

Article

Peak Waste? The Other Side of the Industrial Cycle

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Received: 13 January 2014; in revised form: 25 April 2014 / Accepted: 5 June 2014 /

Published: 30 June 2014

Abstract: The modern industrial cycle is mainly based on non-renewable mineral resources extracted from the Earth's crust. After being processed and transformed into commodities, the products of mining become manufactured products which go through the economic system and are then discarded in the form of gaseous, liquid or solid waste. Eventually, the mass of the output in the form of waste must balance the input in the form of minerals. A large number of model studies have been performed on the first phase of the cycle—the production of mineral commodities—often with a specific interest in fossil fuels, with the objective of determining the future prospects of production. However, very few model studies of this kind have been performed about the future trends of waste generation. In this paper, we examine models of the industrial cycle compared to historical trends in municipal solid waste generation for different regions of the world. We show that waste generation in developed countries goes in parallel with the trends of industrial production and that several regions are showing a declining trend which may be interpreted in terms of “peaking” just as it is often done for the production of fossil fuels. Therefore, the “waste problem” in terms of increasing amounts of waste to be processed and disposed may not be so urgent as it is commonly perceived.

Keywords: urban waste; system dynamics; waste management; industrial ecology; peak oil; peak waste

1. Introduction

The processing and the disposal of solid waste is often considered to be a major problem for society and a considerable debate is ongoing about the best methods to solve it. A typical assumption often underlying the debate is that the production of solid waste, especially in the form of Municipal Solid Waste (MSW), will keep increasing for the foreseeable future. For instance, the World Bank states in a 2013 report [1] that “MSW generation levels are expected to double by 2025”. This assumption is at the basis of choices such as incineration instead of landfilling, since the reduction in volume of the produced urban waste is often seen as a priority [2]. Nevertheless, it appears that very few studies confirm the assumption of continuing waste generation growth. Model studies in the field of solid waste exist mainly for specific kinds of waste, e.g., electronics waste [3] or automotive waste [4], very rarely for the general concept of solid waste or municipal solid waste, with just a few exceptions such as in some system dynamics studies [5,6]. In this field, despite the availability of various kinds of models for the waste stream and composition, it is difficult to apply them to the practical reality of waste management [7]. It appears that the industry that manages urban solid waste does not show the same acute interest in modeling future trends which is typical, instead, of the extractive industry, where much debate is ongoing about such concepts such as, for instance, “peak oil” [8,9].

However, the extractive industry and the waste management industry are not independent. The global industrial system can be seen as a large transformation process that starts with the products of the mining industry and transforms them into marketable commodities. These commodities are transformed then transformed into marketed products eventually to be discarded as waste. Hence, the trends of waste production are directly connected to the overall trends of the world’s industrial production, which in turn is related to the performance of the mining industry. In this sense, if we see the future in terms of extractive “peaks” (e.g., “peak oil” or “peak minerals” [10–12]), then we may expect a similar trend to occur for general waste production, *i.e.*, “peak waste”.

This interpretation seems to be confirmed if we examine the assessment of the world economy carried out in the “Limits to Growth” series of studies [13,14] and more recently [12]. These studies were based on the concept that the limits to growth of the global economic system are not determined by “running out” of mineral resources, but by the fact that the industry tends to use the cheapest resources first. As a consequence, mineral deposits are bound to become too expensive to be exploited, an observation that goes back to William Stanley Jevons [15] which is usually referred to as “the principle of diminishing economic returns”. Dynamic models of the world’s economy are highly aggregated and do not usually deal with specific kinds of waste. However, they normally contain an aggregated parameter defined as “pollution” which includes solid waste. Solid waste as parameter was made explicit in a system dynamic study based on the same methods [5] which showed that a peak in the generation of waste was to be expected in parallel with the general depletion trends of non renewable resources.

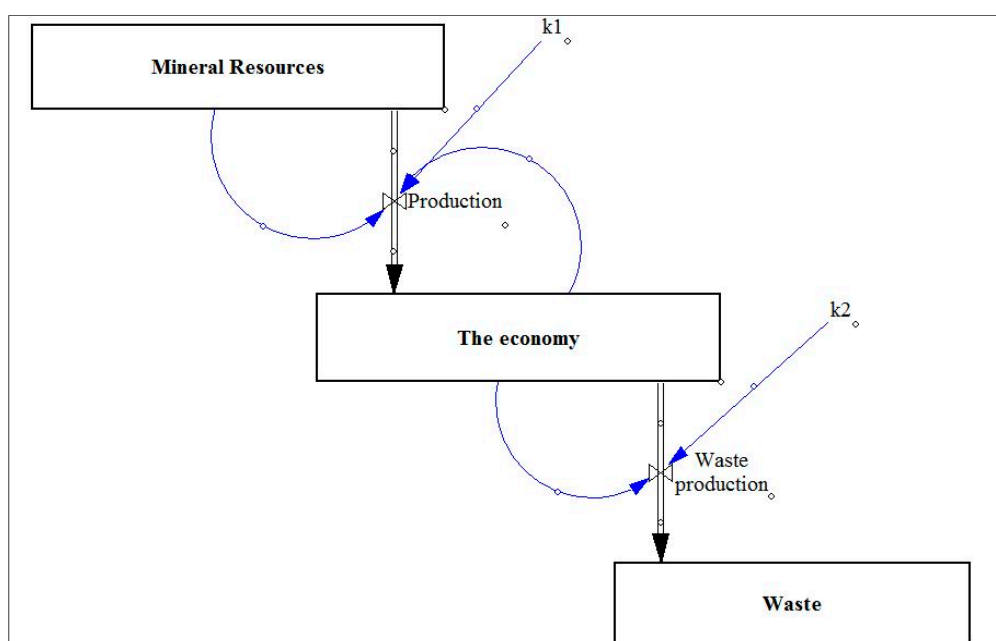
The present study starts from the concepts described above to perform an exploration of the waste production trends in the world following the approach of an earlier study by some of the authors of the present paper [16]. We do not aim at forecasting short term trends, but to determine whether there exist already indications that we are approaching a peak in waste generation, and in particular to municipal solid waste (MSW), which is often perceived by the public and by decision makers as the most pressing problem in modern society. This exploration is made difficult by the lack of reliable data and by the difficulties inherent in aggregating and comparing different parameters related to waste production. However, the result of our study indicates that, in several macro-regions of the world, MSW production has already peaked and is declining and some evidence indicates that the same effect is occurring for all forms of waste. This finding is clearly important at the level of policy choices in waste management, especially in relation to municipal waste management as it may remove some of the urgency felt by operators in planning for larger and larger waste treatment facilities.

2. Models of Waste Production

We will first present a simple model of a generic process of waste production aimed at understanding the general trends of a system that is constrained by a limited amount of resources in input. The model is based on the system dynamics approach [17], a method of modeling based on describing the system studied by “stocks”—amounts of matter or energy that change with time—and “flows,” that describe the flux of matter or energy from a stock to another. Typically, the behavior of these systems is dominated by “feedback” effects; that is by the phenomenon of flows depending on stock sizes. The model reported here follows the approach pioneered by the “Limits to Growth” studies [13,14]; however, it is closely related to the concept of “mind-sized” models proposed in [18] (an earlier version of the model had been presented previously [16]. Here, the models are created using the Vensim™ software package.

Figure 1 shows the simplest conceivable “mind sized” model of waste production.

Figure 1. Schematic system dynamics model used here for describing waste production trends.

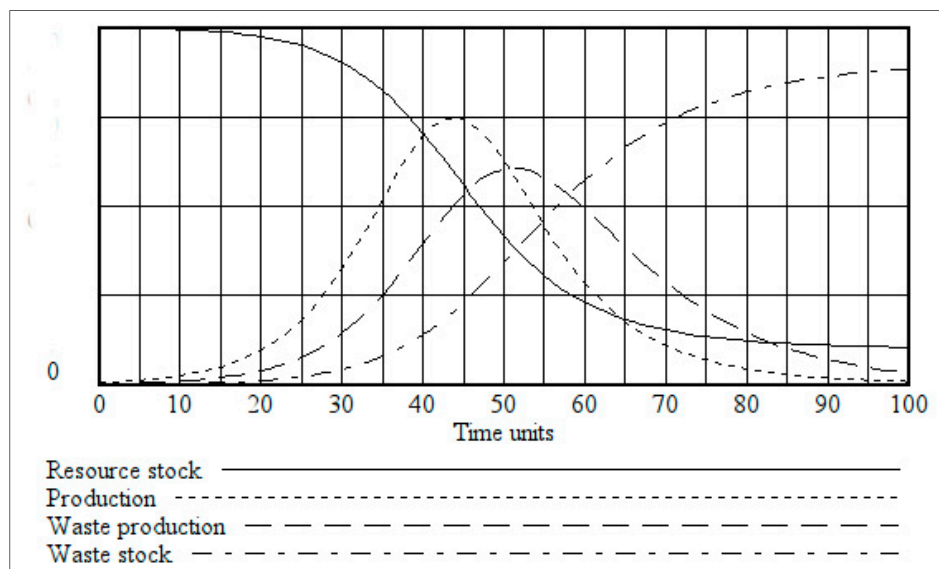


The model consists of three stocks: mineral resources, the economy and waste. The stocks are arranged according to the convention described in [18], that is from top to bottom in order of decreasing thermodynamic potentials. Note that this model is very general and can be applied to any kind of residual material deriving from industrial production. However, the term “waste” normally refers to solid residuals of industrial activities and of household consumption. The first kind is referred to as “industrial waste” while the latter can be termed, among several different acronyms, as “municipal solid waste” (MSW). In contrast, liquid and gaseous wastes are normally referred to as “pollution”, a term that includes also dispersed solid waste which cannot be collected and disposed of (e.g., particulate emission). The model shown here aggregates all these kinds of residuals, but here the focus will be on solid waste and in particular to MSW, for which more detailed and extensive data are available.

In the model, the flow of resources into the economy is assumed to be proportional to the size of both the economy and the resources stocks; in other words, it is subjected to a feedback related to the size of the two stocks it connects. This assumption is the same used in previous studies describing the exploitation of mineral resources [19]. Thus, it normally produces “bell shaped” production curves. The model also takes into account the production rate of waste which, in this case, is assumed to be proportional to the size of the economy, but not to the size of the waste stock. In other words, it is assumed that the costs involved in processing and managing waste are negligible with respect to the overall size of the economy. Finally, note that the waste stock is assumed to accumulate without ever being recycled or dissipated by natural processes. This is another approximation which, however, has a minor effect on the qualitative results of the model.

The behavior of the model is determined by two constants that describe the efficiency of the exploitation of natural resources (k_1) and the rate of waste production (k_2). Figure 2 shows some typical results, which turn out to be robust, in the sense that they can be reproduced for a wide range of initial parameters. The parameters in input are for the results shown are resource stock (initial) = 10 units, economy stock (initial) = 0.01 units, waste stock (initial) = 0.01 units. The Y axis for the waste and resource stock has a maximum value of 10 units, while the Y axis for the production curves has a max of 0.4 production units/time unit. The values of the two constants are $k_1 = 0.025$, $k_2 = 0.1$.

Figure 2. Standard results of the model of waste production.



Note that, in the model, industrial production peaks before waste production, as it should. The distance between the two peaks is determined by the lifetime of products in the economic system. When dealing with municipal waste, we deal mainly with short-lived items, in large part packaging and perishable goods. So, we expect that in the real world the two curves should be very close to each other and probably indistinguishable in the real world.

The model can be modified to take into account further factors. For instance, the relation between the cost of extraction and the amount of resources is supposed here to be simply linear; that is, the cost is supposed to increase in relation to the inverse of the remaining resources (it goes to infinity when there is nothing left to be extracted). Different forms for this proportionality could be considered but, in agreement with the concept of “Occam’s razor”, this simple relation will be maintained here. Note also that the amount of available mineral resources here is supposed to be finite; which is physically reasonable. An objection commonly made to such an assumption is that the concept of resources depends on factors such as prices and technological progress (for a review of this point, see, e.g., [19]). However, this objection makes sense only in the assumption that the model is used as a predictive tool, that is if the “resource stock” parameter is supposed to be an input that leads to forecasting long term production trends and in particular a peaking date. However, here our aim is to describe the trends of the system on the basis of historical data. In other words, our aim is interpretative rather than predictive and, in this sense, the assumption of larger or smaller mineral resources will not change the shape of the calculated curves.

As further modifications, the cost of waste processing can be taken into account by assuming that a fraction of the industrial stock must be dedicated to this purpose. In this case, the shape of the production curves may become asymmetric (the “Seneca” shape) as described in [18]. Again, this assumption does not substantially change the overall results of the model. Then, we may take into account waste recycling by assuming that part of the waste stock may be returned to the industrial system or re-absorbed in the ecosystem. These phenomena may be easily simulated by dynamical modeling but, in general, as long as we assume that the industrial system is driven mainly by non renewable resources, the overall result remains the same, that is both the industrial production and the waste production peak and then eventually go to zero. The main difference with respect to the simpler model is that the curves for industrial and waste production may show damped oscillations as the stocks of recyclable waste are exhausted. Finally, if we assume the presence of renewable resources, the system may converge to a stable state for the production of both waste and industrial products. This final result corresponds well to simple dynamic models of biological systems (see e.g., [20])

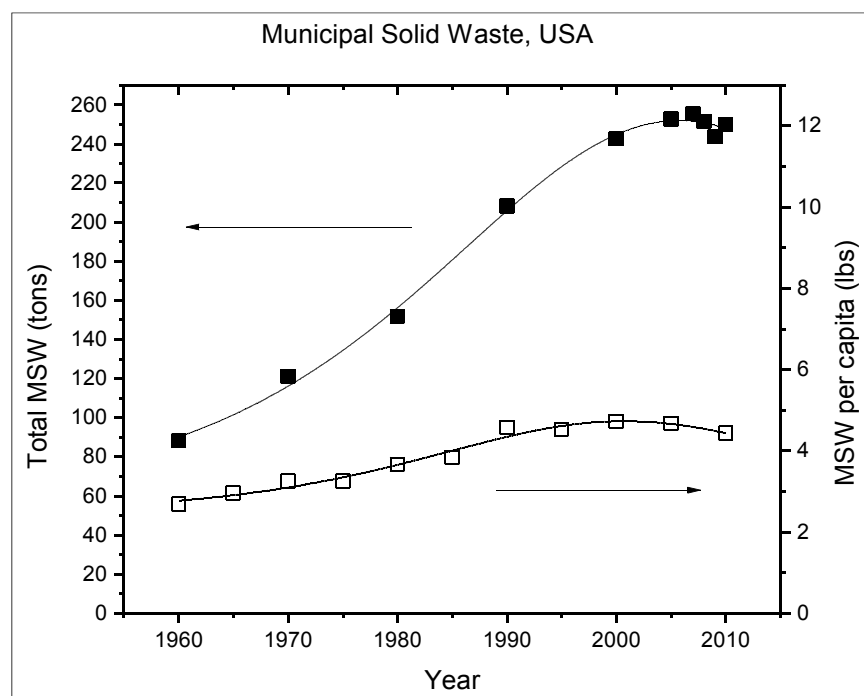
3. Waste Generation Trends—Comparison with the Available Data

Reliable data for the waste stock in the model developed in the previous section do not exist at the global level and not even at the regional level. That is, it is impossible to quantify such stocks as, for instance, the total amount of solid waste generated by human activities and accumulated in the world. We do have, however, data relative to the flows, that is on the yearly waste generation and, in particular, about municipal waste generation. Even in this case, global data are not available for lack of reporting by many countries and often inconsistent reports. Furthermore, the definitions and surveying methods vary widely. Good data are often available at the level of single countries, although normally

reported only in terms of weight, rarely taking into account how composition varies as a function of time, geographical location, urbanization, wealth and other factors. Nevertheless, sufficient data exist on MSW generation so that it is possible to obtain at least a general picture of the main trends of waste generation in a substantial number of countries and for various macro-areas of the world. These data can be used in order to provide a vision of solid waste production as global as possible. Here, we will mainly examine data relative to the US, Europe, China, Japan and Australia. The most detailed and comprehensive data belong to the generation of Municipal Solid Waste (MSW). The bulk of this kind of waste originates from households, commercial enterprises, and public institutions.

We begin with the data for the US, obtained from the Environmental Protection Agency [21]. These data have are shown in Figure 3, fitted by means of the derivative of a logistic function in order to simulate the “bell shaped” curve generated by the models.

Figure 3. Trends in municipal waste generation for the United States.

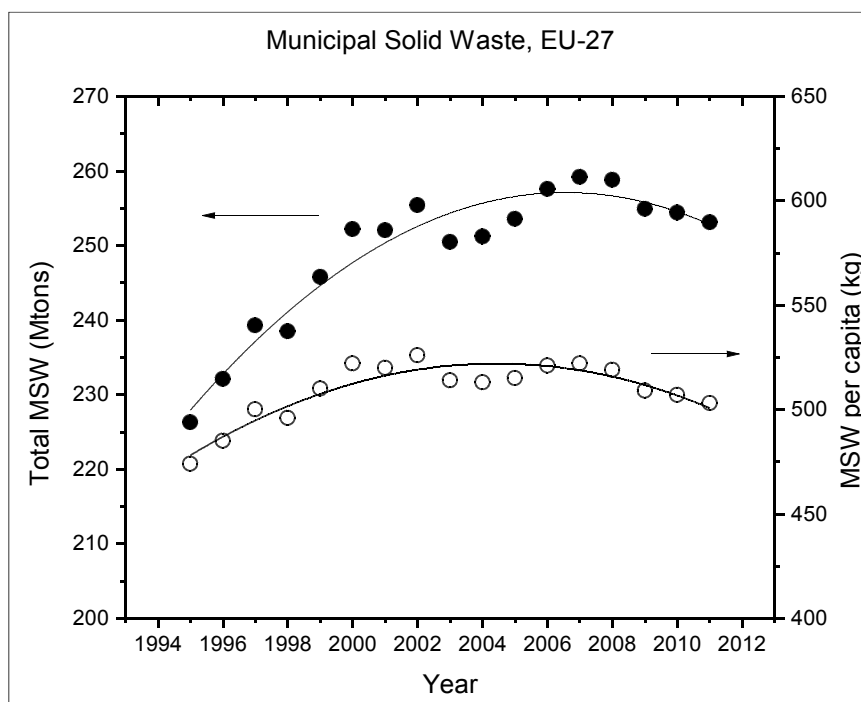


Source: Data from EPA [21].

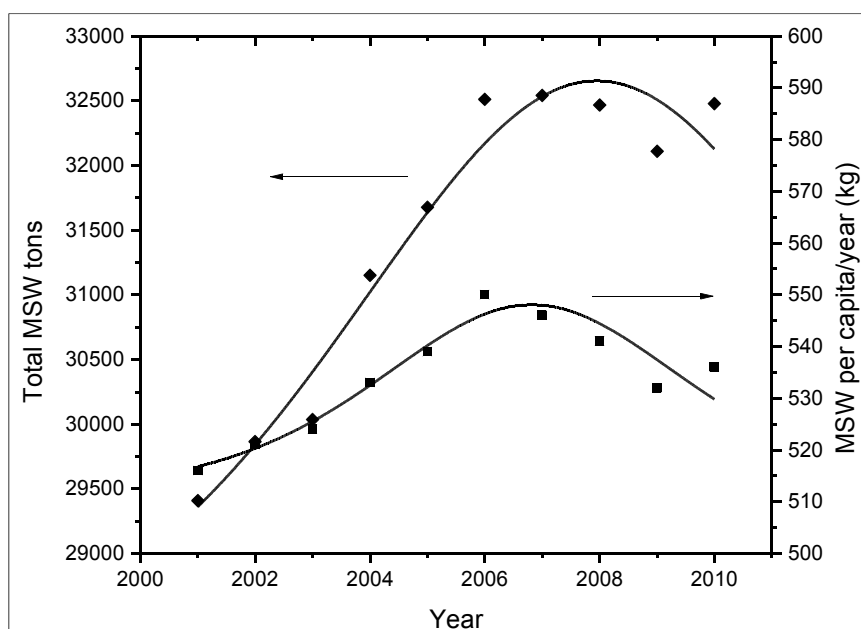
These data show that the overall MSW generation in the US has peaked and is now slowly decreasing. This peaking trend is especially evident for the amount of MSW generated per person.

For Europe the data shown in Figure 4, from Eurostat [22] show that the overall trend for MSW generation is similar to that of the US. The “EU-27” region has indeed seen both the total waste generation and the waste generated per person declining.

There are several individual European countries that have also peaked in terms of total municipal waste generation. For example, Italy is one of the cases of an actual decline in waste generation [23,24], as shown in Figure 5. The same trend is observed for Belgium, Germany, Ireland, Spain, Hungary, the Netherlands, Austria, Portugal, Sweden, the UK and Switzerland [22].

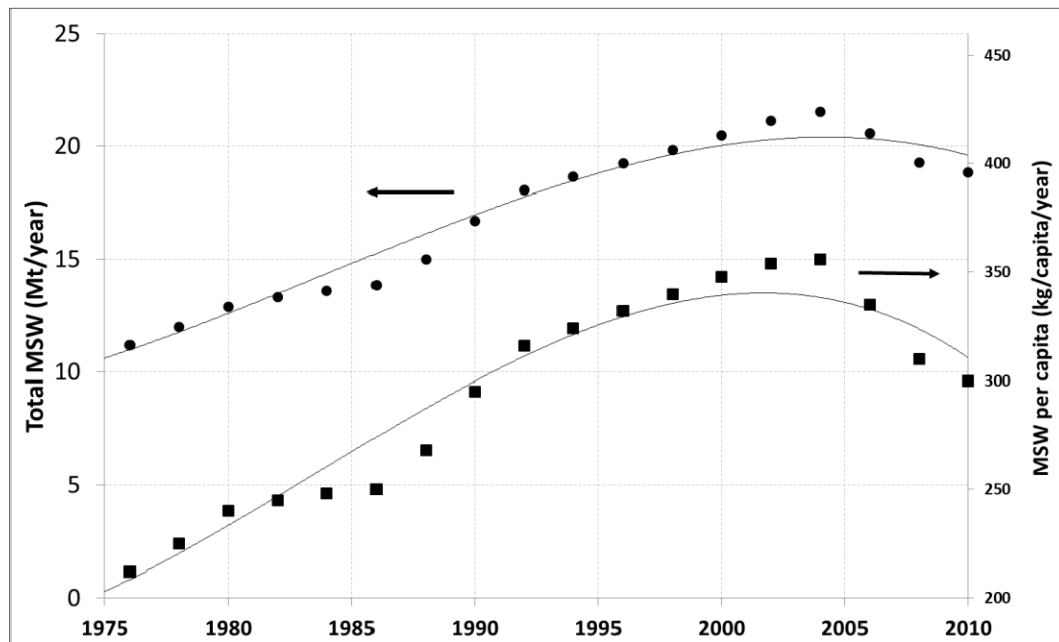
Figure 4. Trends in urban waste production for the European Union (27 States).

Source: Data from Eurostat [22].

Figure 5. Municipal waste generation in Italy.

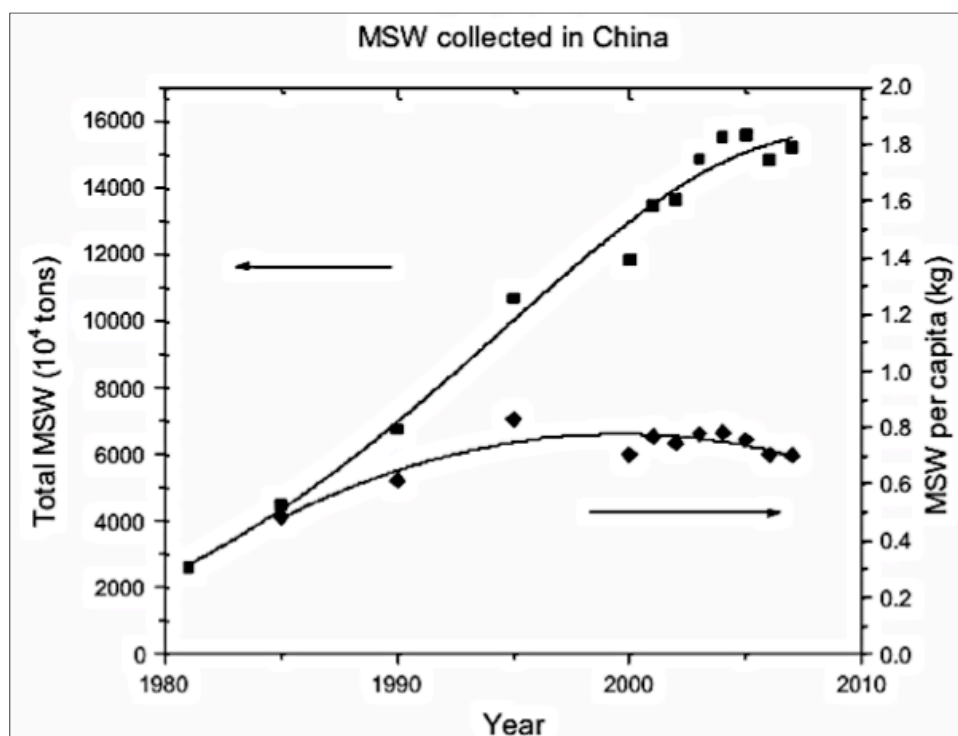
Source: Data from [24].

As a further example of a European country whose waste production has peaked, here are the results for France, shown in Figure 6.

Figure 6. Municipal waste generation in France.

Source: Data from Ademe [25].

Regarding the Asian region, we investigated data from China and Japan. Although the Chinese population has increased over the past two decades and its economy has developed tremendously, China seems to follow the same trend for MSW generation we saw for the US and Europe, even though the total waste production has not peaked yet [26,27]. The data in Figure 7 have been obtained from [28].

Figure 7. Municipal waste generation trends in China.

Source: Data from China Statistical Yearbook [28].

Regarding Japan, although Japanese citizens have nearly the same standard of living as US ones, they generate only 56% of the US MSW per person. The available data are insufficient for a full assessment but it seems that Japanese generation of MSW is also declining [29]. Regarding other Asian regions, in Australia the annual mass of collected MSW shows a slow rising trend [30].

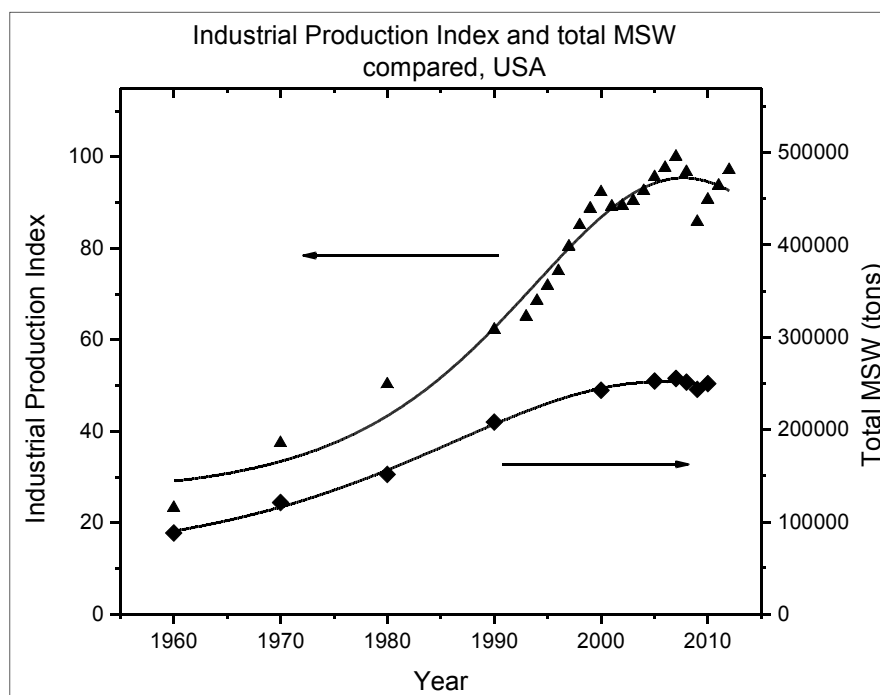
On the whole, the available data do not allow us to conclude with certainty that MSW generation has peaked worldwide but a peaking and declining trend is clearly observable in several major countries all over the world.

4. Industrial Production and Waste Generation

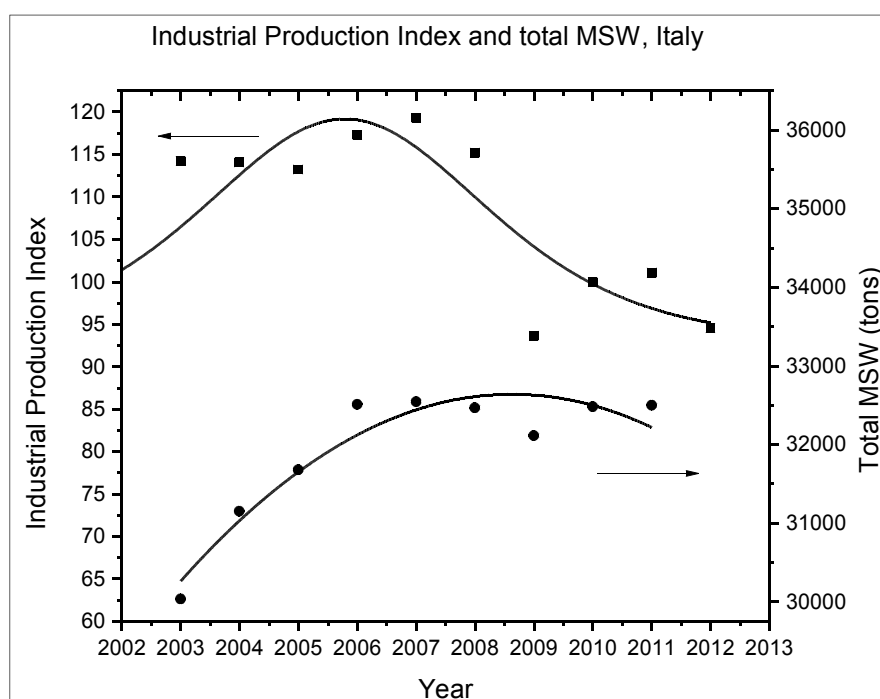
The data on municipal waste generation can now be compared with those on the input side of the industrial process. This input, however, is not easily measured. We could consider it to be proportional to the Gross Domestic Product (GDP) but this parameter, expressed in monetary units, includes a variety of processes that do not directly produce solid waste, e.g., salaries or home sales. A better parameter in this case is industrial production which, however, is not normally measured in physical units, but as an “index” which measures the aggregate production output of manufacturing, mining and utilities by summing up the physical outputs of the various industries weighted from their proportion in the total value-added output of all industries. Obviously, this index does not directly compare with the amount of waste produced, which is measured in units of weight. However, as a first approximation we can still use this index to evaluate at least the consistency of the approach of the present paper.

A second problem is that the amount of solid waste is the sum of two streams: one is industrial solid waste and the other municipal solid waste. It would be possible to consider the amount of industrial solid waste generated, or its subset in terms of hazardous waste, as a better indication of the final output of the industrial process. Unfortunately, data for this kind of waste are often missing or unreliable. In the case of the US the problem derives, among other factors, as the result of the exclusion of wastewater from 1997 in national reporting [21]. The few accessible data for industrial waste in China are updated just up to 2003, revealing an increase in the generation rates [27]. No data appear to be available for industrial waste production in Japan, while those for hazardous waste in Australia clearly show a peak [31]. A trend can be seen for the case of Italy, where we can see that the declining trend of the industrial waste is preceded by a peaking industrial production index around 2006 [22]. However, the available data appear to be insufficient for a significant assessment of the ongoing trends and, as a consequence, here we can only attempt to compare the industrial production index with the amount of municipal solid waste, for which detailed data are more easily available. As stated in a previous section, the lifetime of the consumer products that end up as MSW is short, at most of the order of the year, and so we do not expect a significant shift in the productive trends of the industrial system with respect to those of MSW generation.

A first comparison can be attempted for the US economy. Here, the data from [21] (Figure 8) indicate that industrial production and MSW generation peak at approximately the same time, although industrial production seems to peak somewhat later. The discrepancy is probably to be attributed to the fact, already mentioned, that the two curves are based on data which are not perfectly comparable.

Figure 8. Municipal Solid Waste (MSW) generation trends and industrial production index for the USA.

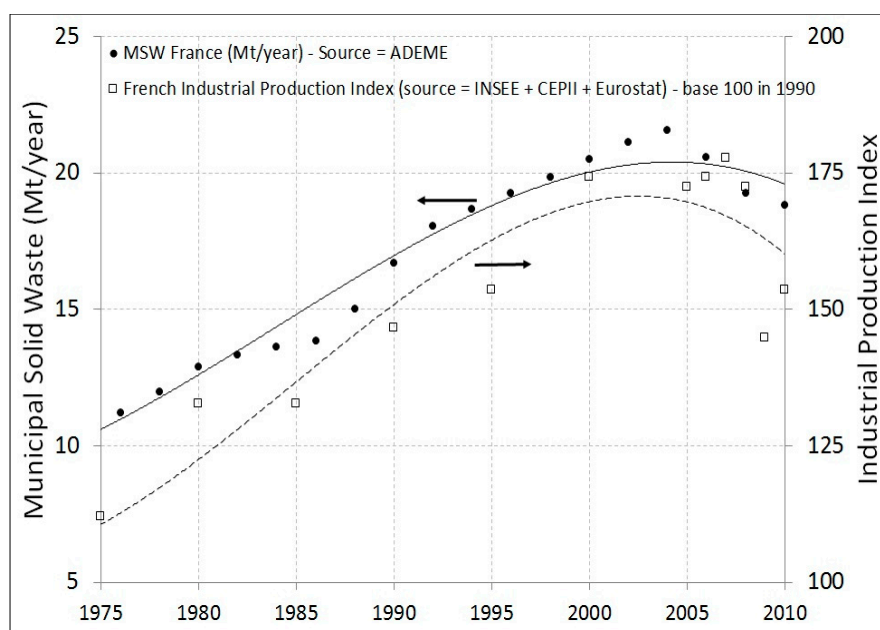
The opposite trend can be seen for the case of Italy, where industrial production peaks approximately four years before waste production (see Figure 9, data from [23] and [24]). Here, the data probably reflect the important contribution of industrial goods which end up in the waste stream and which have a longer lifetime than that of ordinary MSW.

Figure 9. MSW production and industrial production index for Italy.

Finally, below (Figure 10) are the results for France (data from [25]). Here, too, we see that the industrial production index and the MSW generation peak at about the same time although, as in the case of Italy, industrial production appears to peak some years earlier.

There are several other cases that can be examined, for instance the EU-27 case shows a trend in which a peak industrial production turns out to be almost exactly coincident with that of MSW generation. In general, there does not appear to exist sufficient data for a definitive statement on the fact that industrial peaking precedes the MSW peak, even though several datasets indicate that this is the case. However, it is clear that the two peaks are correlated and that MSW generation does not keep increasing forever and tends to follow the trend of industrial production.

Figure 10. MSW production and industrial production index for France.



5. Conclusions

As indicated by dynamic studies performed several decades ago [13], the gradually diminishing returns of the extraction of mineral resources is going to affect the whole world's industrial system and, with it, the amount of solid waste produced. The data and models reported in the present study indicate that the slowing down of waste generation is a robust trend that appears in several developed regions of the world and it may be interpreted as related to the slowdown of industrial growth, in turn related to the increasing costs of extraction of all mineral commodities [32]. In other words, “Peak Waste” could have already occurred for municipal solid waste or be going to occur in the near future. This result is a long term trend in waste generation which is additional to other long term trends such as the one that sees a gradual change in the composition of municipal solid waste. The data on this point are scarce, but it seems clear that better treatment facilities are leading to the recovery of larger amounts of metal which, consequently, do not end up any more in landfills [33,34]. It is clear from these results that “waste” is a continuously changing entity. The data available do not permit a detailed modeling of the worldwide waste trends, but the results of the present study show that the “waste problem”, in terms of the need of new and expensive facilities may be often overemphasized in the current debate

because decision makers still base their planning on the idea of a continuous increase in the amount of waste produced (see, e.g., [1]). Instead, if we are seeing a declining trend in the overall mass of waste produced, our priority should become to improve the recycling of solid waste by working towards a closed cycle economy.

Author Contributions

Ms. Pierini contributed the bulk of the data mining necessary for this article. The other authors were involved mainly with modeling and with assembling the study.

Conflicts of Interest

The authors declare no conflict of interest.

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