High Acceptance of Urine Source Separation in Seven European Countries – A Review

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ABSTRACT

Urine source separation (NoMix-technology) is a promising innovation aiming at a resource-oriented, decentralized approach in urban water management. However, NoMix-technology has a sensitive end-point: people's bathrooms. NoMix-technology is increasingly applied in European pilot projects, but the success from a user point-of-view has rarely been systematically monitored. We aim at closing this gap. We review surveys on acceptance, including re-use of human urine as fertilizer, from 38 NoMix-projects in 7 Northern and Central European countries with 2700 respondents. Additionally, we identify explanatory variables with logistic regression of a representative Swiss library survey. NoMix-technology is well accepted; around 80% of users liked the idea, 75–85% were satisfied with design, hygiene, smell,

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and seating comfort of NoMix-toilets, 85% regarded urine-fertilizers as good idea (50% of farmers), and 70% would purchase such food. However, 60% of users encountered problems; NoMix-toilets need further development. We found few differences between countries, but systematic differences between public and private settings, where people seem more critical. Information was positively correlated with acceptance, and e.g. a good mood or environmentally-friendly behavior. For future success of NoMix-projects, we recommend authorities to follow an integral strategy. Lay people will then find the NoMix-concept appealing and support this promising bathroom innovation.

BRIEF

A review of 38 European pilot projects with urine source separation shows high user acceptance, but also the need for policy strategies and technological development.

INTRODUCTION

Technological innovations are a main characteristic of our society, with a tendency of moving nearer to consumers; every household has highly advanced computers or entertainment electronics. This “technological individualization” will shift to electric power supply (wind and solar power), or on-site water purification, especially in arid regions as The Mediterranean or Australia. Also for wastewater management there are indications of a paradigm change from centralized purification in large wastewater treatment plants (WWTP) to decentralized options in single buildings or households (1–2). Wastewater and human excreta are sensitive issues, connected with strong emotions (3). For technology development it is crucial to understand what is required that consumers accept this change from “flush-and-gone” to innovations in their bathrooms. We study this question using the example of urine source separation (NoMix-technology).

Our wastewater treatment system functions well, but is also heavily criticized (e.g. 4). It is inflexible and lasts for decades making long-term planning under uncertainty (climate change) difficult. The system always lags behind upcoming environmental problems (e.g. pharmaceuticals; 5). Recycling sewage sludge introduces contaminants to agriculture, provoking debates (6). In Switzerland, consumer pressure resulted in a total ban of sludge recycling, nutrients thus being wasted, which is especially displeasing for the limited resource phosphorus (7). Incomplete wastewater treatment contributes to eutrophication, e.g. in the Baltic Sea (8). Even in Europe, only 79 of 542 major cities have full sewage treatment (3). Adapting our expensive system that is extremely wasteful of water to poorer, arid countries is nearly impossible; with devastating consequences for health. Source control and separation (9) offer a solution; separating the ca. 1.5 liters of urine per person and day is a small, but efficient first step. Urine contains most nutrients arriving at WWTP (typically 80% nitrogen, 50% phosphorus; 10), is clean, and applying urine as fertilizer has a long tradition, e.g. in Sweden or China (11).

Urine source separation comes in many variants. In toilets, the principle is always to divert urine from feces in the toilet bowl by a separate outlet. The use of urinals is another possibility, which is not discussed here. Urine is discharged to a storage tank with or without flushing water (see Supporting Information). Many earlier pilot projects with urine source separation adopted ecological sanitation (ecosan) for poor rural or peri-urban areas of developing countries (12). Mostly, dry toilets are installed and urine is directly used as fertilizer. Many projects are highly successful (13) and ecosan deserves wide-spread promotion. Here, we focus on a modern, industrialized setting with water-flushed urine diverting (NoMix-) toilets. We are convinced that new approaches to sanitation are also possible in a rich, urban environment. However, high acceptance by consumers is a prerequisite for wide-spread diffusion of any innovation (14). We hypothesize that to be fully accepted, NoMix-toilets must reach the high standards of conventional bathroom installations. To date, no NoMix-toilet available has reached this benchmark. Recently a Dutch NoMix-toilet was developed that is fully integrated into a bathroom design line (www.sealskin.nl; NMX-toilet). We do not yet have feedback concerning this model. For this paper we focus on the acceptance of NoMix-toilets and nutrient recycling. Other aspects were reviewed elsewhere,

e.g. urine-processing technologies (15), urine as fertilizer (16–17), pathogens (18), and micropollutants in urine (19).

NoMix-toilets have drawbacks, most importantly phosphate precipitation (20) causing blockages, or the necessity to sit to urinate (practical issues reviewed in 21). Nevertheless, NoMix-toilets are increasingly installed. Sweden is the pioneer of modern NoMix-technology, where over 135'000 urine diverting toilets were installed until 2006. Originally, NoMix-technology was Eco-village-oriented, with a recent shift in the Swedish sanitation discourse (22). Today, Swedish EPA considers urine source separation as one option to meet new legislative and environmental goals, and to mitigate eutrophication along the coastline. These initiatives were followed by projects in other Northern and Central European countries, and recently in e.g. Australia (23), or large Chinese cities (24). Unfortunately, not that many NoMix-projects had systematic socio-economic research; and most publications are difficult-to-access internal reports. Moreover, we observe little exchange of experience between pilot projects, resulting in an unnecessary repetition of known facts, including mistakes (25).

The aim of this review is to compile all existing data from user surveys and find similarities or systematic differences between projects. An important obstacle for NoMix-technology and re-use of nutrients is rejection of urine-based fertilizers by farmers and consumers. Only few surveys have elicited the argument; we include these. Furthermore, we use an unpublished representative survey of 501 users of NoMix-toilets in a Swiss library to find explanatory variables correlated with acceptance of the NoMix-toilet and idea. Based on these data, we draw well-founded conclusions that support future NoMix-projects and may interest other fields of technological household innovations.

METHODS

Data collection. We searched the internet and web-of-science for acceptance studies of NoMix-technology; without much success because most are grey literature. We thus used our international contacts to collect existing surveys (many in German, Swedish, Danish, and Dutch). We excluded dry toilets, despite interesting research (26–27). We excluded clearly qualitative data (e.g. in-depth

interviews). The only exception is the detailed, high-quality sociological dissertation in Gebers housing estate, which would have been a pity to omit (28; Supporting Information: Tab. SI-1A). In total, we screened ca. 75 publications and used data from 38 pilot projects or studies in 7 European countries (Tab. SI-1). We may have missed studies, but are confident that we compiled a significant amount of the data available.

Data standardization. First, we discriminated between countries, setting (institutions/private homes), and if possible toilet type, users (e.g. staff/visitors), and sex. Most studies present average responses; which we compiled directly. In some surveys (29–31) questions were assessed on a scale from 1 (worst option) to 6 (best), and a mean was given. For this meta-analysis, we transformed these to percent with: $(\text{mean}-1) / 5 * 100$. Since questions often differed slightly, but aimed at the same variable, and since we had to deal with sparse data, we merged some variables, e.g. “Welcomes NoMix-toilet in public buildings”/“Welcomes NoMix at work place”.

Data analysis. Unfortunately, the data are of varying quality. Often they are not representative because there was no randomized, standardized sampling procedure, sample numbers are far too low, and no attention was given to ensure high responses (32) or exclude bias. Because different questions were asked in the different surveys, there are many missings and not every case could contribute to any individual question. Ideally, for a sound statistical meta-analysis, we would have needed raw data, but mostly only averages over all respondents were available. Nonetheless, we are convinced that these data are very valuable and should be made accessible. Moreover, the results are alike across a range of European countries with different cultures and very different settings (Tab. SI-1). We are confident that they reflect the attitude of people and the results expected from representative national surveys.

We aimed at statistical tests for explanatory variables such as differences between countries, settings (e.g. urban apartments/eco-villages/exhibitions), toilet types, length of NoMix-usage, socio-demographic variables, and environmental attitude. However, given the paucity and inconsistency of data even simple

tests are not meaningful. Therefore, we present these data with overview diagrams grouped into 7 countries. We show some differences between settings (institutions/private homes) and sex. To cluster data we calculated weighted means (Supporting Information).

Logistic regression for explanatory variables. In Switzerland, the polling firm ISOPUBLIC (www.isopublic.ch) carried out a representative survey in a public library (unpublished data, study no. 6, Tab. SI-1A). Interviews were carried out in 2005 among 501 visitors and library staff using the Roediger NoMix-toilet for ca. 6 months. We test for explanatory variables and draw general conclusions.

We analyzed the binary dependent variables (e.g. toilet is same/better versus worse) with a generalized linear model approach (33) and used forward stepwise logistic regression to find explanatory variables most strongly correlated with each dependent variable (as in 34). The theoretically possible full model contained ten explanatory variables (see Fig. 3). We present model information (Tab. 2) and parameters of final models (e.g. unstandardized logit coefficient, Odds Ratio; Tabs. SI-8–SI-11). We used the statistical software SPSS (release 15.0.0, 2006; SPSS Inc).

RESULTS

Overview. We analyzed 33 user surveys of NoMix-toilets from 2720 respondents (=questionnaires) in 7 European countries (Tabs.1; SI-1A). 18 studies came from private homes, 15 from institutions and exhibitions (Tab. 1). The 24 groups of longer-term respondents had used the NoMix-toilet for 17 months on average, with large differences (SD=14.2). We have data from 5 farmer surveys with 231 responses (Tab. SI-1B). These are not representative because of very low response rates and biased returns (35), but they show trends. In the following we present weighted means and standard deviation ($\pm xx\%$). For further details (number of countries, studies, and respondents contributing to result) see Supporting Information (Tabs. SI-2–SI-7).

Acceptance of NoMix-toilets and the NoMix-idea is very good, with mostly a clear majority of over 1200 questioned users giving positive feedback (Fig. 1A; Tab. SI-2). Over all, 84% ($\pm 13\%$) of the respondents think that the NoMix-idea is convincing (Fig. 1Aa). 79% ($\pm 4\%$) would welcome NoMix-toilets in public buildings or at their work place (Fig. 1Ab). Likewise, 79% ($\pm 13\%$) would use a NoMix-toilet at home, move into an apartment with a NoMix-toilet, or recommend it to others (Fig. 1Ac). Only 57% ($\pm 29\%$) are willing-to-pay more for a NoMix- than conventional toilet (Swiss institutions) or purchase NoMix-toilets without subsidies (Swedish homes; Fig. 1Ad). In an Austrian and Swedish household survey, only 48% ($\pm 8\%$) of users would not replace the NoMix-toilet (Fig. 1Ae). This indicates a more negative attitude of people using NoMix-toilets at home, with only 76% ($\pm 17\%$) finding NoMix a (very) good idea, compared to 85% ($\pm 12\%$) in institutions. In Swedish homes, 59% ($\pm 9\%$) of NoMix-users found a large-scale introduction of NoMix-technology likely or possible, compared with only 46% in a Swiss institution.

It could be argued that acceptance is high because samples are not representative. This may be true for the first pioneer projects in Swedish Eco-villages (Tab. SI-1A), but not for many others. However, this was rarely tested: In Austria, 54% of 54 respondents found the ecological wastewater concept an important motivation to move into the apartment (36). In two Swedish Eco-villages, only 14% ($\pm 4\%$) of 68 NoMix users said that ecological concern was a main motivation for moving there (28, 37).

Perception of practical aspects. NoMix-toilets were perceived the same or better compared with conventional toilets by the large majority of nearly 2000 questioned users (Tab. SI-3). Results are grouped for countries (Fig. 1B) and setting (Fig. 1C). Over all groups, 79% ($\pm 11\%$) judged the design positively (Figs. 1Ba, 1Ce), 85% ($\pm 9\%$) the hygiene (Fig. 1Bb), 77% ($\pm 18\%$) the smell (Fig. 1Bc), and 86% ($\pm 11\%$) the seating comfort (Fig. 1Cb). Generally, 75% ($\pm 11\%$) of users were satisfied with NoMix-toilets, or indifferent (Fig. 1Ca).

However, drawbacks of NoMix-toilets were also apparent: only 56% ($\pm 22\%$) found that flushing equals conventional toilets (Fig. 1Cc). Cleaning was judged more laborious, only 52% ($\pm 17\%$) finding it equaled conventional toilets (Fig. 1Bd). The astonishingly high positive response in The Netherlands comes from two employees. Only 59% ($\pm 9\%$) of respondents (all in homes) found that no problems occurred (Fig. 1Be). Reports of blockages of urine drains after 6–12 months of usage are found in many studies. However, e.g. in Austria 70% of 54 users found it easy to deal with problems; but only 23% think that NoMix-toilets do not need improvement. Only 41% ($\pm 14\%$) found NoMix-toilets adequate for children (Fig. 1Cd). In 7 Swedish and 1 Danish study, 74% ($\pm 18\%$) of 207 users reported that urine mostly goes to the right place.

Most practical aspects of NoMix-toilets were judged far more critically by users in homes than in institutions (Fig. 1C). This is also true for most aspects shown in Fig. 1B, e.g. design (Fig. 1Ce) and especially smell: only 48% ($\pm 15\%$) of 11 Swedish studies in homes judged the odor of NoMix-toilets positively, while feedback from the other three countries (all in institutions) was very positive (Fig. 1Bc). For hygiene and cleaning, differences between institutions and homes were negligible.

Behavior. Many of the ca. 1700 questioned people adapted their behavior to the requirements of NoMix-toilets (Tab. SI-4; Fig. 1D). Over all groups and both sexes, 68% ($\pm 7\%$) usually sit on NoMix-toilets to urinate (Fig. 1Da). The percentage sitting was higher at home (78% $\pm 20\%$) than in institutions (68% $\pm 6\%$). Only for sitting, we present differences between sexes; for most other variables these were negligible. More women usually sit on NoMix-toilets (75% $\pm 8\%$) than men (60% $\pm 11\%$).

Depending on the NoMix-toilet model, water is saved if the small flush is used after urinating. 73% ($\pm 8\%$) reported this as their usual behavior (Fig. 1Db), with no clear difference between institutions and homes. However, because the hydraulics of NoMix-toilets are poor, some people flush several times or apply “tricks” as flushing with the shower (30–31). Over all groups, 57% ($\pm 11\%$) usually flush only once

without “tricks” after urinating (Fig. 1Dc). In homes, 64% ($\pm 8\%$) use the small flush, but only 45% ($\pm 2\%$) in institutions.

The most challenging requirement of NoMix-toilets (except Roediger) is the disposal of toilet paper after urinating in a separate bin or the feces compartment without flushing, else no water is saved. 49% ($\pm 20\%$) of users are willing-to-act accordingly (Fig. 1Dd). In Swiss institutions (52% $\pm 18\%$) and German institutions (37%) this number is higher than in Swedish homes (30% $\pm 25\%$). 64% ($\pm 23\%$) disposed of urine-soiled paper in the feces compartment, usually pressing the large flush (Fig. 1De).

Public attitude towards urine as fertilizer. The public and NoMix-toilet users are very open towards human urine in agriculture (Tab. SI-6; Fig. 2A). Of over 900 respondents, 85% ($\pm 13\%$) find this a (very) good idea (Fig. 2Aa). There were hardly differences between the Swiss library, German exhibition, and Swedish homes, while acceptance was markedly lower with 43% by inhabitants of Austrian apartments. The willingness-to-purchase food fertilized with urine was similarly low in Austria, but well-accepted by the others with 68% ($\pm 11\%$; Fig. 2Ab).

Presumably, concerns were often mentioned, but quantitative data are only available for the Swiss library and German exhibition (38). Hygienic concerns by pathogens were addressed, but only by 5% ($\pm 4\%$; Fig. 2Ac). However, 61% in Germany were worried about pharmaceuticals, but only few Swiss (Fig. 2Ad).

Acceptance of urine-fertilizer by farmers was far lower than by the public (Tab. SI-7; Figs. 2B–D). Averaged over two studies, 50% regard urine-fertilizer as good idea (Fig. 2Ba), but only 34% would use or purchase it (Fig. 2Bb), while 34% would maybe use it (Fig. 2Bc). Only 24% would pay the same as for conventional fertilizers (Fig. 2Bd), while most would only use urine if it were cheaper or for free (Fig. 2Be, f). However, 43% of 122 Swiss farmers would change regulations to allow urine in organic farming (35), and 53% of 68 farmers near Berlin would accept more administration (38).

Apart from general skepticism such as “no need for urine-based fertilizer” (Fig. 2Ca) and “bad idea” (Fig. 2Cb), clear arguments were mentioned. Most prominently, 65% feared liability claims, saying that regulations must be changed first (Fig. 2Cd). 46% of Swiss farmers questioned the fertilizer quality (Fig. 2Cc). Very few farmers expected absolutely no acceptance by consumers (Fig. 2Ce), but many feared reduced sales especially for vegetables (Fig. 2Cf–i). Consequently, 50% of farmers mentioned any sort of concern (Fig. 2Da). Specifically, 24% had ecological concerns (Fig. 2Db). In Switzerland, worries about pathogens were very low (Fig. 2Dc), but spreading micropollutants in agriculture was very important (Fig. 2Dd).

Test of ten explanatory variables: NoMix-acceptance. Logistic regression results from 501 users of NoMix-toilets in the Swiss library can help explain the above results. Acceptance of NoMix was very high; 96% found it a good idea, 81% welcomed a NoMix-toilet at work, 59% would (probably) install it at home, and 83% would be willing-to-pay more for a NoMix-toilet than the current € 390 for conventional toilets (Fig. 3A). Acceptance was significantly correlated with people’s environmental-friendly attitude, a good mood, feeling well-informed, and being open for innovations. For NoMix-toilets at work also younger age and higher education were significant (Tabs. 2A, SI-8; Fig. 3A). Less people using NoMix-toilets regularly would pay more. There was a difference for the same question asked at the beginning and end of the questionnaire: the willingness-to-install a NoMix-toilet at home increased from 59% to 64% and was no longer correlated with mood or information (Tab. 2Ac, d).

We discuss one example in detail; the other results can be read accordingly from Tab. 2 and Fig. 3. For “Is NoMix a good idea?” (Tab. 2Aa; Fig. 3Aa), the significantly strongest difference was between people that exhibit only one environmentally-friendly behavior (78% like idea), compared with 97% exhibiting all five behaviors. This variable “attitude” was added first to the model (Step 1). The model explained 8.6% of the variance (Nagelkerke R^2) and was significant with $P < 0.05$. Second, the variable “mood today” was added and third whether people felt “informed”. All other 7 variables were not significant and did not improve the model to explain differences between people finding NoMix a good or bad idea. The full

model (with 3 variables) was highly significant ($P < 0.001$) but explained only 16.1% of variance in the data (Nagelkerke R^2). Also generally, the models with theoretically 10 possible variables only explained 3% to 21% of the variance; and sometimes none.

Explanatory variables for practical issues, behavior, and urine-fertilizer. The NoMix-toilet was perceived as same or better than conventional toilets by 84% (design), 87% (hygiene), 89% (smell), and 88% (seating comfort). More well-informed people judged design and seating comfort positively (Tabs. 2B, SI-9; Fig. 3B), while more younger people judged the design worse than older people. More men judged odor positively, but more women seating comfort. A strange result is that more people liking innovations judged seating comfort worse.

Most respondents were willing-to-adapt their behavior; 70% had just sat down, 83% would sit next time, and 60% would dispose of urine-soiled paper in a bin. The only significant explanatory variable for paper disposal was environmentally-friendly attitude (Tabs. 2C, SI-10; Fig. 3C). Attitude was also correlated with the willingness-to-sit next time, as well as sex (more women sit), younger age, and being better-informed.

Acceptance of urine-based fertilizers was high: 93% found it a (very) good idea. The majority found following applications suitable: public flower beds and lawns (92%), agriculture (85%), organic farming (79%), and balcony plants (79%). 68% would use this fertilizer in their garden, and 69% would (probably) purchase such vegetables. Environmental-friendly attitude, good mood, openness for innovations, and higher education were correlated with many dependent variables (Tabs. 2D, SI-11; Fig. 3D). Fewer younger people would use the fertilizer in their garden. More urban people would use the fertilizer on public lawns, and more Swiss than foreigners. 71% of the Swiss (German/ Austrian) would purchase urine-fertilized products, but only 35% of other foreigners.

DISCUSSION

User views and practical problems. The good news is that NoMix-technology is very well accepted across seven Northern and Central European countries, 33 surveys, seven NoMix-toilet models, and over 2700 users of NoMix-toilets with very diverse backgrounds; students, eco-village inhabitants, exhibition visitors, urban apartment tenants, and many more (Tabs. 1, SI-1). Around 80% regard NoMix-technology as a good idea and accept NoMix-toilets at work or at home (Fig. 1A). Around half of the respondents would even pay more for NoMix-toilets, and 75–85% found that design, hygiene, smell, and seating comfort equals conventional toilets (Figs. 1B, C). Around 70% usually sit to urinate, or press the small flush (Fig. 1D).

However, 60% of people with NoMix-toilets reported of problems, especially urine-pipe blockages after 6–12 months of usage. Scaling can be overcome mechanically or chemically (overview in 21), but requires maintenance. For around 50% cleaning NoMix-toilets is more laborious, the flush is insufficient and only ca. 50% would dispose of lightly-soiled paper in a bin. We point out that NoMix-toilets can consume more water than conventional dual-flush toilets if users flush several times or press the large flush after urinating because of poor hydraulics or toilet paper disposal (34). Non-adequate flushing behavior was reported in many surveys (e.g. 30–31, 34, 36, 39–42) and confirmed with logger data (43–44). NoMix-toilets are difficult for small children, urine or feces landing in the wrong compartment (e.g. 26, 28, 36). This can even apply for adults, users judging that around 25% of urine is lost. Nitrogen and phosphorus measurements in urine tanks confirm that maximally 70–75% of the expected quantity is recovered (37, 41, 44–45,). Apart from user compliance problems (not sitting), in some systems up to 40% of ammonia was lost in urine-ventilation pipes (43). Hence, the NoMix-system definitely needs optimization.

Given the inconsistency of data it is unfortunately difficult to find systematic differences between countries and solidify assumptions with statistical tests. Figure 1 gives the impression that feedback from e.g. Switzerland or Germany is more positive than from Sweden. We caution against quick interpretations; here all Swiss and all but one German study (No. 10, Tab. SI-1) came from institutions (offices, schools, library, exhibitions), but in Sweden all from private settings. There is evidence for systematic differences between people using NoMix-toilets at work or in public buildings and those using NoMix at home. The

latter were more critical, especially concerning practical aspects (Fig. 1C). We tentatively conclude that people generally like the NoMix-idea irrespective of the setting, but are critical when living with unsatisfactory toilets in their own bathrooms. In institutions, drawbacks are less apparent because maintenance is done by cleaning personnel. However, sitting is easier at home, where 78% usually sit on NoMix-toilets, but only 68% in institutions. The necessity to sit is a frequent counter-argument for NoMix-toilets, but from the data this is hardly an obstacle. In public buildings, men use urinals; at home, 58% (Austria; 36), 83% (Sweden; 28) or even 100% (Berlin; 39) of men sit. In institutions, hygienic concerns hinder women from sitting, as mentioned by 44% of 173 Swiss women, but only 15% of 122 men (34).

Longer, more-frequent NoMix-toilet use may explain these different perceptions. Permanent staff at Eawag was significantly more critical than visitors (34). In Tanum, Sweden, only 25% of permanent residents were satisfied with their NoMix-toilet, but 71% of vacationers (46). In Västervik, 77% residents and 83% vacationers were satisfied with NoMix-toilets (42). This solidifies our assumption of a marked difference between every-day and occasional NoMix-toilet users.

Logistic regression results from Swiss library visitors help explain why some people are more open towards NoMix-technology. This supports future project managers to focus on factors that increase acceptance of sensitive household innovations. As in earlier studies (34, 36), being well-informed about NoMix-toilets is positively correlated with acceptance, behavior, and perception, e.g. liking the design (Figs. 3A–C, blue bars). Softer personality factors were also correlated with acceptance: openness for innovations (Fig. 3A, red bars), good mood (yellow bars), and environmentally-friendly behavior (green bars). Significantly more people exhibiting five environmentally-friendly behaviors compared to one would carry out the most difficult NoMix-requirements: pay more, sit down, and dispose of toilet paper in a bin (Figs. 3A, C, green bars). This follows environmental psychology research: some (ecological) behaviors are more difficult to conduct (47) and are carried out by more-committed people. The willingness-to-pay more is lower for people using NoMix-toilets more frequently, which follows the trend

discussed above. As in many studies of environmentally-friendly behavior (48), classic socio-demographic parameters (age, sex, nationality, education) were rarely correlated with acceptance.

Logistic regression shows correlations, but not cause-effect relationships. We recommend that future socio-psychological research carries out hypotheses-testing concerning acceptance of household innovations and changing (environmental) attitudes (49). Future studies should carefully design questionnaires since answers to the same question differed at the beginning and end of the library-questionnaire.

Urine as fertilizer. Acceptance by the general public of urine-based fertilizers was similarly high, with 85% of ca. 900 respondents liking the idea and nearly 70% willing-to-purchase such food (Fig. 2A). Acceptance by Swiss and German farmers in three studies (35, 38, 40) was lower. Only 50% liked the idea and one third were willing-to-purchase urine-based fertilizers; but only if they were cheap or free (Figs. 2B–D). These surveys are not fully representative; responses are low (35, 38) and biased returns are possible (35). Sweden is the only European country extensively applying urine, but we unfortunately found only two qualitative reports of farmers' attitudes (41, 50). These farmers did not observe different plant reactions or extra odor. Apparently, most did not inform customers that urine was used to fertilize food, but presumed positive attitudes.

In the user surveys, German and Swiss institutions no longer differed strongly from Swedish private homes, but acceptance was markedly lower in Austria (Fig. 2A). We explain this with different attitudes of authorities. In Switzerland, direct re-use of urine is not allowed; in the library we explicitly stated that urine was processed to remove pathogens and micropollutants (51). Accordingly, although this is certainly important for Swiss consumers (29) and farmers (Fig. 2Dd; 35), few concerns about micropollutants were mentioned by NoMix-toilet users. As contrast, in Sweden urine is commonly re-used after storage to remove pathogens (18). Sweden even follows a policy of nutrient recycling and subsidizes alternative sanitation, e.g. Västervik (42), Tanum (46), Linköping, and Hudiksvall (52). In Germany, the legal situation is unclear, but presumably unprocessed urine was assumed, explaining the high concerns about

micropollutants. In “Solar City” (Austria), it was initially planned to re-use urine. However, the authorities did not allow this, which could explain the generally negative attitude (36).

We conclude that project managers and authorities should explicitly communicate their strategy (overview conclusions: Tab. 3). People are anxious about fertilizer safety and micropollutants, even though scientific evidence for adverse effects is scarce (discussed in 16). This also supports farmers worried about liability claims (Fig. 2C). Individual countries should decide on their priorities. For instance, in Sweden it can be most important to protect sensitive water bodies as the Baltic Sea from eutrophication (8, 22, 42, 46). Sweden also seems more concerned about phosphorus recycling. This is reflected in surveys asking for reasons to separate urine. In Sweden, 63% ($\pm 30\%$; Tab. SI-5) mentioned nutrient recycling or fertilizer, and 69% ($\pm 16\%$) nutrient removal because of eutrophication, compared with 46% ($\pm 10\%$) in Switzerland. Stakeholder interviews in five projects in The Netherlands (grey water treatment) and Sweden (urine separation) confirmed that drivers for source separated wastewater management differ between countries (53). In Sweden nutrient recycling, emission reduction, and an active government policy were main drivers, while water use reduction, fewer sewer overflows, and reduced emissions were main Dutch drivers.

Again, logistic regression in the Swiss library helps finding factors that increase fertilizer acceptance. Respondents assumed processed urine, which explains the very high acceptance, from over 90% for non-food application of urine-fertilizers to nearly 70% of people willing-to-use this in own gardens and purchase such vegetables (Fig. 3D). Given better data for nutrient re-use, cultural differences between countries might become apparent, since 75% of Swiss, German, or Austrian library visitors would probably purchase such food, but only 35% from other countries. Again, exhibiting more environmentally-friendly behaviors was significantly correlated with fertilizer acceptance; but also good mood, higher education, or openness towards innovations (Fig. 3D).

Promoting acceptance and diffusion of bathroom innovations. What can we learn from these surveys for future pilot projects with NoMix-technology or other household innovations? Many factors influencing acceptance cannot be directly controlled by project managers because they are individual (age, education) or personality characteristics (openness towards innovations, environmentally-friendly attitude), or because they are inherent to the technical system. For instance, the Austrian study concluded that respondents were open towards NoMix-toilets, but that only an improved design could motivate people to keep their NoMix-toilets (36). Given the drawbacks of the currently available NoMix-toilets, it is difficult to imagine a take-off of this innovation (14). Eight surveys from two countries confirmed that only 50% of respondents regard a widespread introduction of NoMix-technology as likely. We are convinced that the practical problems must be overcome with improved NoMix-toilets; and the NMX-toilet (www.sealskin.nl) is a step in this direction. However, unsatisfactory NoMix-toilets should not impede well-managed pilot projects already today (Tab. 3).

Many projects found that information, which can be influenced by project managers, increases user acceptance and compliance. Kvarnström et al. (22) report of Swedish examples; e.g. in the museum “Universeum” in Gothenburg, feces landing in urine bowls were reduced when the NoMix-instructions included reasons for urine collection. Similarly, information was seen as crucial for the well-functioning of 65 NoMix-toilets in a school in Mölndal. Earlier studies found that minimal information such as simple signage (54) or instructions for use of NoMix-toilets (34, 55) significantly increased positive user response, but more-advanced strategies can be designed. A “Think-Before-You-Flush” campaign reduced female hygiene items flushed down the toilet by 28–50% (56). For dry toilets, incentives as maintenance service or lower costs would encourage users to accept these as long-term option (27). Environmental psychology can help designing information or intervention strategies (49, 57).

Our review shows that accepting NoMix-technology in households is critical. To overcome this obstacle, people must be convinced that the concept makes sense for ecological reasons. As example, in a Swedish household NoMix-project with exceptionally low acceptance, most urine was discharged to the WWTP (31). One explanation was that it is de-motivating to live with practical problems without re-use

of urine. Similarly, wastewater authorities stopped the NoMix-project in the Swiss library, because motivation was seen difficult after termination of the research project for fertilizer production (51). Switzerland also followed the idea of NoMix-technology for peak shaving to reduce nutrient loads at WWTPs (10). For households, multi-criteria decision analysis identified that a nutrient-recycling scenario (and not peak shaving) was most attractive for environmental reasons under condition that a better “high-tech” NoMix-toilet was produced and additional costs subsidized (58).

There are excellent environmental arguments for NoMix-technology. Many coastal areas are without wastewater infrastructure. Eutrophication and hypoxic “dead zones” caused by massive nutrient input is one of the biggest threats to marine ecosystems (59). Here, NoMix should be the technology of choice. Already the simplest concept with 80% urine collection combined with discharge of the remaining wastewater to the sea would rapidly decrease nutrient emissions, equaling denitrifying treatment plants normally achieving 50–60% nitrogen removal (60). Eutrophication is already an issue in Europe, and phosphorus recycling will become one, because extraction of this limited resource is environmentally questionable and increasingly expensive (7).

It is possible to convey such arguments to lay people; many are concerned about our planet and are willing to contribute. Compared with other environmentally-friendly behaviors such as reducing car-driving (48), NoMix is an easy technology for end-users, even with the current NoMix-toilets. If project managers, communities, and politicians take their responsibility and come up with an integral strategy, compliance of individuals is likely. This was demonstrated in Sweden, where communities have recognized their central role in mitigating between stakeholders, e.g. in Tanum or Kullön (22). NoMix-technology deserves more support by authorities *and* mainstream research. Based on the presented feedback, urine source separation and nutrient recycling is appealing to lay people and their willingness-to-support the NoMix bathroom innovation is large.

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SUPPORTING INFORMATION AVAILABLE: We provide additional information: Methods (NoMix-toilets; weighted means; overview pilot projects, studies, and references reviewed here (Tab. SI-1), weighted means of answers indicating a positive attitude towards NoMix-toilets and urine used as fertilizer (Tabs. SI-2–SI-7), and stepwise forward logistic regression parameters (Tabs. SI-8–SI-11). This information is available free of charge via the Internet at: <http://pubs.acs.org>.

FIGURES

Figure 1. Attitude towards NoMix-toilets. Answers to questions (see text) concerning acceptance of NoMix (A), practical aspects (B, C), and the willingness-to-behave as required by NoMix-toilets. We present weighted means of answers indicating a positive attitude towards NoMix grouped for countries (A, B, D), and two settings; institutions and private homes (error bars = standard deviation; if there are none, only one study contributed to the respective mean).

Figure 2. Use of human urine as fertilizer in agriculture. (A) Weighted means of acceptance of urine fertilizers by the general public and users of NoMix-toilets (a, b) and some concerns mentioned (c, d). Data are grouped for countries (error bars = standard deviation; if there are none, only one study contributed to the respective mean). (B–D) Attitude of farmers; we present averages of three individual surveys, one in Switzerland (35) and two in Germany (38, 40). (B) Acceptance of urine fertilizer by farmers (a–c) and their willingness-to-pay (d–f). (C) Reasons of those farmers that were skeptical, (D) concerns of farmers (a–d), and on which crops they could imagine applying urine fertilizers (e–g).

Figure 3. Results of logistic regression for explanatory variables. Significant differences between user groups of NoMix-toilets and their answers to different questions (see text) concerning: (A) acceptance of NoMix; (B) perception of practical aspects, (C) willingness-to-behave as required by NoMix-toilets, and (D) attitude towards re-using human urine as fertilizer. The groups are: (1) Attitude: demonstrates only 1 vs. 5 environmentally-friendly behaviors; (2) Mood today: not so good vs. good or excellent; (3) Information: feels not so well vs. (very) well informed about NoMix; (4) Innovativeness: is not so open vs. likes to try new things even if old ones are well proven; (5) Age: oldest (≥ 50 years) vs. youngest (9–

24 years) age group; (6) Education: lowest (primary, secondary school) vs. highest (university, applied university); (7) Frequency: regular use of NoMix (daily to several times/week) vs. rare (less than 3x/month); (8) Sex: women vs. men; (9) Living environment: lives in urban vs. rural place; (10) Nationality: Swiss vs. all other nationalities except German and Austrian. The results are always presented in this order. If a group consisted of more than two levels (e.g. low/medium/high), we only show the contrast between lowest and highest. We present the percent positive answers of one representative survey in a Swiss public library (N = 501 respondents).

TABLES

Table 1. Overview of response rates in studies on NoMix-toilets from different groups: countries, toilet types, and setting (% = percent sample of total number of studies, N = number of respondents).

Country	No. of studies	%	N	Toilet type (alone or with others)	No. of studies	Setting	No. of studies	%	N
Switzerland	6	18%	1794	Roediger	9	Institution: knows NoMix from visits	8	24%	1486
Germany	7	21%	346	Roediger UD vacuum toilet	1	Institution: work place (regular use)	6	18%	577
Austria	1	3%	54	Gustavsberg	9	Households / private homes	18	55%	482
Luxembourg	1	3%	89	Dubblotten	9	Fertilizer questions at exhibition	1	3%	175
The Netherlands	2	6%	30	Wost Man Ecology	8				
Sweden	15	46%	395	Porsgrunn DS	1				
Denmark	1	3%	12	Dry toilet with urine diversion (UD)	1				
Total	33	100%	2720				33	100%	2720

Table 2. Stepwise forward logistic regression model results to test ten explanatory variables for 501 users of NoMix-toilets in Swiss public library. The dependent variables (see Methods and Fig. 3) concern: (A) acceptance of NoMix, (B) perception of practical aspects, (C) behavior, and (D) acceptance and application of a urine-based fertilizer.

(A) Acceptance of NoMix idea and toilet																			(B) Perception of practical NoMix-aspects															
Sources of variation		a) (Very) good idea				b) Have it at workplace				c) Install it in my home 1				d) Install it in home 2				e) Pay more for NoMix				a) Design same / better				b) Smell same / better				c) Seating comfort				
		d.f.	Step	χ^2	R^2	P	Step	χ^2	R^2	P	Step	χ^2	R^2	P	Step	χ^2	R^2	P	Step	χ^2	R^2	P	Step	χ^2	R^2	P	Step	χ^2	R^2	P				
1. Attitude	4	1	12.9	0.086	*					4	9.9	0.076	*	2	11.6	0.080	*	2	12.1	0.065	*													
2. Mood	1	2	6.9	0.132	**					3	4.5	0.050	*																					
3. Information	1	3	4.5	0.161	*	1	26.3	0.082	**	*	2	4.9	0.038	*									1	5.6	0.019	*				2	4.3	0.102	*	
4. Innovative	1					2	18.3	0.136	**	*	1	9.6	0.026	**	1	18.5	0.050	**	*	3	3.6	0.077	+						3	5.1	0.120	*		
5. Age	2					3	17.6	0.187	**	*												2	7.6	0.045	*									
6. Education	2					4	6.9	0.207	*																									
7. Frequency	2																		1	7.6	0.025	*												
8. Sex	1																									1	7.2	0.028	**	1	23.3	0.086	**	*
Full model	(14)		24.3	0.161	**	*	69.1	0.207	**	*	28.9	0.076	**	*	30.1	0.080	**	*	23.4	0.077	**		13.2	0.045	**		7.2	0.028	**		32.7	0.120	**	*
C) Behavior adequate for NoMix-toilet													D) Acceptance and application of urine-based fertilizer																					
Sources of variation		a) Just sat down				b) Sit next time				c) Paper in bin				a) Public lawns				b) Organ. farming				c) Balcony plants				d) My veg garden				e) Buy vegetables				
		d.f.	Step	χ^2	R^2	P	Step	χ^2	R^2	P	Step	χ^2	R^2	P	Step	χ^2	R^2	P	P	Step	R^2	P	P	Step	R^2	P	P	Step	χ^2	R^2	P			

[illegible]

Table 3. Drawbacks of NoMix-technology or barriers to diffusion, and identified improvements or recommended strategies to overcome obstacles.

For more-detailed discussions of practical, legal, or agricultural aspects see (16, 21).

Problem	Drawbacks and barriers	Improvements and recommendations
Design of NoMix toilets	<p>NoMix-toilets have various design-related problems:</p> <ul style="list-style-type: none"> * Poor hydraulics resulting in multiple flushes. * Feces in urine compartment (more cleaning required). * Urine in feces compartment (nutrient loss). * Necessity to sit to urinate, difficult to use for children. * Only water saving, if special disposal of toilet paper after urinating 	<ul style="list-style-type: none"> * Some technical solutions (e.g. install toilet that offers a children's seat). * Enhance user awareness and motivation (good information policy, intervention strategies) so that users adapt behavior to requirements of NoMix-toilets (e.g. sitting). * Motivation can be increased with comprehensive ecological concept. * In the long run, improved design of NoMix-toilets by sanitary firms is required.
Characteristics of urine	<ul style="list-style-type: none"> * Urea hydrolysis leads to precipitation and clogging of pipes, requiring more maintenance, and nutrients are lost in precipitates. * Ammonia losses in piping system lead to bad odor, emissions, and loss of nutrients. 	<ul style="list-style-type: none"> * Removal of blockages (chemically or mechanically). * Avoidance through increased maintenance, e.g. regular flushing with acid. * Unconventional building solutions are needed to keep the retention time of urine short (e.g. wide diameter of pipes, 3% slope, good ventilation in bathroom, odor traps). * In the long run, industrial technology development is needed, e.g. forced precipitation in the toilet to recover nutrients and avoid blockages.
Fertilizer acceptance by	<p>Generally very high acceptance, but some concerns with respect to hygiene (pathogens), and micropollutants (pharmaceuticals) in urine.</p>	<ul style="list-style-type: none"> * Urine can be stored to remove pathogens. * Urine can be processed to remove pathogens and micropollutants or separate them from nutrients (as e.g. in Switzerland). * Clear communication of strategy and positive attitude by project managers, communities, and authorities is very important to increase acceptance. * Each country should decide on priorities (e.g. protect Baltic Sea from eutrophication in Sweden) and initiate or support projects to tackle such problems (e.g. with subsidies).
Fertilizer acceptance by farmers	<p>Farmers are more skeptical; most prominently, they fear liability claims. Other concerns:</p> <ul style="list-style-type: none"> * Requirements for fertilizer quality may not be fulfilled. * Ecological concerns (ammonia emissions). * Hygienic concerns (pathogens). * Micropollutants (pharmaceuticals) in agriculture. * Lower consumer acceptance and reduced sales. 	<ul style="list-style-type: none"> * Some farmers are willing to use untreated urine (Sweden). For these, storage for hygienization is sufficient, if urine-fertilizer is allowed in the country. * Other surveys (Germany, Switzerland) indicate that urine should be processed to meet specific fertilizer needs and avoid unwanted substances in agriculture. * Give feedback to farmers about high consumer acceptance. * Regulations need to be changed in some countries to allow for urine in agriculture or should be specified to detail quality requirements. * Strategy, positive communication, and support by managers and authorities (see above).

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