



VOC emissions from Tetra Pak's converting factories

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Sammanfattning

Det här kandidatarbetet består av en pilotstudie på luftutsläppshanteringen från sex av Tetra Paks konverteringsfabriker med syftet att kartlägga aktuella luftutsläpp av flyktiga organiska ämnen (VOC), luftreningsutrustning och lagkrav. En beskrivning av de påverkan vissa VOC har på miljön är också inkluderat.

Tetra Paks 36 konverteringsfabriker utspridda över hela världen producerar årligen 167 miljarder dryck och matförpackningar. I processerna i dessa fabriker används bland annat lösningsmedel och plaster (polyetylen) som genererar luftutsläpp av VOC. Luftutsläpp av VOC har både negativ direkt och indirekt påverkan på miljön. Till exempel kan utsläpp av VOC:n etylen medföra en rad missbildningar på olika växter. Genom reaktioner mellan VOC och andra luftföroreningar i troposfären skapas ämnen som likt etylen är skadliga för växtlighet, däribland marknära ozon. Forskning kring påverkan av VOC på miljö är dock väldigt begränsad.

VOC-utsläpp är reglerat på både internationell och nationell nivå. Dock är inte alla fabriker i denna studie verksamma i länder som har lagkrav på VOC-utsläpp. Två av de sex studerade fabriker har problem med att uppnå sina nationella lagkrav för utsläpp av VOC. Samtliga sex fabriker genererar VOC-utsläpp men endast två fabriker har reningsutrustning som reducerar mängden VOC i utsläppen.

Nyckelord: Tetra Pak, VOC-utsläpp, marknära ozon, konverteringsfabriker, miljöpåverkan

Abstract

This thesis consists of a pilot study on air emission management from six of Tetra Pak's converting factories with the aim of mapping current air emissions of VOC, air purification equipment, and legal requirements. A description of the impacts of certain VOCs on the environment is also included.

Tetra Pak's 36 converting factories scattered all over the world produces 167 billion beverage and food packagings annually. In the process of packaging production, solvents and plastics (polyethylene), among other substances, are used which generates emissions of VOC. Air emissions of VOC have both negative direct and indirect impacts on the environment. For example, emissions of the VOC ethylene cause a range of growth abnormalities in different plants. The reactions between VOCs and other air pollutants in the troposphere form substances which, like ethylene, are harmful to vegetation, for example ground-level ozone. Research on the effects of VOCs to the environment is however very limited.

VOC emissions are regulated at both the international and national level. However, not all factories in this study are located in countries that have legal requirements for VOC emissions. Two of the six studied factories are having difficulties complying with their national legal requirements for emissions of VOC. All six factories generate VOC emissions but only two factories have air purification equipment that reduces the concentration of VOCs in the emissions.

Keywords: Tetra Pak, VOC emissions, ground- level ozone, converting factories, environmental impact

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List of abbreviations

VOC Volatile Organic Compounds

MSP Million standard packages

AOS Average Order Size

1. Introduction

In daily life, people drink and eat food products packaged in carton. Dairy products like milk and yogurt as well as juices and other beverages, tomatoes, beans, soups, sauces, peas, corn etc, are available in carton packages. Tetra Pak produces about 167 billion of these packages annually in their 36 converting factories, scattered all over the world (Tetra Pak 2012). In the production of these packages, templates (clichés) are manufactured in order for the printers to be able to transfer the eye-catching design to each package. In the process of manufacturing the clichés, large amounts of organic solvent is used resulting in Volatile Organic Compounds (VOC) being emitted to air. In order for the carton to function as a food container it is coated with protecting layers of plastic and other materials in the lamination process. This also results in emissions of VOC, but the largest emission from lamination is plastic smoke and ozone.

VOC have negative effects on humans by increasing the risk of cancer (particularly benzene) and irritation of the airways, which can worsen asthma (particularly aldehydes) (Sjöberg 2004). The threshold for protection of human health for benzene is $5 \mu\text{g}/\text{m}^3$ (yearly average) in the EU (Council Directive 2008/50/EC).

Besides being harmful to humans, VOC have negative environmental impacts, both directly and by being a precursor to other harmful substances, such as ground-level ozone. VOCs, ground-level ozone and other substances that are formed in reactions with VOC have been shown to shorten the life time of plants and reduce crop yields and fruit harvests (*e.g.* Collins & Bell 2002; Felzer et al 2007). Thus, the production of food packagings can ultimately damage the fruits and vegetables that will later be found in the food packagings.

Air emissions of VOC have been internationally regulated since 1983 by the 1979 Convention on Long-range Transboundary Air pollution (CLRTAP 1979). The original convention addressed the harmful effects of general air pollution on humans and the environment. In 1991 the protocol concerning the control of emissions of VOC was adopted in the 1979 convention. In year 1999 the European Union adopted a directive on limitations of VOC emissions caused specifically by use of organic solvents in industrial activities (Council Directive 1999/13/EC). The use of solvents in industrial processes is a major source of VOC emissions (European Environment Agency 2012).

This study focuses on VOC emissions from Tetra Pak's converting factories, air purification management, and the effects of VOC emissions on the environment.

1.1 Aim and scope

Air pollution can cause great damage to both humans and the environment, but this thesis focuses on air pollutions' effect on the environment.

The purpose of this study is to map air emission management at the converting factories within Tetra Pak, by air emission measurements performed by the factories and by mapping the air purification system in use. The thesis also includes a literature review of the effects of air emissions of VOCs on the environment. The specific substances handled in the literature review are possible emissions from Tetra Pak's converting factories and substances formed in reactions where these possible emissions take part.

1.1.1 Limitations

This study includes surveys of air emission from six of Tetra Pak's converting factories with limitations to the emissions from the major sources, which are prepress and lamination (Carlsson 2012). Air emissions from the actual printing are negligible and thus excluded from this study. The same applies to other small air emissions that the factories generate, such as emissions from boilers (which heats the building). Parameters like metrological conditions, wind direction, air-mixing average temperature and height of chimneys are also excluded. The thesis is limited to air emissions of VOC because these emissions are to be expected from prepress and lamination in Tetra Pak converting factories.

2. Method

The method for this thesis is a qualitative survey (2.1) with additional telephone interviews (2.1.1).

2.1 Survey

The survey is designed based on my own knowledge from a similar study conducted on waste water, with information provided by my supervisor Martin Carlsson (2012) and *Enkätboken* (Trost 2007).

The information about Tetra Pak's converting factories' air emissions were collected by a survey of six factories. Since this is a pilot study the number of factories is limited to six in order to evaluate the survey before including all the Tetra Pak's factories. The factories included in this study were chosen because they all use flexography printing technology and water based ink, while being situated in different parts of the world. This would allow comparisons of Tetra Pak's air emissions and air emission management in different countries and regions.

A first draft of the survey was tested on one environmental coordinator at one factory before the final survey was established. This factory is included in the study, having answered the final survey.

The survey was sent out via email to the each factory's environmental coordinator who had two weeks to complete it. For detailed and/or technical issues, the coordinators were instructed to assign the question to colleagues more equipped to answer. In the email was a brief description of the survey and the date for when the survey should be completed, see Appendix A.

The survey had three parts: information sheet, survey sheet and measurement sheet. The information sheet contained information about the aim and the structure of the survey. The survey sheet contained a total of 59 questions (Appendix B). Additional explanations to the questions were added when needed. Most of the questions were factual, but some questions could be interpreted as matters of opinion. For example, the question "Do you have problems with the purification equipment". The interpretation of a problem could be quite different depending on who is responding to the survey (Trost 2007).

Questions were designed either as multi choice questions with a limited number of response options to choose from, or as open questions which could be answered freely, some of which had a set type of answer, e.g. numbers. The multi choice questions were questions where all the possible answers or the most common answers were known. The latter also had

the option “other” with included space to write freely. The purpose of the multi choice questions was to ensure comparable answers and ease the information processing (Troost 2007). This was also the case with the set-answer-type open questions (Troost 2007). The questions were divided into seven sections: General, Air purification system, Costs, Legal requirements, Measurements, Calculations and Activity. In the measurement sheet the factories were to provide the most recent measurements on air emission. The entire survey, including all sheets, is attached in Appendix B.

2.1.1 Telephone interviews

Telephone interviews were conducted with the aim to gain a deeper understanding, and ensure the accuracy, of the factories’ answers. The entire survey was reviewed with additional focus on the parts that were unclear. Additionally, some issues emerged and were clarified during the phone meetings that probably would have passed unnoticed otherwise. The information from the phone meetings is included in the results from the survey. After the phone meetings, the factories had the opportunity to provide additional information (via email) that was missing at the time of the meeting.

2.2 Mass balance calculation

To estimate the amount of each factory’s air emission, mass balance calculations were performed (see figure 1).

The definition of a mass balance is that what is inserted (input) into a physical process must correspond with what comes out (output) (Ontario Ministry of the Environment 2007). In this case a mass balance calculation would account for the solvent being inserted into processes and the output from processes being of equal mass. This means that the sum of output solvent, VOC emissions and solvent residue is equal to the input solvent. For a schematic view, see figure 1 below.

Mass balance is only calculated for the prepress process due to measured amounts of incoming and outgoing solvents and because it is where the highest concentrations of VOC emissions can be found.

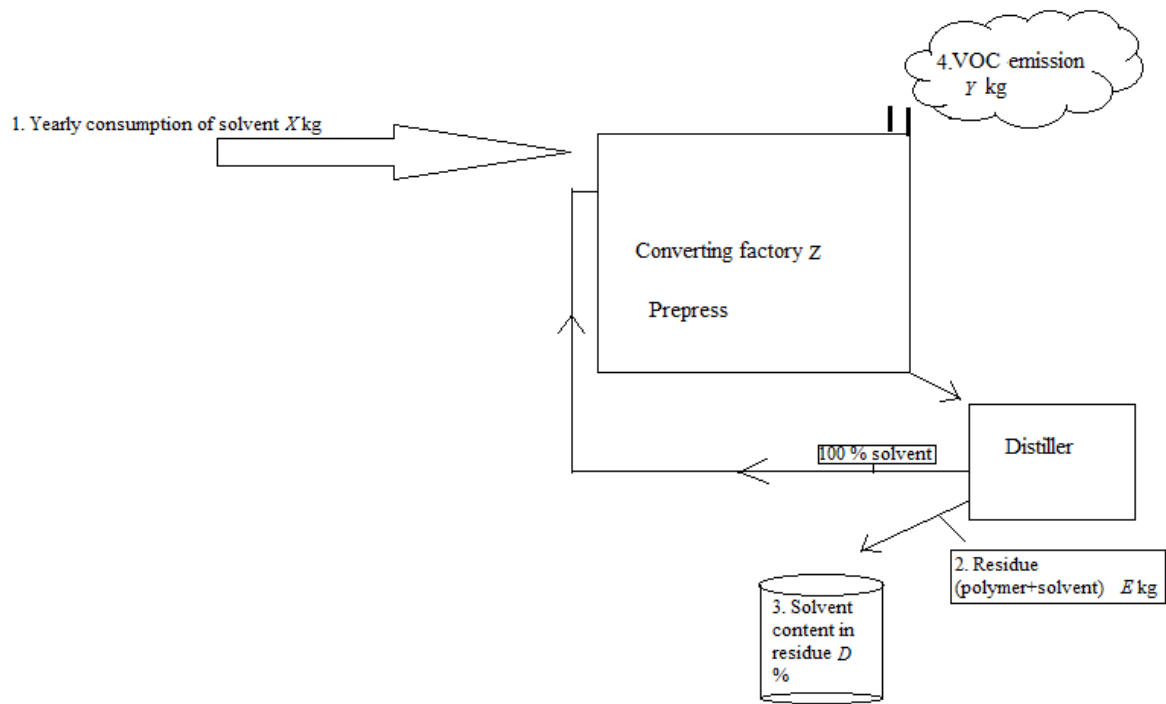


Figure 1. Schematic view of the solvent used in Tetra Pak's prepress process.

The mass balance calculations require the following information:

1. Yearly consumption of prepress solvent (kg)
2. Annual amount of residue generated by the distiller (kg)
3. Estimated solvent content in residue (%)
4. Concentration of VOC in the airflow, airflow/ year and operation hours (mg/m^3 , m^3/year , hours)

If reliable measurements exist, requirement 1 and 4 is enough to do a (calculation of emission) mass balance calculation. If only requirement 1 and 4 is available, requirement 2 can be calculated and hence the yearly loss of solvent in the distillation process. If no measurements exist but requirements 1, 2 and 3 are available the following calculations can be performed:

- A. Solvent in residue (kg) = Solvent in residue, in % (3) * annual amount (kg) of residue generated by the distiller (2) = A Kg
- B. VOC air emission (kg) = Yearly consumption of prepress solvent, in kg (1) - Solvent in residue (A) = B Kg.

A+B (output) equals the yearly consumption of prepress solvent (1) (input).

These calculations do not take into account possible air purification equipment. If the loss through distillation process should be calculated, the following calculation is used.

C. Loss through distillation process:

$$\frac{\text{Solvent in residue (kg)}(A)}{\text{Yearly consumption of prepress solvent (kg)} (1)} \approx C \%$$

3. Review of air emissions of VOC

Volatile Organic Compounds (VOC) are involved in the formation of ground-level ozone together with nitrogen oxides in the presence of sunlight (see section 3.3.2 below). In addition to the indirect effect as a precursor to ozone, VOCs are also a precursor to other substances of which some have direct effects on the environment.

3.1 Definition of VOC

Volatile Organic Compounds (VOCs) are substances which have such high vapour pressure that they spread in air in typical conditions, i.e. 20°C (ESIG 2012). Generally, their solubility in water is low, but many compounds have fat dissolving properties. VOCs consist mainly of at least carbon and hydrogen, but may also contain oxygen, sulphur, halogens and nitrogen. Methane, ethane, CO, CO₂, organometallic compounds and organic acids are excluded from the definition (ESIG 2012). There are up to 13 000 VOCs (Collins & Bell 2002).

The most common short definition of VOC is found in the solvents emissions directive (Council Directive 1999/13/EC), “volatile organic compound (VOC) shall mean any organic compound having at 293.15 K a vapour pressure of 0.01 kPa or more, or having a corresponding volatility under the particular conditions of use” (Council Directive 1999/13/EC).

A few examples of VOCs are:

- Formaldehyde
- Isopropanol
- Naphthalene
- Benzene
- Toluene
- Xylene
- Ethylene

3.2 Direct effects of VOC

There are very few studies conducted on VOCs’ direct impact on the environment (*e.g.* Collins & Bell 2002). Most studies on VOC are about their contribution in photochemical oxidant formation (see below 3.3.2) (*e.g.* Collins & Bell 2002). One VOC that has received attention due to evidence of its direct negative impact in the field (as opposed to laboratory experiments) is ethylene, but even these studies are rather limited (Collins & Bell 2002).

In Cape’s (2003) research review a serious shortage of information regarding VOCs is pointed out. While some VOCs have been proven to have a direct effect on plants in laboratory studies, these studies are generally performed with high concentrations (much higher than the concentrations observed in the field) over a very short period of time (Cape

2003). Very few studies with realistic concentration over a longer period of time have been conducted (Collins & Bell 2002).

3.2.1 Ethylene (C₂H₄)

Ethylene naturally occurs as a plant hormone which regulates growth, flower development, fruit ripening, abscission of organs and senescence (Collins & Bell 2002). Ethylene is a dangerous air pollutant because it regulates these processes, which means that it, as an air pollutant, can cause growth abnormalities in plants (Abeles & Heggstad 1973).

Reported effects of ethylene on plants are inhibition of bud growth, reduced flower and fruit production, yellowing of conifer needles, premature opening of tree flowers, epinasty, chlorosis or red/purple discoloration of leaves, induction of roots from stems, and premature fruit ripening (Collins & Bell 2002). Taylor and Gunderson (1988) also found that ethylene reduced plants' ability to assimilate CO₂, not only by inhibiting the plants' stomatal effects but by actually damaging the tissue in which the process takes place which raises a question of ethylene's chronic effects on plants.

Abeles and Heggstad (1973) performed a study on plants grown in chambers filled with filtered air, unfiltered air and air containing various higher concentrations of ethylene. The study showed ethylene's detrimental effects on plant growth quite clearly. For example the red kidney bean had 26 fruits when grown in filtered air, 10 fruits in unfiltered air, 5 fruits in air containing 25 ppb ethylene and no fruits at a ethylene concentration of 50 ppb. Similar results were observed in other species (Abeles & Heggstad 1973).

3.3 Indirect effects of VOC

3.3.1 Precursors for nitrophenols

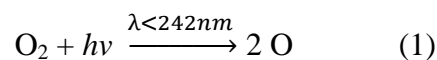
The primary source of nitrophenols is automobile exhaust but they can also be formed in the atmosphere by reactions of benzene, NO_x and alkylated aromatics with hydroxyl radicals (Collins & Bell 2002). Other known precursors are toluene and m-xylene (Belloli et al 2000). Nitrophenols has been studied as a possible contributor to forest decline and 2,4 – dinitrophenols phytotoxic effects have been observed and studied (Collins & Bell 2002). Dinitrophenols causes a decline in growth, nutrient uptake and transpiration. The damage in plants is caused by dinitrophenols acting as uncouplers of oxidative phosphorylation. This means that dinitrophenols essentially prevents the cells from converting energy to a form (ATP) that is usable in the cell. Because of dinitrophenols toxicity it has been used as herbicides and insecticides (Leuenberger et al 1988).

3.3.2 Ozone

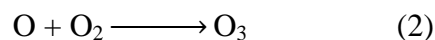
Most of the ozone is found in the stratosphere, protecting us from dangerous UV-radiation. The continuous depletion of the stratospheric ozone is a global environmental threat (Braslavsky & Rubin 2011). However, the increasing amount of anthropogenic ozone in the troposphere is also a problem (Braslavsky & Rubin 2011). These two environmental problems are considered as separate problems since the gas exchange between the spheres is very slow (Petersson 2008). The largest source of anthropogenic ozone is definitely from traffic, but other activities such as industrial and energy production are also large contributors (Pleijel 1999). This section deals with the formation of ozone in different parts of the atmosphere.

3.3.2.1 Reactions in stratosphere

In order to form ozone, O_2 needs to be decomposed to free oxygen molecules (O), which is shown in reaction (1) below. To break up oxygen molecules (O_2) high energy UV rays, which are marked $h\nu$, and a light containing wavelength shorter than 242 nm, (which is marked above the arrow below), are required.



Thereafter, these atoms of free oxygen react with oxygen molecules according to reaction (2) below.

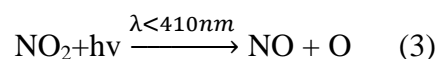


Some of the ozone formed in reaction (2) is also decomposed in reaction with light which keeps the ozone level balanced. Lights with such short wavelength that are required in reaction (1) do not reach that far down to earth, and thus ozone cannot be formed in the same way in the troposphere (Pleijel 1999).

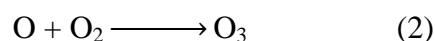
3.3.2.2 Reactions in troposphere

Tropospheric ozone is commonly referred to as ground-level ozone.

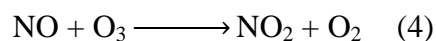
In the troposphere not only the right wavelength of light is required to form free oxygen atoms, but also the presence of nitrogen oxides (NO_x) and hydrocarbons, (Petersson 2008), see reaction (3) below. Most of the ozone is formed during the day and the summer months due to light dependency of the reaction (3) (Petersson 2008).



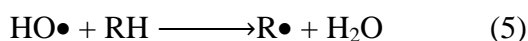
After reaction (3) follows reaction (2) in the same way as it did in the stratosphere.



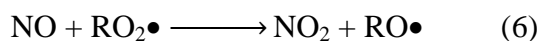
The formed ozone from reaction (2) is consumed in reaction (4) between ozone and nitrogen monoxide (NO).



The reaction cycle formed by reaction 2, 3 and 4 does not result in high levels of ozone (Pleijel 1999). The additional reaction steps that follow generate high levels of ozone with influence of Volatile Organic Compounds (VOC). These reaction steps are most easily described by naming the organic substance RH. In reaction with free radicals in the atmosphere the organic substances (RH) are decomposed, see reaction (5).



The formed hydrocarbon radical $\text{R}\bullet$ then reacts with the oxygen in the air and a peroxy radical $\text{RO}_2\bullet$ is formed. This radical competes with ozone to oxidize NO to NO_2 which means that, unlike in reaction (4) where the ozone is consumed, NO is converted to NO_2 as in reaction (6) below:



The nitrogen oxides basically behave as a catalyst and may be regenerated as long as suitable organic compounds are available in the air. When the organic substances are broken down into carbon dioxide, $\text{RO}_2\bullet$ and $\text{RO}\bullet$ are formed. This means that nitrogen dioxide, which is the basis for ozone formation, can be regenerated repeatedly if suitable organic compounds are present in the air. Consequently, ozone concentration rises since no ozone is consumed in the reaction cycle.

Specific Volatile Organic Compounds' (VOC) efficiency to contribute to the formation of ozone is diverse. Alkenes, aldehyde, and aromatics are considered most contributing, while methanol and ethanol are less reactive and thus contribute less (Elvingson 2001). The potential of ethane is 1.5 times greater than for ethylene, and o-xylene has twice the potential of ethane to form ozone (Colvile 2002). The actual concentration of the substances is however not at all as important as the right ratio between VOC and nitrogen oxides (Naturvårdsverket 1990).

Usually, ozone levels in urban areas and at major roads are lower compared to rural areas. This is due to emissions from cars contain much nitrogen monoxide and a little of nitrogen dioxide. Nitrogen oxide (NO) depletes the ozone quickly as in reaction (4) and hence levels of ozone are reduced locally. However, nitrogen dioxide, the basis for ozone formation, is formed in the process, which in turn can result in high levels of ozone. This can take place tens of kilometers away from the emission source (Elvingson 2001).

Newly-formed ozone is long lived and has the ability to travel relatively long distances which is a long-range transnational problem (Elvingson 2001). But the local situation is of great importance. An example of this is photochemical smog, which occurs when air masses are trapped by local high topography (such as high buildings) and through the influence of sunlight forms a toxic mixture of hydrocarbons and ozone (Colvile 2002).

Naturally emitted VOC, termed BVOC (Biogenic Volatile Organic Compounds), may also have a significant influence on the formation of ozone. On its own, BVOC are not forming a significant amount of ozone (Castell et al 2008) and some BVOC, such as terpenes from trees, can even reduce the photochemical reactivity (Colvile 2002). But through interaction with anthropogenic emissions of VOC, ozone formation may increase significantly, which means that both of these factors and their interactions must be considered in strategies for reduction of ozone precursor substances (Castell et al 2008).

3.3.2.3 Effects of ozone

It has long been known that ozone, besides having detrimental effects on human health and material, is one of the most significant air emissions that cause damage to plants. The visible effects of ozone on plants is primarily that the leaves become spotted and brown colored, due to chlorophyll production being inhibited (chlorosis), whereafter the leaf tissue dies (necrosis). The result is a premature aging which result in both lower yield and poorer quality of the harvest. A correlation between the visible and physiological effects does not appear to be present in all plant species (Pleijel 1999; Felzer et al 2007). Physiological effects on plants are inhibited stomatal conductance, reduced root growth, impaired reproduction, reduced photosynthesis among others (Felzer et al 2007). The decrease in photosynthesis results, according to Reich (1987 in Felzer et al 2007) in a growth reduction of 13 % for hardwood and 30 % for crops. Direct effects of ozone on tree species have been documented in California where forest decline certainly not have been proven but changes in forest composition took place (Innes & Skelly 2002).

Agricultural crops

Most of the studies on ozone's effects are conducted on crops, which have suitable properties for experiments as they have a short life time (Pleijel 1999). From an economic perspective, wheat is one of the most important crops and after many studies there is very strong scientific evidence that wheat is very sensitive to ozone (Pleijel et al 1997). Beans are perhaps even more sensitive, but the ozone sensitivity differs for the many different varieties (Pleijel et al 1997).

Dingenen et al (2008) estimated that the global crop losses due to ozone in 2010 were 8-12 % for wheat, 6-16 % for soybeans, 3-4 % for rice and 3-5 % for corn. Similar figures are presented in previous studies on ozone levels in 2000 (Avnery et al 2011). Converted into money this would correspond to a global economic loss of 14-16 billion dollars per year (based on world prices of 2000). For countries and regions with an economy based on agricultural production this means a high risk of economic growth reduction due to crop losses caused by ozone damage (Dingenen et al 2008).

Delgado-Saboriat et al (2008) estimated yield losses of lemon and orange to 10 % and 8 % due to high levels of ozone in the western Mediterranean area. In this area, these trees are a major economic resource and which means that such a loss has serious consequences for the local economy.

Several experiments across Europe and Sweden show that the growth of wheat is significantly increased when ambient air does not contain ozone (Pleijel et al 1997; Pleijel 1999). In the studies, (field) chambers were used in which the wheat were exposed to different concentrations of ozone, from filtered air with very low levels of ozone to unfiltered air with ozone added. The aging was faster the higher ozone exposure was (Pleijel et al 1997; Pleijel 1999).

In pace with the growing population the need for greater crop yields increases. Instead of using environmentally poorer methods that increased fertilization, water consumption and/or larger land areas, a reduction in O₃ can achieve the same result but in a sustainable way (Avnery et al 2011).

Estimations of ozone's adverse effects on vegetation are often based on the exposure index AOT40 (Accumulated exposure Over Threshold). With this exposure index, the level of ozone in the air is calculated but no account is taken of the plants' uptake of ozone. The uptake capacity of plants varies depending on their stomatal conductance since it is through the stomata the plants' gas exchange is regulated. For instance, in regions or periods with dry air stomatal conductance reduces and the ozone uptake decreases (Elvingson 2001; Bell et al 2002).

4. Tetra Pak's converting factories

The material for what will become some kind of beverage- or food packaging is produced in the converting factories. In the Tetra Pak's converting factories across the globe the same fundamental principles are widely used to make these packagings. The processes differ somewhat between factories and the principal parameters affecting the composition of air emission are the following: Printing Technique (flexography, rotogravure or offset), type and composition of printing ink (water based, solvent based, ultra-violet or electron beam and purification equipment. In addition to these parameters, there are others that have an effect, for example the range of operating hours.

4.1 Converting process

The route to a finished Tetra Pak beverage- or food package starts at the paper mill where the board is made, followed by processes that are taking place in the converting factories where the board is turned into the finished product. In short the converting process can be divided into three phases; prepress (4.1.1), printing (4.1.2) and lamination (4.1.3).

4.1.1 Prepress

In the prepress phase order-specific clichés are produced. Through exposure of UV-light the design is transferred onto photopolymer plates. In order for the material to get its printing surface it is run through a plate developer where the material is washed with a 100 % organic solvent. The waste solvent is purified by a distiller and reused in the plate developer. The residue from the distillation contains dissolved photopolymers and solvent. Thereafter the material is dried in a drying oven (plate dryer) and treated with UV-C and UV-A light in a plate finisher. The finished clichés are mounted on sleeves, ready to be loaded into the printing presses.

The prepress equipment that are generating air emissions are the plate developers, plate dryers, plate finishers and solvent distillers.

4.1.2 Printing

The board comes in rolls that fed into the printing process where it converges with the cliché. The cliché is attached to a roller and its raised areas are coloured in the ink stations to produce the wanted design (flexography method). The solvent concentration in the water based ink, which is the most common type of ink used in Tetra Pak, is less than 8 %. The outgoing air flows from printing are high and thus the potential air emissions contains very low concentrations of VOC compared to prepress.

4.1.3 Lamination





The lamination system includes at least one ozone generator and one laminator that consist of a laminate station, an inside station and a decor station. The printed board is passed on to the lamination where it is laminated with polyethylene, on the inside and outside. The polyethylene is extruded on the board as thin film. If the carton will become an aseptic packaging the carton is laminated with aluminum foil between two polymer layers on the inside. Ozone is used to facilitate the oxidations of the polymer and the aluminum during the lamination. In this process there are emissions from the extrusion hoods containing VOCs, for example formaldehyde, formed by melted polyethylene.

After this the rolls continue to the slitting process where the roller size is adjusted to the customers filling machines.

4.1.4 Description of possible emissions

Below is a summary table (see table 1) of the materials/substances that are input into the processes, which substances that may be released to air and the equipment that generates emissions.

Table 1. Materials/substances, emissions and emission sources, from prepress and lamination in Tetra Pak.

	Input material	Emission	Emission sources
Prepress	-Photopolymer plates  -Organic solvent	-VOC -Photopolymer/solvent sludge	-Plate developer  -Plate dryer and finisher  <i>Combined</i> <i>Separate</i> -Distiller 
Lamination	-Various Polymers (polyethylene, adhesive polymers) -Ozone	-VOC -Ozone -Plastic smoke	-Laminator (laminate station, inside station and decor station) -Ozone generator

5. Results

The results below are divided into measurement methods (5.1) processes (5.2-5.3), air purification system (5.4), legal requirements (5.5) and the yearly reporting of VOC (5.6). Unless otherwise specified, the result is based on the production values of 2011.

5.1 Measurement methods

Of the five factories that are doing any kind of measurements, three (A, B and C) use direct-reading FID-instruments (Flame Ionization Detector). Other used methods are carbon filters, membrane filters and potassium iodide method (measurement of ozone). The method used in Factory D and F are some forms of gas analysis, but due to language barriers it is difficult to interpret what they actually do.

Factory A makes measurements on the air from the prepress, (printing) and lamination in the ventilation pipe a few meters after purification. Factory B makes their measurements of air from the chimneys on the roof. They make measurements on the air from lamination (after electrostatic filter), and from all prepress equipment (the plate developer, plate dryer and plate finisher).

Factory C makes measurements at a single point where all the air from prepress and lamination meets before purification and at a measuring point after purification. Factory D measures the air on 12 points in the production hall, residential area, potential residential area and additional points within the factory area. It may be noted that these measurements are primarily of NO₂, SO₂, CO and particles but it is unclear which processes the air comes from.

Factory F measures the air from prepress and lamination after purification. The cost of the factories' measurements varies between 3200 and 7775 Euros per year.

5.2 Prepress

The factories' total estimated airflows from prepress equipment varies between 1700 m³/h - 5400 m³/h. Factory E has little information about their equipment, and thus lacks the estimation of airflow. Five factories have their own distiller while Factory E sends their solvent residue to a supplier that distils the solvent for them.

All factories except Factory E use the solvent product called Flexosol, containing the components: *Decahydronaphthalene* (>25 %), *Bensylalcohol* (2.5–10 %), *Naphtha (petroleum)* (>25 %) and *2-Ethylhexan-1-ol* (<=2.5 %). Factory E uses the solvent product called Resoflex, which contains *Alcohol*, *aliphatic hydrocarbon* and *glycols ethers*. The quantity of each component is not released by the manufacturer.

Table 2 shows yearly consumption of prepress solvent, calculated airborne VOC emissions before and after purification, the loss through distillation process and the solvent content in the residue in the factories. The values in table 2, except for the input solvent, are calculated according to the mass balance calculation in section 2.2.

Table 2. Yearly consumption of prepress solvent, estimated airborne VOC emission before and after purification, loss through distillation process and solvent content in residue.

Factory	Consumption of solvent (kg)	Airborne VOC emission (kg) <u>Before purification</u>	Airborne VOC emission (kg) <u>After purification</u>	Loss through distillation process (%)	Solvent content in residue (%)
A	12750	2900 ¹	2900 ¹	77 ³	48 ³
B	9350	4200 ²	No purification	55 ³	22 ³
C	9765	4900 ³	1500 ³	20 ³	12 ³
D	12690	2900 ³	No purification	-	-
E	169700	38000 ³	No purification	-	-
F	11900	6100 ³	4900 ³	48 ³	30 ²

¹Measured value, not including finisher, ²Measured value, ³Estimated values

The airborne VOC emissions from factories with purification equipment are calculated twice: with pre-treatment values and after purification.

Estimated airborne VOC emissions from Factory A and B are based on measured values and calculated from No. 1-4 (see 2.2).

- In Factory A, airborne VOC emissions from the plate finishers are excluded which means that this value is somewhat higher in reality.
- Factory B's table values are based on measurement from all prepress equipment (plate developer, plate dryer and plate finisher).
- The table values of Factory C are calculated from the yearly consumption of prepress solvent (kg) and annual amount of residue generated by the distiller (kg). The airborne VOC emission (after purification) from Factory C, 1500 kg, comes from distillers. From 2012 the air from the distiller is linked to their purification equipment which will lower their air emission of VOC from prepress and lamination to zero.
- Some information is missing from Factory D and E, and their values are estimated from the yearly consumption of prepress solvent (kg) with an assumption based on Factory A's emission, which has the lowest proportion of airborne VOC emissions per consumed kg solvent. However, not all the air from the prepress process is included in Factory A's air emission measurement, and thus the assumption is a conservative

estimate. The purchased solvent in Factory E is at least 10 times higher, and their air emission seven times higher, than the other factories'. According to Factory E, this is due to the large production, production diversity and age of the machines, which they estimated to 20 years (they are not sure about the exact age).

- Factory F has measurements of emissions of benzene, toluene and xylene, which are estimated to 100.9 kg. These substances are only three of many VOCs and therefore the table value for Factory F is an estimate of the total air emission, not the value (100.9) they provided. The post-purification value of 4900 kg is calculated with the assumption that the purification equipment purifies air from VOC with an efficiency of 20 %.

Table 3 and 4 show comparisons between estimated air emissions of VOC (before purification) from prepress and production quantity, i.e. airborne VOC emission per packaging (MSP=Million standard packages per year), solvent per square meter clichés, airborne VOC emission per square meter clichés and airborne VOC emissions per AOS (Average Order Size).

Table 3. Factories' estimated airborne VOC emissions before purification in comparison with MSP and clichés (m²).

Factory	Airborne VOC emission (kg)	MSP	Airborne VOC emission (kg) /MSP	Clichés (m ²)*	Solvent (kg) / clichés (m ²)	Airborne VOC emission (kg) / clichés (m ²)
A	2900 ¹	3107	0,9	14217	0,9	0,20
B	4200 ²	3999	1,1	29847	0,3	0,14
C	4900 ³	2929	1,5	43282	0,2	0,11
D	2900 ³	3734	0,8	39930	0,3	0,07
E	38000 ³	4483	8,5	6462	26	5,9
F	6100 ³	6752	0,9	41650	0,3	0,15

¹Measured value, not including finisher, ²Measured value, ³Estimated values * information about square meter clichés was obtained in conjunction with the phone meetings.

Table 4. Factories' estimated airborne VOC emissions before purification in comparison with AOS.

Factory	Airborne VOC emission (kg)	AOS-Production order (m)*	Airborne VOC emission (kg)/product (m) AOS
A	2900 ¹	12940	0,22
B	4200 ²	14810	0,28
C	4900 ³	8090	0,61
D	2900 ³	12510	0,23
E	38000 ³	16240	2,3
F	6100 ³	42090	0,15

*information on factories' average order size have been obtained through contact with Jeanette Hansen in Tetra Pak.

The amount of clichés differs between the factories and therefore also their airborne VOC emissions per clichés (m²). In both table 3 and 4, Factory E stands out with their high table values for solvent and airborne VOC emission per: MSP, clichés and AOS.

5.3 Lamination

The air flow from the lamination is significantly higher than from the prepress and is between 6000-8000 m³/h per station (laminator, inside and decor), but the concentrations of emissions are lower. Two factories (A and B) have air flows from the laminator containing 15.5 mg/m³ VOCs and an annual amount of approximately 1600 kg respective 1700 kg (in 2011). Factory F has a concentration of 6.8 mg/m³ "non methane hydrocarbon" but this measurement is after purification. The other factories have no measured values on the concentrations of lamination. Factory C is the only factory that has measurements of ozone emissions. The measurements are made after the purification equipment, and the result is 3.5 mg/m³ air when the laminator is running, and 8.5 mg/m³ air when the laminator is turned off. In 2011 the total amount of ozone in air emission from Factory C was 730 kg.

5.4 Air purification system

There are three factories that have purification equipment while the other three have minor filters. Processes purified by the respective type of equipment are presented in table 5 below.

Table 5. Factories' purification equipment for prepress and lamination

Factory	Prepress	Lamination	Equipment
A	X	*	Coalescence equipment/electrostatic filter
B		*	Electrostatic filter
C	X	X	Zeolite filter
D		*	Electrostatic filter
E		*	Electrostatic filter
F	X		Active carbon

*Less significant purification equipment.

5.4.1 Active carbon

Factory F has an active carbon filter that purifies the air from the prepress. This filter purifies the air of VOCs by 20 %, specifically benzene, toluene and xylene. Active carbon is a medium-cost equipment and according to Factory F, the purchase price was 44 000 Euros and the yearly cost is 100 000 Euros. The energy consumption is 65 700 kWh/year. Factory F has not reported any problems with their purification equipment. The filter purifier is turned off at times when the filter material is changed. The used filters are sent away as hazardous waste.

5.4.2 Zeolite

Factory C purifies all air from lamination and air from the cliché production processes and dryers.

The zeolite absorbs hydrocarbons and ozone after which it is purified and reused. The contaminants are burned and the residues from the combustion are carbon dioxide and water.

The supplier of Zeolite filter, Zeotech claims that the equipment purifies with an efficiency of ≈ 100 % for ozone, 100 % for VOC and 90-95 % for plastic smoke. Factory C answered that the efficiency is 90 % for hydrocarbons. An advantage of zeolite filter is that it is very effective. Zeolite equipment is expensive and other disadvantages are high energy consumption, large equipment, that it must be run with natural gas and that the residue is carbon dioxide. The purchase price is around 1 000 000 Euro and the yearly cost is 46 370 Euro. The yearly energy consumption is 556 103 kWh/year which is much higher than for active carbon filter. Factory C has mentioned that they have some minor valve problems, which do not affect the purification efficiency.

Since the zeolite plant consists of four “beds” there is no problem if one bed fails, because the next bed would take over.

In 2011, when a new bed was installed, the zeolite equipment was shut off for two weeks. During this time, the lamination stopped but the prepress production continued under the permit given by the authorities. Measurements were made and the total emissions for 2011 were not even close to be exceeded.

5.4.3 Coalescence

Factory A’s purification equipment consist of coalescence equipment that was installed a couple of year ago. The efficiency to purify the air of VOC is, according to the supplier of the equipment, about 100 %. But according to measurements performed by Factory A, the actual maximum efficiency is 10 %. Besides being very ineffective, the equipment is quite expensive. The purchase price was 600 000 Euro and yearly running expenses are 12 000 Euro. The energy consumption is around 35 000 kWh/year.

5.4.4 Electrostatic filter

Four factories (A, B, D, and E) have electrostatic filters, which are mainly used to reduce the amount of particles in the outgoing air. The residue of the purification is in Factory E's case polyethylene oil, which is sent to a certificated purification company.

According to Factory E, the electrostatic filter purifies VOC, particles and odour. They have not done any measurements, but according to their supplier the filters purification efficiency should be between 93 and 99 %. Factory E entered that they have problems with variable efficiency of the six installed filters purifications. The reason for the efficiency difference is under investigation. The purification equipment has failed a couple of times and at those times it takes a long time to replace parts. On these occasions, the authorities were not contacted because it is not mandatory to do so. The laminators were not switched off at these times.

5.5 Legal requirements

Five of the six factories have legal requirements for air emission either by local requirements, international legislation or factory-specific permits given by the authorities.

5.5.1 Factory A

Factory A has local legal requirements on the concentrations of VOCs, SO₂, NO₂, particle material and air flow. Regarding VOC emission, Factory A is allowed to emit 100 mg/m³ at an air flow of 3000 m³/h and 50 mg/m³ at an air flow of 8000 m³/h. The flow that is allowed to be released is therefore dependent on the concentration per cubic meter.

The measurements of emissions from the prepress have shown that the air contains 186 mg/m³ (plate finisher is excluded) which exceeds the legal requirement. A few years ago, the factory realised that they exceeded the requirements which led to the installation of coalescence equipment that turned out to be very ineffective in purifying air from VOC. Thereafter, about a year ago, two extraction hoods were installed as a temporary solution in order to dilute the concentrations of VOC and improve the working environment for prepress operators. These extraction hoods are located above the plate developers and plate dryers, and are routed to the coalescence equipment. Even after adjustments the legal requirements are exceeded which is an ongoing discussion between the factory and the authorities. The measurements of VOC in the air from the laminators are below the limit.

5.5.2 Factory B

Factory B has legal requirements on the concentration of VOC and the amount VOC per hour. For VOC, the requirement is 110 mg/m³ with a maximum of 1 kg/h and for specific VOCs,

the requirement is 20 mg/m^3 with a maximum of 0.2 kg/h . Overall, they are allowed to emit 9 tons VOC per year.

For a few years the factory has had problems complying with the legal requirements. They have done separate measurements on air from the different parts of the prepress processes. Measurements of air from plate dryers and plate finishers were 701.7 mg/m^3 and 217.2 mg/m^3 , which are above the regulated limit. A specific measurement on air from the plate developer showed 9.3 mg/m^3 , and combined with the measurements on the other two prepress equipments this would correspond to an approximate combined concentration of 260 mg/m^3 from the prepress. Measurements on the air from plate developers and from the laminators provided values below the limit. The factory has been in contact with Factory A, and was warned not to buy coalescence equipment and instead awaits help to find other purification equipment.

5.5.3 Factory C

Factory C has a permit that includes emissions from organic solvent which may not exceed 40 tons/year, and emissions of total nitrogen (volatile and condensable hydrocarbons) and ozone may collectively not exceed 6 tons per year. The factory has no problems complying with the legal requirements. Emissions were estimated to 7.57 tons of organic solvents and 2.66 tons of emissions of total nitrogen and ozone.

5.5.4 Factory D

The factory has different legal requirements and it holds a permit by the authorities. This permit contains 39 different substances of which more than 10 are VOCs. The legal requirements are for total emissions per year and grams per second for the 39 specific substances. The limits specified in the requirements are dependent on whether it is in production hall, a few meters from the building, residential or potential residential area. The factory has no problems complying with the legal requirements.

5.5.5 Factory E

Factory E has no legal requirements, but they will probably get some when a new environmental license is implemented in 2017.

5.5.6 Factory F

The factory has both local legal requirements on the amount (kg/h) and national legal requirements of concentrations of some specified substances. The requirements includes benzene with an upper limit of 1 mg/m^3 with 0.36 kg/h , the sum of toluene and xylene of 15 mg/m^3 with 2.93 kg/h and “non-methane hydrocarbon” of 50 mg/m^3 with 6.3 kg/h . The

factory has no problems to complying with the legal requirements. Factory F is also required to pay attention to the regional air pollution index. In accordance with the index, the factory must be prepared to reduce their air emission by 15 % to 30 % in periods of severe air pollution, despite their current emission level.

5.5.7 All factories

Regarding upcoming legal requirements in the next few years, Factory E has entered that new legislation will be implemented in 2017. What this includes depends on the inventory of industries that authorities shall perform in 2013. Factory D think that they will get stricter legislation in the coming years.

Four factories (A-D) have indicated that they risk a fine if they do not comply with legal requirements. Factory C entered that they risk prison and Factory F entered that they will be penalized in some way by the government if there is no improvement regarding exceedances within a specified period. Regarding Factory F, the specifics of the legal consequences are unclear.

5.6 The yearly reporting of VOC

Every year, the factories report their VOC emission internally to Tetra Pak (Global Environment). This calculation includes the use of organic solvents (purchased minus returned). Plastic smoke emissions (laminator) and combustion gases from burning of solvent or plastic smoke should not be included. Despite the description above, and an internal “VOC calculation guideline”, what the factories have included in the VOC emission differs. Table 6 below shows the reported numbers from the factories.

Table 6. Factories reported VOC emissions

Factory	VOC emissions (kg)
A	21100
B	40660
C	7572
D	27512
E	4250
F	148566

The differences between the factories are large and it is unlikely that they would have counted the same way. Some may have counted the water based ink (which contains a maximum of 8 % solvent) as 100 % and some may have included CO₂ emissions from combustion.

6. Discussion

The selection of factories might not be entirely representative for the 36 converting factories within Tetra Pak. However, it is likely that all 36 factories have individual configurations of process equipment with or without various types of purification equipment and different sizes of production. The six factories in this study provide a wide span in regards to these parameters.

Emissions

The solvents used in the converting factories' cliché plate making process, Flexosol and Resoflex contain substances that result in emission of VOCs. The factories that use Flexosol emit air that contains 1500-6100 kg VOC. Whether these emissions can be viewed as large or small in relation to the effects that the emissions have on the environment is difficult to estimate. Thus it is also difficult to determine the effect each factory has on the environment. Assumptions can be made about the relationship between the amount of VOC emissions and the size of environmental effects. For example, Factory E that emits 26 times the amount of VOC emissions of Factory C can be assumed to have much larger effects on the environment. What these effects are, however, are not easily determined. Sufficient information about specific substances in the emission from each process is not available. There is not enough research done on all the direct effects of VOCs on the environment, and more importantly, on the vast number of possible synergistic effects and transboundary effects with other substances in the troposphere. Therefore, and in accordance with legislation and legal requirements it is probably more effective to view VOC emissions as a collective problem. That is, not as a problem of emissions of specific substances. However, legal requirements in some regions include limits for specific substances, e.g. toluene, xylene and benzene for Factory F, that have effects that are known to some extent. These local legal requirements should not be viewed as a negative, but may not be as effective as having requirements for total emission of VOC.

When comparing airborne VOC emission and production the amount of emissions is not solely affected by the number of produced packagings (MSP). Surely, larger production means higher emissions but small AOS means that more clichés need to be manufactured which in turn raises the consumption of solvents and thus also results in larger air emissions.

The comparisons between the factories' emissions and production, in table 3 and 4, shows that Factory E has the highest consumption of solvent and highest airborne VOC emission, compared to produced number of packagings. This cannot be explained by their

AOS value because it is high. Factory C has a significantly higher value of estimated airborne VOC emission per MSP and AOS than factories A, B, D and F. This may be explained by the large amount of clichés per MSP, indicating a large variety of packagings. Additionally, Factory C had after purification, an air emission from prepress and lamination of 1500 kg VOC in 2011, and today (2012) these VOC emissions are estimated to zero.

The concentration of VOC in the air from the lamination (approximately 15.5 mg/m³ in Factory A and B) is relatively low compared with the prepress (approximately 186-260 mg/m³ in Factory A and B). The high airflow from the lamination (totally 18 000-24 000 m³/h) results in VOC emission around 1700 kg per year (measurements from Factory A and B). The yearly emission of VOC from lamination was expected to be lower in comparison with emissions from prepress, due to the fact that unlike prepress, where large amounts of solvent is being used, no solvent is used in the lamination process. The emissions from lamination are not necessarily an environmental problem however, due to the low concentrations. Studies on harmful effects of VOC on vegetation have generally been conducted with very high concentrations over a short period of time. Effects of long time exposure of lower levels of VOC are, in large, unknown (Cape 2003; Collins & Bell 2002).

There are uncertainties regarding the large amount of Resoflex used in Factory E. They use at least 10 times the amount of solvent used in the other factories while producing about 15-50 % of the amount of clichés produced by other factories. The amount of consumed solvent has been confirmed but it is unclear why such a high amount, compared to other factories (see table 2), is necessary in their prepress equipment. Factory E's equipment is a few years older than equipment in the other factories but it is unlikely that they use 10 times the amount of solvent used in the other factories simply because of older equipment. The efficiency of the distiller should also be taken into account but this information is not available. Factory E is the only factory that lets a supplier distil their solvent but it is not certain if a smaller amount of solvent would have been used if they had their own distiller in the factory.

An estimated minimum of 38 000 kg of VOC is emitted from Factory E but because of missing information about manufacturer data on air flow, measurement of the airflow, efficiency of the supplier's distiller, the concentration of VOC is unknown. The estimated amounts of airborne VOC emission before purification from the other factories are quite similar to each other (2900-6100 kg).

Table 2 shows that the solvent loss in the distillation process is quite varied between factories, which may be a secondary source of airborne VOC emissions, as well as an

economic matter. The more solvent lost through distillation, the more new (purchased) solvent must be added to the system which thus may result in larger “downstream” airborne VOC emissions depending on what becomes of the residue. Solvent remaining in the residues together with polymer remains is handled as hazardous waste and destroyed off site where it thus generates some type of pollution. This emission is not included in factories calculation for VOC emissions, which perhaps it should be.

When annually reporting VOC emissions to Tetra Pak (Global Environment), the factories do not include the same content. For example, Factory F has excessive emissions, which may indicate that they counted some substances, e.g. water based ink, as 100 % solvent instead of the actual solvent content (0-8 % solvent).

When VOC emissions are calculated, the factories are to take no account of e.g. emissions of combustion gases from purification equipment. These emissions consist of carbon dioxide (CO₂), which is a greenhouse gas, and should be taken into account when emission calculations are performed. This could preferably be done as a CO₂ emission calculation in addition to the VOC emission calculation. The CO₂ emissions should also be taken into account when purification equipment is purchased. If many factories would have for example a Zeolite system, the combined contribution to carbon emission would be quite large.

Purification system

Most of the participating factories had relatively new process equipment except Factory E, whose prepress was more than 20 years old. Old equipment might not be as effective and may need more solvent. An efficient distiller to reduce the use of solvent is also an effective method of reducing airborne VOC emissions.

The Zeolite plant in Factory C that purifies both air from prepress and lamination, results in air emission with basically no VOC content. On the other hand, the air emission contains some carbon dioxide. Emissions of carbon dioxide and other impacts on the environment due to use of Zeolite equipment could be worth including in further studies. Zeolite is expensive and energy-consuming equipment, but it is efficient in purifying the air.

The active carbon used in Factory F purifies the air from the prepress, but the factory does not purify air from the lamination. Factory F claims that the active carbon purifies the air from VOC with an efficiency of 20 % but their estimated emissions are still higher than that of Factory B which has no purification system. Admittedly, Factory F’s production is larger than Factory B’s but not high enough to explain such high emissions.

The electrostatic filter used in four factories is effective for removing particles, but there is no evidence from the measurement to support the suppliers claim that the equipment purifies the air of VOC. Air with high content of particles is a major problem in many countries, thus the equipment has other environmental benefits.

The coalescence equipment used by Factory A is not working at all. The efficiency is a maximum of 10 %, not 100 % as the supplier claims, while being more than ten times as expensive as the active carbon, and none of the factories should invest in this equipment.

Legislation

All the factories, except Factory E, are subjected to some form of legislation on airborne VOC emissions. Two factories (A and B) are not complying with their legal requirements, but the effect on the environment from the exceeding levels of emissions is not easy to investigate. It is a possibility that the air emissions from the plate finisher in Factory A also contains exceeding values of VOC, much like Factory B 's measurements on air from the plate finisher (217.2 mg/m³). Factory B has exceeding concentrations of VOC in the air from prepress, but is complying with the annual limit of 9 tons of VOCs. Factory A and B's values are from one measurement occasion and it is not certain that this measurement is representative for the yearly production. These factories (A and B) should install new purification equipment.

Factory D only has measurements of toluene, which does not exceed the legal requirement. They have no measurement on VOC to air and in their permit list there are 39 substances regulated of which more than 10 are VOCs. Since there are no measurements on other VOCs it is unknown if these substances appear in exceedingly high concentrations. This raises questions about why no measurements are taken on the other VOCs and whether or not Factory D actually complies with their permit and legal requirements. Factory D has relatively low airborne VOC emissions (table 2), but this is based on conservative estimates and is probably considerably larger in reality.

Factory E has no legal requirements regulating airborne VOC emissions. Given the international pressure to protect the environment and indications given by the authorities, who will perform an air emission inventory in 2013, it is likely that limits to air emission will be enforced in the near future. In that case the factory needs to inventory and monitor their air emissions and possibly install purification equipment (for prepress) to reduce emissions.

Factory F has no problem complying with their legal requirements, but they must be prepared to occasionally reduce air emissions by 15 % to 30 %, regardless of their current emission level, in accordance with a local index of air pollution. As described for Factory A

and B above, it is not certain that Factory F's values are representative for the yearly production.

7. Conclusions and recommendations for Global Environment, Tetra Pak

The primary cause of VOC emissions, and thus the environmental effects they lead to, is the fact that some factories do not have any air purification equipment. In the case of Factory D, which does not have any purification equipment for the prepress, legal requirements exist but emissions of all the substances included in the permit are not monitored, and therefore it is unclear if they are complying with their legal requirements and/or permit. Factory E which has no legal requirements for air emissions, have no purification equipment and does not make any measurements. The measurement methods for measuring airborne VOC emissions differ somewhat between the factories and thus there are some uncertainties in the measured values. This also applies to the estimated values calculated by the mass balance calculation (2.2). However there are still reasons for Tetra Pak to urge their factories to install purification equipment and make scrupulous measurements according to legal requirements and permits to improve corporate reputation as environmentally sound and progressive.

To reduce VOC emissions the process equipment should be inventoried and evaluated. For example, does older prepress equipment (plate developer) consume more solvent? This applies in particular for Factory E that uses large amount of the solvent product Resoflex in the prepress. If the age of the equipment does influence emissions of VOCs, recommendations should be made to upgrade existing equipment or install new equipment.

Regarding secondary emissions, factories that lose much solvent in their distillation process should upgrade or install new equipment.

The air from lamination contains an annual amount of approximately 1600 kg and 1700 kg VOC for Factory A and B respectively. Not all the factories have permits on emissions from lamination, but whether or not they do it might still be worthwhile to purify this air as well to reduce negative impacts on the environment.

For further studies

- A follow-up of this study should be conducted, including all 36 converting factories. Besides the questions in this study, questions about the amount of produced clichés (m²) per year and the Average Order Size (AOS) per year should be included.
- For further studies including surveys, whether new or follow-up, a pilot survey should be done beforehand. Once the survey is sent out, every factory should have at least

two weeks' time to answer the survey. This should be followed by phone meetings with each factory to ensure that all parts of the survey are thoroughly completed and issues clarified.

- A new study of other emissions such as greenhouse gases from purification equipment, emissions from printing and VOC emissions from distiller (off site) should also be conducted.

8. References

- Abeles, F.B., Heggstad, H.E (1973). Ethylene: An Urban Air Pollutant. *Journal of the air pollution control association*, 23 (6), 517-521.
- Avnery, S., Mauzerall, D.L., Liu, J., Horowitz, L.W (2011). Global crop yield reduction due to surface ozone exposure: 1. Year 2000 crop production losses and economic damage. *Atmospheric Environment*, 45, 2284-2296.
- Belloli, R., Bolzacchini, E., Clerici, L., Rindone, B., Sesana, G. (2000). Nitrophenols In Air and Rainwater. In: Hathaway, R.A., Tanner, R.L (eds). *Environmental Chemistry of the Atmosphere: 2000 and beyond*, 17 (3), 511-515.
- Braslavsky, S.E., Rubin, M.B. (2011). The history of ozone Part VIII. Photochemical formation of ozone. *Photochemical & Photobiological Science*, 10, 1515-1520.
- Cape, J.N. (2003). Effects of airborne volatile organic compounds on plants. *Environmental Pollution*, 122 (1), 145-157.
- Castell, N., Stein, A.F., Salvador, R., Mantilla, E., Millán, M (2008). The impact of biogenic VOC emissions on photochemical ozone formation during a high ozone pollution episode in the Iberian Peninsula in the 2003 summer season. *Advances in Science and Research*, 2, 9-15.
- CLRTAP. (1979). 1979 Convention on Long-range Transboundary Air Pollution. Retrieved 2012-12-03, from <http://www.unece.org/fileadmin/DAM/env/lrtap/full%20text/1979.CLRTAP.e.pdf>
- Collins, C.D., Bell, J.N.B (2002). Effects of volatile organic compounds. In: Bell, Nigel & Treshow, Michael (eds.). *Air pollution and plant life*, 173-186. 2nd. ed. Chichester: Wiley.
- Colvile, R.N (2002). Emission, dispersion and atmospheric transformation. In: Bell, Nigel & Treshow, Michael (eds.). *Air pollution and plant life*, 23- 4. 2nd. ed. Chichester: Wiley.
- Delgado-Saborit, J.M., Esteve-Cano, V.J. (2008). Assessment of tropospheric ozone effects on citrus crops using passive samplers in a western Mediterranean area. *Agriculture, Ecosystems and Environment*, 124, 147-153.
- Dingenen, R.V., Dentener, F.J., Raes, F., Krol, M.C., Emberson, L., Cofala, J. (2009). The global impact of ozone on agricultural crop yield under current and future air quality legislation. *Atmospheric Environment*, 43, 604-618
- Directive 1999/13/EC (1999) Limitation of emissions of volatile organic compounds due to the use of organic solvents in certain activities and installations. European Council, March 11. Retrieved 2012-12-03, from <http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=CONSLEG:1999L0013:19990329:EN:PDF>
- Directive 2008/50/EC (2008) On ambient air quality and cleaner air for Europe. European Council, May 21. Retrieved 2013-02-10, from <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:152:0001:0044:EN:PDF>
- Elvingson, Per (2001). *Luften och miljön*. 1st. ed. Göteborg University, Department of applied environmental science.

- ESIG - European Solvent Industry Group, 2009. VOC definition in Europe.
Retrieved 2012-12-03, from
<http://www.esig.org/uploads/documents/81-518-voc%20definition%20in%20europe.doc>
- Felzer, B.S., Cronin, T., Reilly, J.M., Melillo, J.M., Wang, X. (2007). Impacts of ozone on trees and crops. *C.R Geoscience*, 339, 784-798.
- Innes, J.L., Skelly, J.M. (2002). Forest decline and air pollution: an assessment of 'forest health' in the forests of Europe, the Northeastern United States, and Southeastern Canada. In: Bell, Nigel & Treshow, Michael (eds.). *Air pollution and plant life*, 23- 4. 2. ed. Chichester: Wiley
- Leuenberger, C., Czuczwa, J., Tremp, J., Giger, W. (1988). Nitrated Phenols In Rain: Atmospheric Occurrence Of Phytotoxic Pollutants. *Chemosphere*, 17 (3), 511-515.
- Naturvårdverket (1990). Strategi för flyktiga organiska ämnen (VOC) - utsläpp, effekter, åtgärder. Solna: Naturvårdsverket
- Petersson, G. (2008). Växthusgaser och ozonskikt marknära ozon. In G. Petersson, *Kemisk miljöbetenskap*. 1-12. Gothenburg: Chalmers University of Technology.
- Pleijel, H., Ojanperä, K., Danielsson, H., Sild, E., Gelang, J., Wallin, G., Skärby, L., Selldén, G. (1997). Effects of ozone on leaf senescence in spring wheat –possible consequences for grain yield. *Phyton*, 37, 227-232.
- Pleijel, H. (1999). *Marknära ozon: ett hot mot växterna*. Stockholm: Naturvårdsverket
Retrieved 2012-11-05, from
<http://www.naturvardsverket.se/Documents/publikationer/620-6076-7.pdf>
- Sjöberg, K. (2004). *Luftkvalitet i tätorter*. Stockholm: IVL Svenska miljöinstitutet
Retrieved 2013-02-10, from
<http://www3.ivl.se/rapporter/pdf/B1607.pdf>
- Taylor, G.E., Gunderson, C.A. (1988). Physiological Site of Ethylene Effects on *Carbon Dioxide* Assimilation in *Glycine max* L. Merr. *Plant physiol*, 86, 85-92.
- Trost, Jan & Hultåker, Oscar (2007). *Enkätboken*. 3rd ed. rev. and exp. Lund: Studentlitteratur.

Internet sources

- European Environment Agency 2012. *Non-methane volatile organic compounds (NMVOC) emissions (APE 004) – Assessment published Dec 2011*.
Retrieved 2012-12-19, from
<http://www.eea.europa.eu/data-and-maps/indicators/eea-32-non-methane-volatile-1/assessment-1>
- Ontario Ministry of The Environmen. (2007). *Step by step guideline for emission calculation, rcord keeping and reporting for airborne contaminant discharge*.
Retrieved 2012-12-18, from
http://www.ene.gov.on.ca/stdprodconsume/groups/lr/@ene/@resources/documents/resource/std01_079079.pdf
- Tetra Pak. 2012. *Tetra Pak in figures*.
Retrieved 2012-12-18, from
http://www.tetrapak.com/about_tetra_pak/the_company/facts_and_figures/Pages/default.aspx

Interviews or Personal Communication

Carlsson, M., Environmental Specialist, Global Environment, Tetra Pak Technical Service AB, 2012

Hansen, J., Systems Engineer A, Tetra Pak Packaging Solutions AB, 2012

Appendix A – Email to the factories

Dear XX,

The Environmental Master Pillar has had numerous requests for help in the areas of managing waste water and air emissions/VOC's. To help in these areas, we are collecting data from all the factories about your current practices and requirements for waste water and air emissions. The waste water mapping that was conducted this summer is now completed and it is time to move on to air emissions.

I have worked within Tetra Pak for several years but the last three years I have been studying Environmental Science at Lund University. This is a pilot study and it will be compiled in the report that is my thesis. During this study, Martin Carlsson at Global Environment will be my supervisor. This study is also in your interest since part of the goal is to work towards reducing your air emissions. Therefore it is mutually beneficial that you respond as detailed as you can.

I want you to submit your answer no later than November 1 2012, which means you have two weeks to respond to the survey. Between November 2 and November 9, I will hold a phone meeting with the environmental coordinator from each factory to go through all the received answers.

Please note that there are three tabs on the attached spreadsheet, the first containing information about the survey, the second containing the survey, and the third measurements of air emissions.

Thank you all very much for your input and the time you spend in contributing to this project. The information you share with the Master Pillar will be used for a mapping project with the goal of helping factories manage their air emissions.

Please submit your answers in English and at your earliest convenience, but no later than November 1 2012.

Best regards

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Appendix B – Survey

Information sheet

Global Environment is conducting this survey in order to map air emissions from all of Tetra Paks' converting factories. This study also includes air purification and legal requirements for air emissions, which differs widely between the factories. The study is significant in Tetra Paks' work to reduce the environmental impact of its operations. Although some countries have no legal requirement concerning air emissions, it is nevertheless important for Tetra Pak's work with reducing air emissions globally.

The results of the survey will be used in a report on air emissions from converting factories. The report will also contain parts that deal with the air emissions impact on the environment. The report aims to obtain more knowledge about the amount of air emissions from Tetra Paks' converting factories and their impact on the environment.

This is a pilot study in which seven of the 36 converting factories have been selected to participate. It is important that you respond to the survey as detailed as you can, and if there is any confusion, please contact me so I can clarify.

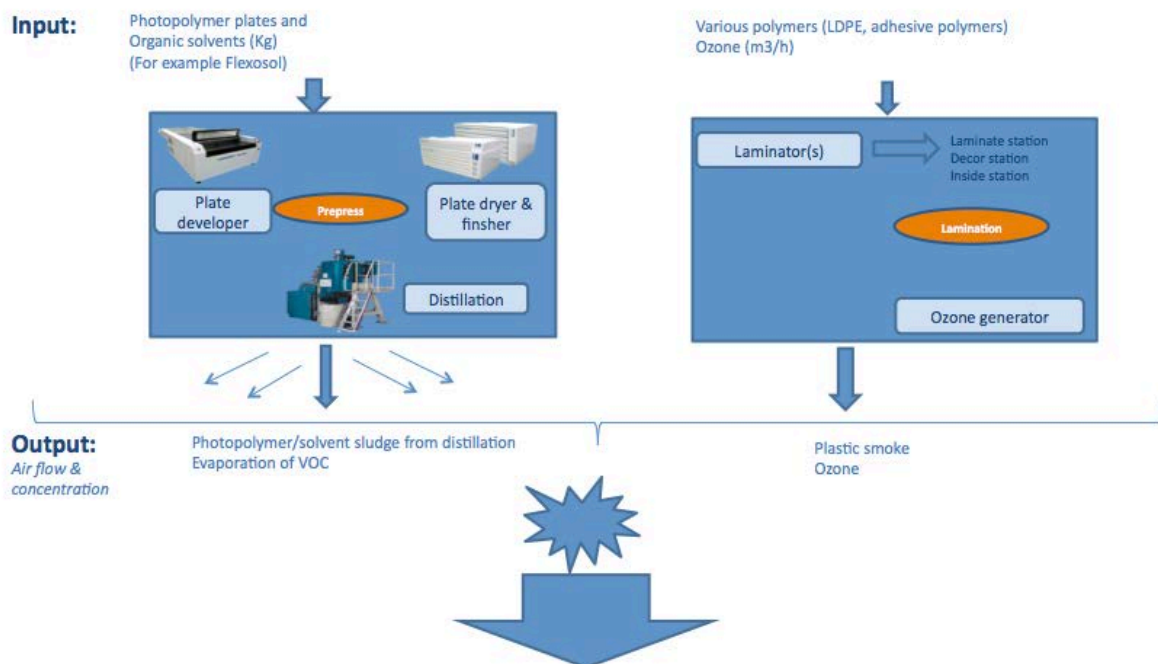
- In the sheet *Survey*, there are a number of questions related to air emissions from processes in the factories. Air emissions/flue gas from boilers (which heats the building) are not included in this study. We have identified the major sources of air emissions from converting factories, which are prepress and lamination. Therefore, we have chosen questions related to these sources and thus excluded printing which we believe causes negligible emissions.

- In the sheet *Measurements*, the measurements of air emissions that have been conducted in your factory should be filled out. More information about the measurements is found in question D1-D3 in the sheet *Survey*.

The questions are divided into seven sections: A-General, B-Air purification system, C-Costs, D-Legal requirements, E-Measurements, F- Calculations and G-Activity. Every question that has an explanation is marked with red in the right corner of the cell. In the cells that are marked with light blue, you have the opportunity to write freely. The cells that are highlighted with purple have a drop-down menu from which you choose your answer.

The survey is sent to you because you are the environmental coordinator in a converting factory but the idea is not that you on your own should be able to answer all the questions. We know that some questions are detailed and therefore we are asking you to collect responses from personnel within your organization (process engineers, etc). Your task is to answer the questions you can answer and delegate the other questions, and then compile the responses in the survey.

I want you to submit your answer no later than November 1 2012, which means you have two weeks to respond to the survey. Between November 2 and November 9, I will hold a phone meeting with the environmental coordinator from each factory to go through all the received answers.



Survey sheet



Environment master pillar - Air emissions survey

A. General		Unit	Answers				Comments	
1. Factory name								
2. Prepress			Type of prepress equipment	Installation year	Air flow (m ³ /h)			
a) Number of prepress	Plate developer Plate dryer & finisher Distillers Other equipment with air emissions, please specify.							
b) What is the yearly consumption of prepress solvent?		kg						
c) Name of solvent								
d) How much residue is generated by distiller yearly?		kg						
e) What is the estimated solvent content in the residue?		%						
f) Operation hours		hours/year hours/week						
3. Printing								
a) Operation hours		hours/year hours/week						
4. Lamination			Type of lamination equipment	Installation year				
a) Number of laminators	Laminators Ozone generator Other equipment with air emissions, please specify.							
b) Operation hours		hours/year hours/week						
c) Exhaustion temperature	Laminator station Inside station Decor station	°C						
d) Air flow for extraction hoods	Laminator station Inside station Decor station	m ³ /h						
B. Air purification system								
1a.) Type of air purification equipment			Purification equipment 1	Comments	Purification equipment 2	Comments	Purification equipment 3	Comments
b.) Supplier of air purification equipment								
2a.) Which processes are purified by the purification equipment?								
3. Are all the parts in each process (prepress, lamination or other) being purified?								
4. What is purified by the respective equipment?								
5. What is the efficiency of each purification?								
	HCC	%						
	Ozone	%						
	SOx	%						
	NOx	%						
	Particles	%						
	Ammonia	%						
	Other, Please specify	%						
	Other, Please specify	%						
6a.) Do you have problems with the purification equipment?								
b.) What problems do you have?								
7a.) Do you have any back-up or shut down equipment in case of failure of the purification equipment?								
b.) What is your back-up or shut down equipment?								
8a.) Have the purification equipment failed or been turned off at any time during the past few years?								
b.) Why was it turned off?								
c.) Were measurements taken on this occasion?								
d.) Did you contact the authorities at this occasion?								
e.) Were the rest of the operation shut down at this time?								
8. Are there any residue after the purification?								
C. Costs								
1. What are the running expenses of your treatment system?		Unit	Answers	Comments	Answers	Comments	Answers	Comments
2. Purchase price for the purification equipment		Euro						
3. Energy consumption		Euro						
4. Costs for air emissions measurements		Euro/year						
D. Legal requirements								
1a.) Are there any legal requirements on air emissions?								
b.) What are the requirements?								
c.) Are there any recommendations (not included in legal requirements) regarding air emissions?								
d.) Do you have any problems complying with the requirements?								
f.) What are the problems?								
g.) What is the consequences if you don't comply with the legal requirements?								
2a.) Do you have any specific permit with the local authorities?								
b.) What is included in the permit?								
3a.) What is the approximate distance to nearest residential area?								
b.) Have you had any complaints about odor from the factory by people who live nearby?								
4. Are there any indicators that some legal requirements on air emissions in your country will be implemented or that the current requirements becomes stricter within the next few years?								
E. Measurements								
1a.) How often are measurements of air emissions performed?								
b.) Who performs the measurements?								
c.) What measurement method is used?								
F. Calculations								
1. How do you calculate the air emissions?								
2. What is the result of the calculations?								
G. Activity								
1a.) Are you planning to do any action to reduce the air emissions?								
b.) What type of action are you planning?								



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