind farm and residential buildings is to be 10 times the turbine height [63]. In practice, due to the dispersed development of large areas of Poland, the rule led to the collapse of investments in previously dynamically developing renewable energy sources. The restrictive institutional setting and the imposed burdens it brings to investments is sufficiently discussed by Hajto et al. [64]. Furthermore, aaccording to Dawid [65], the Act on Wind Energy Investments, make new wind farm investments almost impossible.

Finally, the decarbonisation of the economy, which is an emerging policy priority for the European Commission, will be of key importance for green growth and decoupling in Poland. Research shows that the decarbonisation pathway of the Polish economy will not only lead to a significant decrease in CO_2 emissions but will also result in lower electricity production costs in 2015-2050 by approximately 15% in comparison to the baseline pathway [66].

While the decoupling indices (Tables 4 and 5) and the green growth mapping (Tables 3 and 6) are useful tools for ex post characterizing growth incidences, it is rather difficult to draw any policy implications since nothing can be inferred about the likely drivers behind those ranking. To this end, we attempt to examine the likely policy implications, by means of cross-correlation, in the next section.

Drawing and Discussing the Policy Implications

This section tries to examine the likely causality between the GDP_{pc} and the EDF and GHG emissions in terms of the Environmental Kuznets Curve (EKC) hypothesis, in order to discuss any policy implications that could emerge [67]. Against the conventional wisdom, we opt for a cross-correlation (CC) as opposed to the regression analysis that dominates the EKC literature. The CC is a common method for estimating the association of two time-variant events over some time intervals, by shifting time (time reversal) and repeatedly calculating the correlation between current values in one vector with the past (or future) values in another vector. Essentially, a sequential match of measurements is selected from each time series such that both vectors contain the same number of occasions, and then the Pearson correlation is calculated for these two vectors [68].

The typical CC coefficient between the proxy of economic prosperity, G_t and the level of human pressure on the environment, E_t can be written as [69]:

$$CC_{E_tG_t}(k) = \frac{\sum_{t=1}^{n-k}\left(G_t - \overline{G}\right)\left(E_{t+k} - \overline{E}\right)}{\sqrt{\sum_{t=1}^{n-k}\left(G_t - \overline{G}\right)^2\left(E_{t+k} - \overline{E}\right)^2}} \quad (8)$$

...where $t = 1,...,\ n$ indicates time and k the number of lags. Also, $\overline{G}$ and $\overline{E}$ stand for average values. If $k = 0$ then the $CC_{E_tG_t}(0)$ is the synchronous correlation between the variables (the Pearson correlation coefficient). By contrast, when $k = 1$ the $CC_{E_tG_t}(1)$ refers to the correlation between G_t and E_{k+1} (lead or future value), while if $k = –2$ the $CC_{E_tG_t}(–2)$ stands for the correlation between G_t and $E_{k–2}$ (lag value). If $CC_{E_tG_t}(k) \neq 0$ for k>0, then past values of G_t are helpful to forecast variation in the values of E_t. Otherwise, if $CC_{E_tG_t}(k) \neq 0$ for k<0, we can say that past values of E_t are helpful to forecast variation in the values of G_t. In the special case under which $CC_{E_tG_t}(k) \neq 0$ for both k>0 and k<0 we have bidirectional causality [70].

Such a modeling choice is justified on the grounds of three independent arguments. First, in the scholarly literature there is a notorious lack of consensus concerning the appropriate explanatory variables to be examined in the EKC hypothesis (see for Stern [71] and Gassebner et al. [72]). Second, there is a confusing plethora of regression models and estimation techniques (see Narayan and Smyth [73], Jobert et al. ([74], Pérez-Suárez and López-Menéndez [75] and Abdouli et al. [76]). And third, there is a cumbersome problem, namely the issue of multi-collinearity (see Narayan and Narayan [77]) which when ignored, results in biased and unstable estimates [78, 79].

While procedures for estimating the CC coefficients are available in most commercial econometric software, the issue is not covered in the popular textbooks, see for example Hamilton [80] and Lütkepohl [81]. A noteworthy exception is Neusser [70]. For the purpose of this analysis, we follow the recent methodological postulate by Narayan et al. [82] which says that positive lag cross-correlations, $CC_{E_tG_t}(k<0)>0$, and negative future cross-correlations, $CC_{E_tG_t}(k>0)<0$, means that the value of the environmental index, E_t, will decline with an increase in the economic index G_t. Shahbaz et al. [83] use this procedure to examine the link between globalization and energy consumption.

Table 7 presents the results for the cross-correlations results for Poland in the examined period. To avoid spurious correlations all data series were de-trended using the Hodrick-Prescott filter. Minitab® has chosen the appropriate number of lags.

According to Narayan et al. [82] the static nature of the estimates in Table 7 does not provide any guidance about the future association between the examined variables. The development of their rationale requires aggregating these estimates. Table 8 does that, by presenting the sum of correlations and the average correlations from Table 7.

Table 7. Cross correlation results.

Lags/Leads	GDP_{pc}&EDF	GDP_{pc}&GHG
-15	0.005	0.291
-14	0.084	0.227
-13	0.166	0.156
-12	0.250	0.079
-11	0.332	-0.002
-10	0.411*	-0.087
-9	0.481*	-0.174
-8	0.539*	-0.263
-7	0.580*	-0.354
-6	0.600*	-0.444*
-5	0.596*	-0.536*
-4	0.567*	-0.626*
-3	0.511*	-0.717*
-2	0.429*	-0.806*
-1	0.323	-0.894*
0	0.196	-0.980*
1	0.063	-0.847*
2	-0.054	-0.718*
3	-0.155	-0.593*
4	-0.239	-0.472*
5	-0.306	-0.358
6	-0.357	-0.250
7	-0.393*	-0.150
8	-0.415*	-0.058
9	-0.426*	0.026
10	-0.424*	0.101
11	-0.412*	0.166
12	-0.388	0.222
13	-0.353	0.270
14	-0.307	0.308
15	0.005	0.338

*-Statistical significant at the 5% level

Prior to comment on the results, their consistency has to be examined. This can be done by checking whether the sum of correlations and the average correlation have the same sign in Table 8. This is true for both lags and leads in both correlations, which means that the overall changes in the per capita income induce a consistent pattern of changes in the ecological deficit and in the GHG emissions.

Concerning the association GDP_{pc}&EDF, Table 8 shows that the average lag cross-correlations, $CC_{E_tG_t}(k<0)>0$ is positive and the average lead cross-correlations, $CC_{E_tG_t}(k>0)<0$ is negative. The latter implies that while an increase in the per capita income has increased the ecological deficit in past, this will change in the future. The incidence of growth will reduce the pressure on the natural resources. The latter may be the joint product attributed to two distinct processes. First, such an event could be the result of a rise in the "eco-efficiency" which means that a unit of GDP is produced now with less environmental resources York et al. [30]. Beyond that, there might be a change in the consumption patterns, which involve substitution of environmentally harmful with less harmful goods and services.

Very often, eco-efficiency and substitution are mentioned as requirements for the economy's dematerialization [84]. Some advocate that the link between dematerialization and the resulting decoupling is a matter of society's choice since it depends on the "appropriate" policy measures that mobilize technology and put forward incentives to reduce human pressure on the environment [85]. Notwithstanding, the whole issue is far from settled, see Bithas and Kalimeris [86] and Fletcher and Rammelt [87] for a critique. Gómez-Baggethun [88] refers to the resource efficiency and the policy induced substitution as technological and political utopias that cannot be sustained *ad infinitum*.

By contrast, Table 8 shows that both the average lag and lead cross-correlations for the link GDP_{pc}&GHG are negative. That means that the past reduction of GHG emissions as a result of growth will continue to exist in the future. Put it in the EKC jargon, Poland has reached a position, where the composition and technological effects dominates the scale effect. Hence, growth reduces the environmental impacts. Narayan et al. [82] have identified similar pattern for Poland's CO_2 emissions as well as for Germany, Czech Republic,

Table 8. Summary of the cross-correlation results.

	Lag		Lead	
	Sum of correlations	Average correlation	Sum of correlations	Average correlation
GDP_{pc}&EDF	5.873	0.392	-4.417	-0.294
GDP_{pc}&GHG	-4.149	-0.277	-2.015	-0.134

Iraq, Slovak Republic and Sweden among others. The positive role of the eco-efficiency and substitution, discussed above, applies here as well.

To recapitulate, the likely policy implications of the decoupling indices are examined by the cross correlation analysis. The analysis tried to investigate whether economic growth determines the changes in the ecological deficit and in the level of GHG emissions. The results provide evidence that economic growth in Poland will bring about a decline in the ecological deficit. Likewise, economic growth has reduced GHG emissions and will continue to do so in the future. The previous argument seems to echo a Parsonian modernization postulate, in the sense that economic growth is treated as a crucial determinant ("evolutionary universal") of society's change (implicitly through its impact on democracy, institutions and organizational capacity) [89]. This line of argument is not new, and the criticism raised is sound and fair [90, 91]. Notwithstanding, such a hypothesis prevails the EKC literature [92]. To cut a long story short, it seems that modernization theory, albeit severely criticized, is not dead. Various revivals and modifications have been put forward in the scholarly literature. Just to name a few: ecological modernization [93], reflexive modernization [94], re-modernization [95], global modernity [96].

Conclusions

The paper applied the most appropriate decoupling indices in order to map the development trajectory of Polish economy. In the period between 1990 and 2016, Poland has achieved remarkable things. Primarily, growth seems that did not deteriorate the quality of the environment, since the human pressure on the environment, as captured by the resource and impact decoupling indices, was not associated with growth. Furthermore, from the cross-correlation analysis has emerged some rather interesting observations with profound policy implications. Poland has been a successful paradigm in terms of the ecological modernization theory. Growth seems to unfold without imposing significant pressure on the natural resources (a captured by the ecological deficit) and without causing environmental degradation (as captured by the GHG emissions).

Notwithstanding, it is the authors' contention that further research, using additional environmental indices, is needed to reveal the complete nature of decoupling and reveal the whole spectrum of policy implications. Moreover, a comprehensive set of data concerning the nexus of energy-growth-environment will allow decomposition analysis, and through this, it might be possible to determine the driving forces behind the decoupling trajectories.

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Conflict of Interest

The authors declare no conflicts of interest.

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