TITLE: Emission of pollutants: From understanding time trends and regional patterns to predicting the future

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INTRODUCTION

Setting. Emissions of pollutants into the environment are notoriously difficult to determine because of scarce data and underdeveloped theories [Pennington et al. 2005, Meesters et al. 2014, Douziech et al. 2017]. As a result, orders of magnitude differences between estimated and monitored concentrations have been noted. While mechanistic models have been developed for the fate, exposure and effects of pollutants, emissions can still only be obtained from bookkeeping on a case by case basis. Fortunately, regularities are gradually emerging. Over time, emissions have been noted to increase exponentially, (cor)related to population density, economic production and material use. After a substance has been banned, discharge also decreases exponentially, implying that societies release a fixed fraction of the remaining amount each year. Across space, pollution varies with latitude, linked to population density and economic production as well. Even more, production and emission are related to size, e.g., of companies, cities and countries. Release of air pollutants has been demonstrated to scale to company and city size [Fragkias et al. 2013, Lamsal et al. 2013, Steinmann et al. 2014, Han et al. 2015, Janjajam 2018]. While current bookkeeping estimates assume emissions to be linearly related to the number of people in companies, cities, data show that sub-linear and super-linear relationships occur frequently too. Deviations from linearity can be understood from similar patterns observed for the consumption or production of fuel, electricity, water, commodities in e.g., equipment, cities and countries of different sizes.

Gaps. These patterns and trends have mainly been observed for a few macro-pollutants (see references above). Similarities across substances (e.g., nutrients, metals, organic toxicants), sources (e.g., from rural/agricultural or urban/communal-industrial to water or air), periods and regions (local-global) have not been analysed. In particular, explanations for micro-pollutants have been based on anecdotal information rather than systematic investigation.

Objectives. Following these gaps, we aim to 1. relate emissions to time/space (latitude) and co-varying variables such as population density and economic growth. 2. relate emissions to company, city or country size and co-varying variables such as energy use. 3. explain slope and intercept differences of 1 and 2 across substances, sources, periods and regions etc.

METHODS

Theory derivation. Select appropriate models (e.g., SIMPLETREAT). Relate transport rates of air, water (e.g., irrigation/drainage, drinking/sewage), materials (production/waste) carrying the pollutants and transformation rates breaking down the pollutants to size, e.g., of cities or catchments (REUSE), temperature, chemical properties (QSAR [Nolte et al. 2017]) and other variables. Specific substances might require additional development of theory. In particular, although emission of particles is uncertain because of poor information on aggregation and other processes [Meesters et al. 2014], levels in mixtures might converge to simple size distributions, like those of natural particles. Size distributions of mineral fragments and dead organic particles or living organisms are remarkably similar. Data collection. Collect data on production, use and emission of substances from literature and databases on industrial (e.g., registration offices), agricultural (e.g., recommended or actual use), communal (e.g., influent concentration STPs) sources per company, city, region, country. If this information is lacking, concentrations can be used to reconstruct emission trends and patterns [e.g., Lindim et al. 2015]. Data treatment. Derive trends and patterns by fitting these data to exponential, power or other functions of time, size and other variables such as Gross Domestic Production (GPD). Determine whether slopes (exponents) and intercepts (coefficients) of these functions differ statistically significant across substances, sources, periods and regions.

EXPECTED RESULTS AND DISCUSSION

Results. Typically, we will provide figures and tables (with intercepts and slopes and their 95%-CIs) showing emissions as a function of time, size (companies > cities > countries) and other relevant variables. We will start with relatively "easy" cases and then move to more "difficult" one's, keeping feasibility in mind. We will start with explanatory variables like population and production, look at inert macro-pollutants (e.g., carbon dioxide), move to degradable micro-pollutants (e.g., pesticides) and end with nano-micro particles. For the same reason, we will first focus on sources and regions for which most data are available (e.g., waste water, high-income countries) and then move to other cases (e.g., solid waste, low-income countries). Discussion. We will focus on differences between substances, sources, periods and regions. We will we interpret these differences by looking at underlying causes, for example, differences in chemical properties (e.g. molecular mass, octanol-water, air-water partitioning), physical conditions (e.g., temperature), manufacturing habits, population characteristics (e.g., income) and the like.