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Ecological Footprint and Major Driving Forces in West Jilin Province, Northeast China

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Abstract: The environmental impact caused by local people (ecological footprint of consumption, EFc) and the actual environmental impact that the ecosystem burdens (ecological footprint of production, EFp) in West Jilin Province, Northeast China from 1986 to 2006 were evaluated by using ecological footprint (EF) method. And the major driving forces of EFc and EFp were analyzed by STIRPAT model. Both EFc and EFp showed increasing trends in 1986–2006, accompanied by decreasing ecological deficits but expanding ecological overshoots. Population (P), GDP per capita (A_1), quadratic term of GDP per capita (A_2), urbanization (T_{a1}), and quadratic term of urbanization (T_{a2}) were important influencing factors of EFc, among which T_{a2} and T_{a1} were the most dominate driving forces of EFc. A_1, A_2 and T_{a2} were important influencing factors of EFp, among which A_2 and A_1 were the most dominate driving forces of EFp. In 1986–2006, the classical Environmental Kuznets Curve hypothesis did not exist between A_2 and EF (both EFc and EFp), but did between T_{a2} and EF. The results indicate that enhancing the urbanization process and diversifying economic sources is one of the most effective ways to reduce the environmental impact of West Jilin Province. Moreover, importance should be attached to improve the eco-efficiency of resource exploitation and consumption.

Keywords: ecological footprint; STIRPAT model; ecological deficit; ecological overshoot; West Jilin Province

1 Introduction

Fast population growth and economic development has sharply increased the global resources demand and exacerbated environmental deterioration, which is the most troubling and complex issue the world faced (Alam *et al.*, 2007). In response to the awareness of such tense situation, sustainability has been an international goal since Rio Earth Summit (Wackernagel *et al.*, 2004). To evaluate the environmental impact with corresponding anthropogenic drivers is one of the most important steps to implement sustainability strategies (Fan *et al.*, 2006; Lin *et al.*, 2009; Madu, 2009; Sun and Xu, 2009), and it is also a focus for scientific researchers. The ecological footprint (EF) method, created by Rees (1992), is an important method to quantify ecological impact and sustainability status of human activities, and it has been widely used and discussed for its simplicity and strong comparability. The STIRPAT model, originally proposed by Dietz and Rosa (1994), is a well known statistic method to analyze the anthropogenic impacts on environment, modified from IPAT equation (Ehrlich and Holdren, 1971; 1972). Compared with IPAT equation, STIRPAT model is easier for calculation, and can also decompose the anthropogenic factors. Thus, EF method and STIRPAT model were widely used in exploring human-environment relationship. For instance, York *et al.* (2003) analyzed and compared the driving forces of energy footprint and CO_2 emission at national scale all over the world, and Jia *et al.* (2009) studied the long term anthropogenic effects on ecological footprint of Henan Province, China. The conjunction of EF method and STIRPAT model has become an effective tool for sustainable development decision-making.

For trade is a fact of life, the resources consumed by a given region may be productions from somewhere else, then the ecological productive area consumed by this region does not coincide with the geographic territory

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where the same population lives (Bagliani *et al.*, 2008b). At present, 81% of the world's population consumes more resources than that is renewably available within their own borders. Such disparities between those who profit from resources consumption and those who bear the environmental burden strongly led to overuse of resources (Wackernagel *et al.*, 2004; Kissinger and Rees, 2010). Therefore, when use EF to regional scale, tracing final consumption as well as the original points of impact will help people understand their interactions with the biosphere beyond their borders more clearly, including revealing ecological burden shifting and negative ecological trade balances (Moran *et al.*, 2009; Sun and Liu, 2009). However, in the previous studies concerning EF method and STIRPAT model, little attention has been paid to distinguishing the environmental impact caused by local consumption and the actual environmental impact that ecosystem burdens. Global Footprint Network (2009) calculated the ecological footprint of consumption and production respectively for 240 countries of the world, and the results showed that EFc and EFp differ greatly due to the diversity of human lifestyle and resources abundance.

In this paper, West Jilin Province was taken as the study area, the environmental impact caused by local people and the actual environmental impact that ecosystem burdens were evaluated by using EF method. Then, the STIRPAT model was used to analyze the anthropogenic driving forces of EF, aiming to serve for local sustainable development decision-making.

2 Study Area and Methodology

2.1 Study area

West Jilin Province (WJLP), located between 43°53′–46°18′N and 121°38′–126°17′E in the western Songnen Plain, is an important agro-pastoral transition region in the northern China, and is also a typical area of venerable ecotone, with a total area of 47.0×10^3 km^2. WJLP is both a main agricultural base and an important energy base of Jilin Province, with the mean annual temperature of 3–5℃, annual precipitation of 350–500 mm, and annual potential evaporation of 1 600–2 000 mm. The total population has increased rapidly from 15.0×10^3 in 1949 to 48.1×10^3 in 2006, and more than 67% of them take agriculture as the main source of income. In recent years, due to inner ecological vulnerability, over cultivation and over grazing and so on, some problems such as frequent natural disasters, severe land degradation, water scarcity and weak water conservancy facilities, low resisting ability to natural disasters, imbalance industry structure and low productivity are serious (Sheng *et al.*, 2001; Pan *et al.*, 2003; Wang *et al.*, 2005; Yue *et al.*, 2008).

2.2 Methodology

2.2.1 Calculation method of ecological footprint

The ecological footprint measures the anthropogenic impacts by calculating the critical natural capital required to support a defined population or productive activity, in terms of biologically productive areas (Wackernagel *et al.*, 1999; Monfreda *et al.*, 2004; Kitzes and Wackernagel, 2009). The EF can be calculated by equations (1) and (2) (Wackernagel *et al.*, 1999):

$$EFc = \sum_{i=1}^{n} \frac{r_i C_i}{Y_{\mathrm{g}i}} = \sum_{i=1}^{n} \frac{r_i (P_i + L_i - E_i)}{Y_{\mathrm{g}i}} \tag{1}$$

$$EFp = \sum_{i=1}^{n} \frac{r_i P_i}{Y_{\mathrm{g}i}} \tag{2}$$

where *EFc* is ecological footprint of consumption (ha); *EFp*, ecological footprint of production (ha); C_i, consumption of resource i (kg); E_i and I_i, export and import of resource i (kg) respectively; $Y_{\mathrm{g}i}$, global productivity of resource i (kg/ha); P_i, production of resource i (kg); and r_i, equivalence factor. The *EF* is calculated based on constant global productivity to demonstrate the environmental impact change, and r_i is referred to Monfreda *et al.* (2004).

The production- and consumption-based approaches actually consider, on the whole, the same kind of environmental data, but use different accounting principles: the former assigns the environmental impact to each area on the basis of the geographical location of the resources, and the latter on the basis of consumer responsibility (Bastianoni *et al.*, 2004; Bagliani *et al.*, 2008b).

The biocapacity reflects the ability of regional available land resources and the equation is as follows (Wackernagel *et al.*, 1999):

$$BC = (1-12\%)\sum_{j=1}^{n} a_j y_j r_j \tag{3}$$

where *BC* is biocapacity (ha); a_j, area of land type j (ha); and y_j, yield factor of land type j. Comparison of EF and BC reveals whether existing natural capital is sufficient to support the current consumption and production pattern (Monfreda *et al.*, 2004):

$$ED = BC - EFc \tag{4}$$

$$EO = BC - EFp \tag{5}$$

$$ETD = EFc - EFp \tag{6}$$

where ED is ecological deficit (ha); EO, ecological overshoot (ha); and ETD, ecological trade deficit (ha). ED refers to the difference between a population′s ecological footprint and the biocapacity locally available to the population. EO is a state in which resources are used more rapidly than the biosphere can replenish them (Wackernagel *et al.*, 2004). Negative value of ED presents the resources demand can not be achieved locally, and negative EO shows that the rate of resources exploitation has exceeded its maximum carrying capacity and local ecosystem is depleting. The positive ETD indicates a net import of resources while the negative indicates a net export at a regional scale (Monfreda *et al.*, 2004).

2.2.2 STIRPAT model

STIRPAT model is a well known statistical method reformulated from the IPAT environmental accounting equation. $I = PAT$ equation was first studied by Ehrlich and Holdren (1971; 1972) to assess the environmental impact I of anthropogenic factors, including population (P), affluence (A) and technology (T). There have been multiple uses and many modification forms such as $I = PBAT$, $I = PACT$, $I = mPACTS$ and so on. York *et al.* (2003) refined it to a stochastic form, named STIRPA model, which is as follows:

$$I = aP^{b}A^{c}T^{d}e \tag{7}$$

where constant a scales the model; b, c and d are the exponents of P, A and T respectively; and e is the error item.

In order to test calculation and hypothesis conveniently, this model can be transformed to a linear logarithmic form as follows (York *et al.*, 2003):

$$\mathrm{Ln}I = a + b\mathrm{Ln}P + c\mathrm{Ln}A + d\mathrm{Ln}T + e \tag{8}$$

Other factors can be added to the basic STIRPAT model if they are conceptually appropriate for the multiplicative specification of the model. Thus, P, A and T can be decomposed. Also, quadratic terms can be added to the model to test the classic Environmental Kuznets Curve (EKC) hypothesis (York *et al.*, 2003; Bagliani *et al.*, 2008a).

2.3 Data sources

The calculation of EF requires a large amount of information about natural resources, economy and agricultural productivity, *etc*. There are several data sources for this study: *Jilin Statistical Yearbook 1986–2006* (Jilin Statistical Bureau, 1987–2007), *Jilin Yearbook* (Editorial Board of Jilin Yearbook, 1987–2007), *Baicheng Statistical Yearbook 1996–2006* (Baicheng Statistical Bureau, 1997–2007), *Baicheng Annuals 1986–1995* (Editorial Board of Baicheng Annuals, 1999), and *Songyuan Statistical Yearbook 1992–2006* (Songyuan Statistical Bureau, 1993–2007).

3 Results and Analyses

3.1 Ecological footprint

3.1.1 Ecological footprint of consumption

From Fig. 1 it can be seen that the environmental impact of resources consumption of WJLP presented an increasing trend from 1986 to 2006 with the total EFc variying from 5.10×10^6 ha to 9.86×10^6 ha. Meanwhile, the per capita EFc increased from 1.265 ha to 2.051 ha, which was a little higher than the average level of China in 2006 (1.85 ha) (Global Footprint Network, 2009). The largest area for EFc was used as fossil land (40.8% – 49.6%), and the second was used as arable land (29% – 42%), which varied from 2.08×10^6 ha and 2.15×10^6 ha (0.517 ha and 0.532 ha per capita) in 1986 to 2.91×10^6 ha and 4.89×10^6 ha (1.108 ha and 0.604 ha per capita) in 2006 respectively. Other areas, accounting for 17.1%–21.0% of the EFc, also increased but with fluctuation.

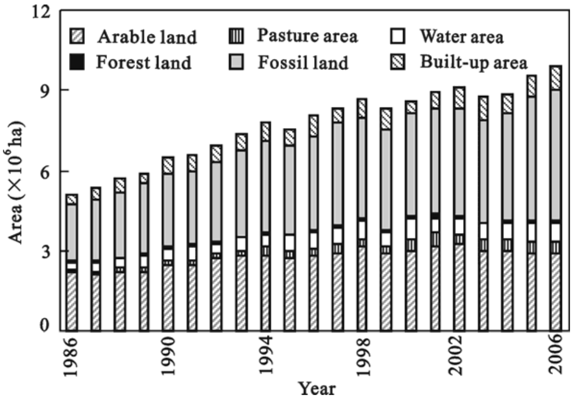

Fig. 1 Ecological footprint of consumption of West Jilin Province

Figure 2 shows that in 1986–2006, the total BC of WJLP changed from 3.23×10^6 ha to 10.4×10^6 ha, while the per capita BC varied from 0.802 ha to 2.174 ha, revealing that this region has an increasing ability to provide natural resources for human demand. The BC of this region was about 2.55 times as that of China in 2006 for the abundance of arable land resources. Arable land made the largest contribution (70.1%–80.6%) to BC, and its productive area increased rapidly from 2.60×10^6 ha to 8.27×10^6 ha due to the increase of absolutely area and land productivity. Built-up land was the second largest contribution (8.2% –10.0%) to BC with the area varied from 340×10^3 ha to 863×10^3 ha. BC dropped to 5.04×10^6 ha in 2000 due to the lowest productivity caused by drought disaster.

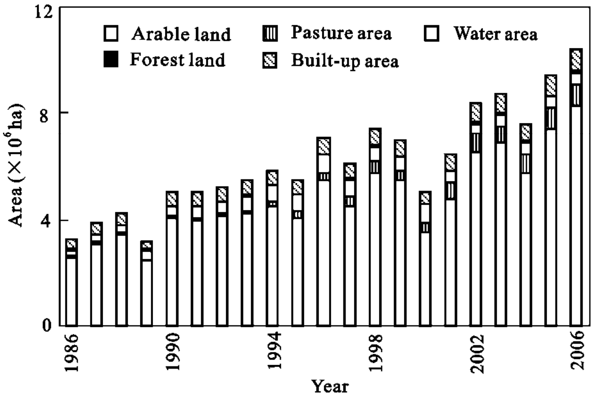

Fig. 2 Biocapacity of West Jilin Province

From 1986 to 2006, the ED varied from –1.87×10^6 ha (–0.464 ha per caipta) to 590×10^3 ha (0.123 ha per capia) (Fig. 3), which illustrated that WJLP could locally satisfy its consumption of natural resources in 2006. From the view of EFc, the human-environment relationship of WJLP was superior to that of China since the average ED reached –1.0 ha for China in 2006 (Global Footprint Network, 2009).

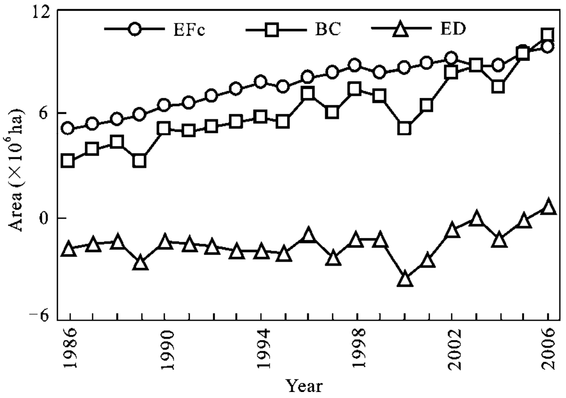

Fig. 3 Ecological deficit of West Jilin Province

3.1.2 *Ecological footprint of production*

The results of EFp for WJLP from 1986 to 2006 are shown in Fig. 4. The environmental impact of resources exploitation grew rapidly with the total EFp changing from 6.32×10^6 ha to 19.6×10^6 ha. The EFp reached 4.095 ha per capita in 2006, about 2.61 times as that in 1986 and 2.15 times as China′s EFp in 2006 (Global Footprint Network, 2009). Arable land took the largest share (36.2%–53.5%) of EFp while fossil land the second (31.3%–49%), which increased from 3.30×10^6 ha and 2.09×10^6 ha (0.818 ha and 0.519 ha per capita) in 1986 to 8.11×10^6 ha and 7.71×10^6 ha (1.687 ha and 1.605 ha per capita) in 2006, respectively. Other lands accounted for 13.4%–21.9% of EFp and the total area varied from 938×10^3 ha in 1986 to 3.86×10^6 ha in 2006.

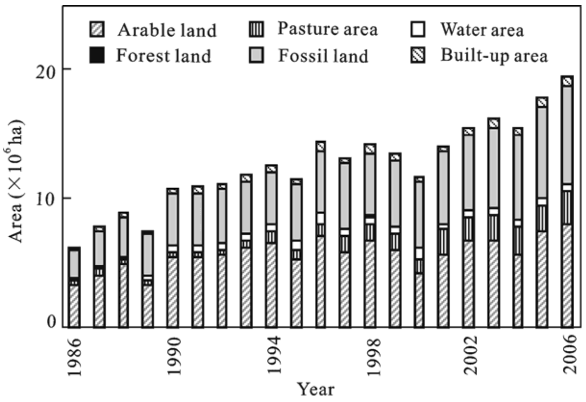

Fig. 4 Ecological footprint of production
of West Jilin Province

ETD of WJLP expanded from –1.22×10^6 ha (–0.304 ha per capita) in 1986 to –9.82×10^6 ha (–2.043 ha per capita) in 2006 (Fig. 5), which meant that WJLP exploited more natural resources than those the region consumed. Both biomass and fossil resources had remainder for export with the ETD varying from –1.21×10^6 ha and –10.3×10^3 ha respectively in 1986 to –7.00×10^6 ha and –2.82×10^6 ha in 2006. This could explain the fact why WJLP has been an important food base and fossil base for long time.

At the same time, resources exploitation of WJLP exceeded its local biocapacity and the EO increased from –3.09×10^6 ha (–0.304 ha per capita) in 1986 to –9.23×10^6 ha (–2.043 ha per capita) in 2006 (Fig. 6), which consequently caused a depletion of the ecosystem. The EF result of WJLP was in accordance with the view that ecological remainders or deficits might fail to reveal whether ecosystems are managed sustainably or not (Monfreda *et al.*, 2004). A remainder may be unsustainably used for exports, and therefore may not indicate

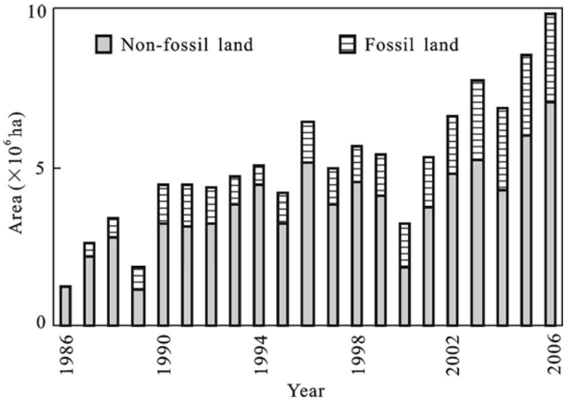

Fig. 5 Ecological trade deficit of West Jilin Province

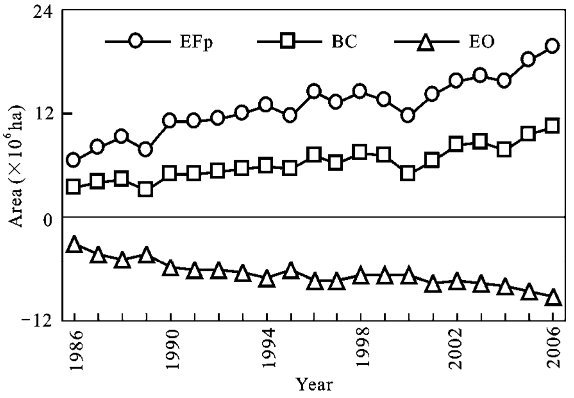

Fig. 6 Ecological overshoot of West Jilin Province

remaining capacity (Lenzen and Murray, 2001). As an important agriculture base and energy base, WJLP has high economic reliance on primary resources exploitation. For example, the per capita grain output increased from 750 kg in 1986 to 1 841 kg in 2006, which was about 4.57 times and 1.81 times as those of China and Jilin Province respectively. Expanding biomass production for export has caused severe environmental degradation in WJLP. From the view of EFp, the human-land relation of WJLP was much tenser than that of China since its EO is much higher than China's average level (–1.05 ha). Therefore, the current production pattern could not be sustainable for long time.

3.2 Major driving forces based on STIRPAT model

The potential driving forces of EF included the population, affluence, economic structure, efficiency of resources use, *etc.* (York *et al.*, 2003; Long *et al.*, 2006; Dietz *et al.*, 2007; Madu, 2009). According to the previous studies on STIRPAT model, we chose the following indicators to construct the STIRPAT model: population (P), affluence (denoted by GDP per capita (A_1) and quadratic term of A_1 (A_2)), urbanization (denoted by the percent of the urban population (T_{a1}) and quadratic term of T_{a1} (T_{a2})), and percent of the economy in the primary industry (T_b). Firstly, Ordinary Least Square (OLS) regression estimation of the STIRPAT model presented Variance Inflation Factor (VIF) values to test if these drivers had collinearity. According to Table 1, the VIF for all the variables except T_b exceeded the accepted standard (VIF < 10), which indicated that high multicollinearity existed between the variables might cause uncertain impacts. In order to avoid collinearity, the classical statistical technique ridge regression, used to fit the model, requires a careful selection of an appropriate ridge regression coefficient K. As it is a biased estimation, K should be chosen as small as possible and should simultaneously have small VIFs and steady going regression coefficients (Lin *et al.*, 2009). In this case, STIRPAT model was regressed with a step length 0.05 of K changing within [0, 1]. When K is equal to 0.05, the variables' coefficients are relatively going steady and their VIFs are sufficiently small. Ridge regression can be performed directly by the software SPSS 13.0.

The results of STIRPAT model for EFc and EFp are shown in Table 2 and Table 3. Each model of the two dependent variables provided a good fit and the models could explain more than 97.7% of the variance in EFc and more than 88.8% of the variance in EFp.

Table 1 Regression coefficients for STIRPAT model of EFc based on OLS

	Unstandardized coefficient	S.E.	t	Sig.	Collinearity statistics	
					Tolerance	VIF
P	0.154	5.454	–1.7450	0.101	0.037	27.3
A_1	–4.436	0.554	0.2779	0.785	0.000	14115
A_2	0.009	0.004	2.5604	0.022	0.017	56.6
T_{a1}	–5.567	6.548	–2.1170	0.051	0.000	6745.9
T_{a2}	–13.861	2.479	–2.2860	0.037	0.000	6030
T_b	–0.129	0.094	–1.3770	0.189	0.187	5.39

Notes: P, population; A_1, GDP per capita; A_2, quadratic term of A_1; T_{a1}, percent of urban population; T_{a2}, quadratic term of T_{a1}; T_b, percent of the economy in the primary industry

Table 2 Regression coefficients for STIRPAT model of EFc (n = 21)

	Model 1	Model 2	Model 3	Model 4
P	1.1400^{***} (5.407)	1.0589^{**} (4.572)	0.9399^{***} (4.061)	0.8768^{***} (3.547)
A_1	0.0557^{***} (3.865)	0.0398^{***} (4.281)	0.0457^{***} (2.958)	0.0324^{***} (3.183)
A_2		0.0020^{***} (2.735)		0.0017^{**} (2.252)
T_{a1}	0.9514^{***} (6.083)	0.8982^{***} (5.235)	0.5733^{***} (6.021)	0.5407^{**} (5.148)
T_{a2}			-0.2477^{***} (–5.783)	-0.2389^{***} (–5.126)
T_b	0.0066 (0.166)	0.0290 (0.647)	–0.0057 (–0.143)	0.0141 (0.307)
a	–0.9100 (–0.2764)	0.2837 (0.079)	2.1320 (0.586)	–1.4110 (0.793)
R^2	0.977	0.977	0.978	0.977

Notes: **, *** represent statistically significant at the level of 0.10, 0.05 and 0.01, respectively; *a* represents constant

Table 3 Regression coefficients for STIRPAT model of EFp (n = 21)

	Model 5	Model 6	Model 7	Model 8
P	0.0896 (1.307)	0.6215 (0.855)	0.6433 (0.843)	0.4076 (0.515)
A_1	0.1601^{***} (3.414)	0.1062^{***} (3.636)	0.1475^{***} (2.889)	0.0975^{***} (2.993)
A_2		0.0069^{***} (2.935)		0.0065^{**} (2.627)
T_{a1}	1.1240^{**} (2.208)	0.9432^{*} (1.752)	0.6453^{**} (2.054)	0.5232 (1.556)
T_{a2}			-0.3134^{**} (–2.218)	-0.2806^{**} (–1.881)
T_b	0.0681 (0.525)	0.1441 (1.023)	0.0524 (0.392)	0.1265 (–0.863)
a	2.7365 (0.256)	6.7832 (0.064)	6.5854 (0.548)	10.0420 (0.814)
R^2	0.888	0.893	0.893	0.894

Notes: *, **, *** represent statistically significant at the level of 0.10, 0.05 and 0.01, respectively; a reprents constant

As for environmental impact of resources consumption, model 1 was the basic equation of STIRPAT model. It can be seen that T_{a1}, A_1 and P had positive effects on EFc, and the increase of urbanization level, economic development and population would result in a net increase of EFc. T_b was a denotation of economic structure, but had no significant effect on EFc. Then, the impacts of A_2 and T_{a2} were added to model 2 and model 3 respectively, and both of them were added to model 4. The results of model 4 showed that P, A_1, A_2, T_{a1} and T_{a2} had important effects on EFc, among which T_{a2} and T_{a1} were the most important drivers of EFc with the coefficients being –0.2389 and 0.5407, respectively. The results revealed that urbanization, which varied from 25.0% in 1986 to 32.4% in 2006, was the dominate driver of EFc, for higher urbanization level often causes a lifestyle with higher consumption. There was no curvilinear relationship between economic development and EFc. However, the coefficients of T_{a2} in model 3 and model 4 were negative, indicating that the classic EKC hypothesis existed between urbanization level and EFc. It implied that urbanization which was associated with it brought about a reduction on environmental impacts in WJLP, because all kinds of resources had been utilized more adequately in the process of urbanization which led to a down trend of resources consumption. In other words, sometimes more efficient use of resources may entail economic growth and reduction in resources consumption.

For environmental impact of resources production (Table 3), model 5 was the basic equation of STIRPAT model. According to model 5, T_{a1}, A_1, P and T_b had positive effects on EFp, however, P and T_b had no significant effects on EFc. Therefore, the increase of urbanization level, economic development would result in a net increase of EFc. Then, the impacts of A_2 and T_{a2} were added to model 6 and model 7 respectively, and both of them were added to model 8. The results of model 8 indicated that A_1, A_2 and T_{a2} were important factors affecting EFp, among which A_1 and A_2, with the coefficients being 0.0975 and 0.0065 respectively, had the most important effects on EFp. All the models in Table 3 indicated that economic level was the dominate driver of EFp, which was consistent with the fact that WJLP had a high economic reliance on agriculture and energy exploitation. In 1986–2006, the total GDP of WJLP increased by 22 times with an average annual growth rate of 15.8%. Therefore, WJLP would face larger environment impact if without taking effective countermeasures to enhance economic efficiency, as the annual economic growth was planned to be more than 16.7% by local government. P, T_{a1} and T_b were unimportant drivers of EFp because their coefficients were not significant. Also, there was no curvilinear relationship between economic development and EFp for the coefficients of A_2 were positive in model 6 and model 8, but there was curvilinear relationship between urbanization level and EFp. Urbanization would provide more work chances to the people who directly depended on primary agricultural activities for their survival and consequently reduced direct impact on environment. However, the urbanization level of WJLP should be further enhanced in the future, as it is still far less than the contemporary level of Jilin Province (45.1%) and China (43.9%).

4 Conclusions

Ecological footprint of West Jilin Province was calculated to evaluate the environmental impacts caused by lifestyle consumption (EFc) and the environmental impacts that ecosystem actually burdens (EFp) from 1986 to 2006. STIRPAT model was used to analyze the major driving forces of EF, and the main conclusions are as the follows.

Both EFc and EFp kept increasing in 1986–2006. In spite of decreasing ecological deficit, the ecosystem was degrading, which was caused by quickly expanding ecological overshoot due to excessive resource exploitation for export. Population, quadratic term of GDP per capita, urbanization and quadratic term of urbanization were the important anthropogenic factors affecting EFc, among which urbanization level was the dominate driver; GDP per capita, quadratic term of GDP per capita and quadratic term of urbanization were the important anthropogenic factors affecting EFp, among which economic development was the dominate driver.

The classical EKC hypothesis did not exist between economic development and EF (both EFc and EFp) but existed between urbanization level and EF. The findings indicated that, to reduce the environmental impact of WJLP, urbanization should be enhanced and the diversification of economic sources should be developed. Also, urgent attention should be paid to the measures to improve the economic efficiency of resources exploitation and consumption.

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