Overcoming Drought

A scenario for the future development of the agricultural and water sector in arid and hyper arid areas, based on recent technologies and scientific results

New Generation Greenhouse Technology
Use of unconventional Water Sources
Urban Water- and Matter Circuit
Cross Technology Synergisms
Exemplary Regions of Agadir (Morocco) and Gabes (Tunisia)
Policy and Research Recommendations

Martin Buchholz (Editor)

Implementation Guide of the “Cycler Support” project, a specific support action accomplished under the 6th Framework Programme of the European Union, aimed at the implementation of research activities related to wastewater use and recycling within new generation greenhouse system (RTD FP 6 – INCO, Ref. Nr. 031697)
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References
Comprehensive Summary

The Cycler Support project, funded by the 6th Framework Programme of the European Union was aimed at bringing together knowledge from different research areas, mainly from greenhouse horticulture and water management, to investigate the potential of growing food on the base of unconventional water sources. This includes on one hand the integrated crop production using the urban water and matter cycle as a base for water and plant nutrients. On the other hand, also technologies of rainwater harvesting and water desalination are investigated.

A long term scenario is described, that shall envisage a future sustainable economic base and the development of 100% of the surface in the perimeter of urban areas in arid and hyper-arid regions. This includes high productive crop production within a new generation of water efficient greenhouses, but also reflects the development of the open landscape, that can be developed e.g. by changing the relief and by adding non-degradable carbon being generated as a waste product from the urban matter cycle.

New generation greenhouses: A group of new greenhouse technologies allows to collect condensed water from air water vapour within greenhouses. This means, that much less conventional water has to be used. Together with rainwater collected from the roof tops of the greenhouses, it is possible to reach a water autonomous situation of irrigation water supply in many regions of the world.

Urban greywater can be used as an additional water source in irrigation and can be recycled back as fresh water in the urban areas. Saline water can be used in the greenhouses for evaporative cooling in a way, that also the condensed water yield is increased. Seawater can be directly used for irrigation directly, if it’s sufficiently mixed with condensed water, so that the salinity is decreased and can be managed by salt uptake of the vegetation and periodical flushing of drainage water.

A first example for the new technology is the Watergy greenhouse, a closed air environment. There is an internal, buoyancy driven air circulation with rising hot and humid air, that flows up into a tower. Within a cooling duct, the air then is cooled down by a heat exchanger, that makes the the air cooler and heavier, so it flows down, back into the greenhouse. The water that has been evaporated by the plants in the greenhouse and by additional air humidifiers in the greenhouse roof is condensed back by the cooling process.

A specific advantage of a closed greenhouse is, that no insects can enter, so that pesticides can be ambundant. Additionally, carbon dioxide can be accumulated in the closed system as a plant fertilizer. Already now, a 100% additional crop productivity has been approved within this prototype, mainly due to the CO2 enrichment. Growing larger amounts of crops at higher quality means a big economical advantage for farmers.

Another new generation greenhouse type is the seawater greenhouse. It has been developed by the british company “Seawatergreenhouse”. It is an open system with a linear air flow. There is a fan that blows air out of the greenhouse. Fresh air is comig in but is cooled by evaporation pads at the greenhouse air inlet using seawater for evaporation. This means that cool air can be provided relatively cheap, if seawater is availabble in the local neighbourhood. The water, that has been evaporated by the plants and the water vapour from the pads can be condensed out of the air by a cooling wall. In this way, a large amount of water introduced into the system can be recycled.
To go beyond the stage of using ventilators, that are very energy consuming, it is proposed to develop a new kind of slope greenhouse, that can use the buoyancy effect to induce air exchange. Again, it is possible to use seawater for evaporative cooling of the incoming air and greenhouse crop production can be performed in the area behind the cooling pads. In a second compartment along a mountain slope, the growing air temperatures can be used to evaporate more seawater from ponds, that can be placed within several terraces. This part can be combined with algae production as these species, compared with higher plants, can tolerate hotter temperatures as well as increased water salinity. Finally, a simple air to air heat exchanger can be placed at the upper outlet of the greenhouse system to cool down the hot and humid air and to force condensation.

The greenhouse could change both, the surface heating effect and the related desiccation of the air, and by this will contribute to fight against the negative climatic effect of hot spots, hindering rainfall in coastal areas due to insufficient evaporative cooling of vegetation surfaces.

**Productive system using the urban water and matter cycle.** A general risk in Mediterranean countries and other arid and hyper-arid areas on the world is growing drought and water scarcity, that destroys the base of food supply and the most important export business for many regions. Insufficient waste water treatment is also the base for groundwater contamination and related problems with diseases.

Treated wastewater from clearage fields can be filtered with a specific gravel filter. The drainage from these filters can be used for irrigation water supply of the new generation greenhouses. The risk of food contamination until now hinders applications like this in the official agricultural policies. It is proposed to first evaluate the quality of the water before and after the new gravel filter and within the final crops in detailed field studies.

For the case of insufficient crop quality, it is proposed to use membrane ultra filtration, which is a more expensive method, but still much less energy intensive than for example sea water desalination. Both filters have the specific advantage, that plant nutrients can remain in the water and can be used for crop production.

An alternative for the treated waste water from clearage fields is the direct separation of greywater and urine within the households. In this case, the water can be directly treated by the gravel filter or even can be used directly for irrigation and the greenhouse irrigation system itself is used as a treatment facility. The final product is fresh food and clear water, that can be sold on the local market as well as for export.

For the case, that gravel filter or ultra filtration does not allow a sufficient crop quality, it is also possible to irrigate non-food crops within the greenhouses, that can for example be used as a base for construction materials. Here we have the risk concerning an insufficient value of non-food products, that would not allow capital intensive greenhouse production. For that case, it is proposed to further develop greenhouse integrated solid state fermentation, that allows to produce industrial raw materials like improved textiles and cellulose, materials that have a much higher value than just raw biomass. Bamboo could replace steal and biologically treated hemp could replace cotton, but both products could be produced with obviously lower energy and water consumption, compared to the products that can be substituted.
Solid state fermentation can also be used to produce protein enriched food from oil or starchy crops like soy, peanut, rice or potatoes that can provide a valuable substitute for fish and meat. Again, these products can be produced with obviously lower energy and water consumption, compared to the products that can be substituted. These examples show the potential of increased surface productivity, far beyond just using biomass as an energy source, that can launch up totally new markets for the greenhouse business.

**Integrating saline water in the greenhouse water cycle:** Seawater can be used as an additional water source, especially for coastal areas, that could even allow a total independency from rain. In the closed greenhouse, seawater can be used for humidification of greenhouse air in the roof area as well as during night, using the stored thermal energy with having condensation yields on the greenhouse roof. For the open slope greenhouse, seawater can be used for the cooling of the incoming air as well as for the slope greenhouse, for the solar still in the slope part behind the crop area. In this way, a much more water independent production of crops and biomass can be introduced.

A specific problematic wastewater in coastal areas is coming from the fish industry, as it increases the total salinity of urban wastewater, thus making it problematic for reuse in irrigation. It is here proposed to separate this kind of wastewater and to use it as a nutrient source for aqua farming. Seawater can be used to dilute this wastewater to decrease its salinity. The runoff water from the aqua farming can still be used as a nutrient source for algae production, thus allowing a total removal and use of the organic residues. Algae production can be integrated into the solar still part of the slope greenhouses.

**Pyrolysis, as a pollutant sink in the urban matter circuit, producing a non-degradable soil improver as a by-product:** Looking at the waste stream after the product’s life cycle, the wastewater has already been mentioned. Organic solid waste can be divided into agricultural waste, which for example can be contaminated with pesticides and domestic waste, that can also contain toxic constituents.

The risk of accumulation of pollutants in closed matter circuits can be minimised by having pyrolysis as a general treatment method for solid waste. Beside having the possibility of producing oil and gas with this method, residues from the process like charcoal and carbon dioxide can be redirected into the greenhouse areas.

How does pyrolysis work? Agricultural residues, domestic solid waste and sludge has to be dried, using solar energy. This can be done as a common method either on open fields or in open greenhouses. The dried biomass is transported to a centralised pyrolysis device, where it is processed into oil, gas and solid charcoal. The oil can be used as an export good. It needs post processing, that can be done in a more decentralised unit. The gas can be used locally in combustion units, while the produced carbon dioxide from that units can be used for CO2 supply in closed greenhouses. The charcoal can be used as a permanent, non degrading soil improver at the productive land, that , as a positive feedback enhances the production of the biological resources.

**Combined recovery of water from greenhouse irrigation and of cooling water from concentrating solar thermal power stations (CSP):** On the scale of a whole region, greenhouse areas can be placed on the perimeter of cities, producing food for export and for the local market. Electricity can be produced by concentrating solar power stations, that can be used in combination with the greenhouses, using common heat storages for cooling purposes, without increasing the volume of these storages, as it is possible to just increase the
temperature amplitude, which for the greenhouses ranges between 25 and 40°C and for the power stations between 40° and ~45° C. The stored heat can be used in combination with seawater desalination in the solar still of the slope greenhouse or in closed greenhouses during night with water condensation on the inside greenhouse cover. The size of the steam turbine of a concentrated solar power unit also triggers the size of one surrounding greenhouse unit.

Agadir as one off the exemplary regions: The central structure of Agadir is already attached to neighboured greenhouse areas, that could be improved to provide the functions of the closed urban water and matter circuit. For the further growth of the urban region, it is proposed to have a kind of decentralised concentration instead of further growth out of the centre. There is an area along the coastal main road with several larger villages, there is Biugra as the largest satellite town and there is a chain of villages along the road to the city of Taroudant. These areas have direct contact to the surrounding landscape. They can be further developed for the integration of the urban matter circuits and energy flows, providing a sufficient supply of labour, food, water and energy. Finally a supply system for seawater is proposed. It can be used as an additional water source in the greenhouse areas, that will allow the regional production system to be more or less totally independent from rainfall. Agadir, the metropolitan area of Southern Morocco at the edge of the desert by this could be an example for new cities southbound the coast and for other hyper arid regions of the world.

Policy and Research recommendations: The innovative, multifunctional character of the new proposed systems as a productive unit for food/non-food crops and clean water on the one hand, and a treatment system for wastewater and saline water on the other, requires support on policy and administrative level to speed up the implementation of these technologies. Starting up programmes to support implementation of the ECOSAN approach (incl. wastewater separation and safe reuse) are proposed. Based on the implementation of existing standards on wastewater reuse, a supporting development of adapted standards for new generation greenhouse systems is discussed. Recommendation for regional action plans, enabling wastewater reuse are given.

For the context of greenhouse horticulture, a label for sustainable agricultural production including sustainable use of water is proposed. Closed greenhouses in combination with pyrolysis waste treatment shall be officially confirmed as a carbon sink in the international carbon trade system. Cooling water recovery of concentrated solar power units and methods for using the waste thermal energy for solar desalination processes within greenhouses should be supported by specific CSP directives and should be included in related subventions. Coastal saline water supply networks can be developed as a part of regional infrastructure planning.

For near term measures, a number of 10 model research areas are proposed, being (1) closed greenhouse research for food crops, (2) research for non-food crops including greenhouse integrated solid state fermentation, (3) open greenhouse research with natural convection, built on mountain slopes, using saline water from the sea for evaporative cooling, (4) integrated aqua farming for fish and algae production using waste water and solid waste from fish processing, (5) formation of model urban areas for wastewater pre-selection with related use of greywater and treated urine in greenhouse projects (6) wastewater post treatment systems adapted to reuse of water and solved plant nutrients in horticultural production systems, (7) sea- and brackish water desalination systems adapted to use in horticultural production, (8) pyrolysis model project for treatment of urban waste, sludge and agricultural waste with charcoal as a main output product to be used as a soil enhancer, (9) rain fed cultivation in arid areas based on charcoal soil supply and surface rainwater harvesting and (10) concentrated solar power projects with cooling water recycling in closed greenhouses.
Résumé

Le projet d'appui Cycler, financé par le 6ème PCRDT de l'Union européenne visait à rassembler les connaissances de différents domaines de recherche, principalement celles relatives à l'horticulture sous serre et la gestion de l'eau, à étudier le potentiel de production sur la base de sources d'eau non conventionnelles. Cela comprend, d'une part, la production intégrée des cultures en utilisant les eaux domestiques et le recyclage de la matière comme source d'eau et d'éléments nutritifs pour la plante. D'autre part, les technologies de captage des eaux de pluie et de dessalement de l'eau ont également fait l'objet investigation.

Un scénario à long terme est décrit, qui doit envisager une future base économique durable et le développement de 100% de la surface dans le périmètre urbain des zones arides et hyperarides. Ceci inclut une importante production de cultures dans une nouvelle génération des serres à utilisation efficiente d'eau, mais reflète également le développement du paysage ouvert, qui peut être développé par exemple en changeant les secours et par l'ajout de carbone non-dégradable généré comme un déchet à partir du recyclage des déchets urbains.

Nouvelle génération de serres: Un groupe de nouvelles technologies de serres permet de recueillir l'eau condensée à partir de vapeur d'eau de l'air dans les serres. Cela signifie que beaucoup moins d'eau conventionnelle doit être utilisée. Ensemble avec la collecte de l'eau de pluie provenant du toit des serres, il est possible de parvenir à une situation autonome d'approvisionnement en eau d'irrigation dans de nombreuses régions du monde.

Les eaux grises urbaines peuvent être utilisées comme une source additionnelle d'eau dans l'irrigation et peuvent être recyclées en eau douce dans les zones urbaines.

L'eau salée peut être utilisée dans les serres pour le refroidissement de manière à ce que le rendement en eau condensée soit augmenté. L'eau de mer peut être directement utilisée pour l'irrigation, si elle est suffisamment mélangée avec l'eau condensée, de sorte que la salinité diminue et peut être gérée par l'absorption des sels par la végétation et le rinçage périodique des eaux de drainage.

Un premier exemple de la nouvelle technologie est la serre de type Watergy, un environnement à air fermé. Il y a une flottabilité interne de circulation d'air avec la hausse de l'air chaud et humide, qui circule dans la tour. À l'intérieur d'un conduit de refroidissement, l'air est ensuite refroidi par un échangeur de chaleur, qui rend l'air plus frais et plus lourd, et retourne dans la serre. L'eau qui a été évaporée par les plantes en serre et par des humidificateurs d'air dans le toit de la serre est condensée par les processus de refroidissement.

Un avantage spécifique de la serre fermée, est que les insectes ne peuvent pas entrer, de sorte que les pesticides peuvent être abonnés. En outre, le dioxyde de carbone peut être accumulé dans le système fermé comme un engrais. Déjà maintenant, 100% de productivité additionnelle des cultures a été approuvée dans ce prototype, principalement en raison de l'enrichissement en CO2. Produire de plus grandes quantités de cultures à plus haute qualité est un grand avantage économique pour les agriculteurs.

Une autre nouvelle génération de serres sont les serres à eau de mer. Elles ont été développées par la compagnie britannique “Seawatergreenhouse”. C’est un système à flux d'air linéaire. Il y a un ventilateur qui refoule l'air de la serre. L'air frais est rentre mais il est refroidi par les plaquettes d'évaporation à l'entrée de la serre en utilisant l'eau de mer pour l'évaporation. Cela
signifie que l'air frais peut être fourni relativement bon marché, si l'eau de mer est disponible dans les lieux. L'eau, qui a été évaporée par les plantes et la vapeur d'eau des plaquettes peuvent être condensées dans l'air par un mur de refroidissement. De cette façon, une grande quantité d'eau introduite dans le système peut être recyclée.

Pour aller au-delà de la phase d'utilisation des ventilateurs, qui sont très consommateurs d'énergie, il est proposé de mettre au point un nouveau type de serres à pente, qui peuvent utiliser l'effet de flottabilité pour provoquer l'échange d'air. Encore une fois, il est possible d'utiliser l'eau de mer pour le refroidissement par évaporation de l'air entrant et la production des cultures sous serre peut être réalisées dans la zone située derrière le bloc de refroidissement. Dans un deuxième compartiment le long d'une pente de montagne, l'accroissement de la température de l'air peut être utilisé pour évaporer plus d'eau de mer de bassins, qui peut être placé dans plusieurs terrasses. Cette partie peut être combinée avec la production d'algues comme ces espèces, en comparaison avec les plantes supérieures, peuvent tolérer des températures plus chaudes ainsi que la salinité accrue de l'eau. Enfin, un simple air-air échangeur de chaleur peut être placé à la partie supérieure de sortie de la serre pour refroidir l'air chaud et humide et forcer la condensation.

L'effet de chauffage de surface et la dessiccation relative de l'air, et par cela contribuera à lutter contre les effets climatiques négatifs des points chauds, qui empêchent les précipitations dans les zones côtières en raison de l'insuffisance de refroidissement par évaporation des surfaces de végétation.

**Système de production utilisant les eaux urbaines et le recyclage de la matière.** Un risque général dans les pays méditerranéens et d'autres zones arides et hyperarides dans le monde sont la sécheresse accrue et la rareté de l'eau, qui affecte la base de l'approvisionnement alimentaire et la plus importante activité d'exportation dans de nombreuses régions. L'insuffisance de traitement des eaux usées est également à la base de la contamination des eaux souterraines et les problèmes liés à des maladies.

Les eaux usées traitées à partir des champs de nettoyage peuvent être filtrées dans un filtre de gravier. Le drainage de ces filtres peut être utilisé pour l'irrigation et l'approvisionnement en eau de la nouvelle génération des serres. Le risque de contamination des denrées alimentaires, jusqu'à présent, empêche des applications comme dans les politiques agricoles officielles. Il est proposé d'abord d'évaluer la qualité de l'eau avant et après le nouveau filtre de gravier et dans les cultures finales en détail dans des études sur le terrain.

Pour le cas de l'insuffisance de la qualité de la culture, il est proposé d'utiliser des membranes à ultra filtration, qui est une méthode plus chère que le filtre de gravier, mais reste beaucoup moins chère que par exemple le dessalement de l'eau de mer avec l'osmose inverse. Les deux filtres ont l'avantage que les éléments nutritifs peuvent rester dans l'eau et peuvent être utilisés pour la production des cultures.

Une alternative pour les eaux usées traitées des domaines de nettoyage est la conséquence directe de la séparation des eaux grises et de l'urine dans les eaux ménagères. Dans ce cas, l'eau peut être directement traitées par le filtre de gravier ou même peut être utilisée directement pour l'irrigation et le système d'irrigation sous serre lui-même est utilisé comme une installation de traitement.

Le produit final est les aliments frais et l'eau claire, qui peuvent être vendus sur le marché local ainsi que pour l'exportation.
Pour le cas où le filtre de gravier ou l’ultra filtration ne permet pas une qualité suffisante de la culture, il est également possible d’irriguer les cultures non alimentaires dans les serres, qui peuvent par exemple être utilisées comme base pour les matériaux de construction. Ici, nous avons le risque relatif à une insuffisance de la valeur des produits non alimentaires, qui ne permettrait pas une production intensive sous serre. Dans ce cas, il est proposé de poursuivre le développement de fermentation de solide sous serre, qui permet de produire des matières premières industrielles comme le textile et la cellulose améliorés, les matériaux qui ont une valeur beaucoup plus élevées que de simples matières premières de biomasse. Le bambou pourrait remplacer l’acier le chanvre biologiquement traité pourrait remplacer le coton, mais les deux produits pourraient être produits avec évidemment moins d’énergie et de consommation d'eau, comparativement à des produits qui peuvent être remplacés.

La fermentation du solide, peut aussi être utilisée pour produire des aliments enrichis de protéines à partir des cultures oléagineuses ou à amidon comme le soja, l'arachide, le riz ou de les pommes de terre qui peuvent remplacer le poisson et la viande. Encore une fois, ces produits peuvent être produits avec évidemment moins d'énergie et de consommation d'eau, comparativement à des produits qui peuvent être remplacés. Ces exemples montrent le potentiel de l'augmentation de la productivité, bien au-delà de simplement utiliser la biomasse comme source d'énergie, qui peut lancer totalement de nouveaux marchés pour les affaires de serre.

Intégration de l'eau salée dans le cycle de l'eau des serres: l'eau de mer peut être utilisée comme une source d'eau, en particulier pour les zones côtières, et pourrait même permettre une totale indépendance de la pluie. Dans la serre fermée, l'eau de mer peut être utilisée pour l'humidification de l'air sur le toit ainsi que pendant la nuit, à l'aide de l'énergie thermique stockée ayant des rendements de condensation au niveau du toit des serres. Pour des serres à pente ouverte, l'eau de mer peut être utilisée pour le refroidissement de l'air entrant comme pour les serres à pente, pour le solaire dans la pente derrière l’aire de culture. De cette manière, une production de biomasse plus indépendante de l’eau peut être introduite.

Une problématique spécifique des eaux usées dans les zones côtières est due à l'industrie du poisson, car elle augmente la salinité des eaux usées urbaines, ce qui rend difficile leur réutilisation dans l'irrigation. Il est ici proposé de séparer ce type d'eaux usées et de l'utiliser comme source de nutriments pour l'agriculture aquatique. L'eau de mer peut être utilisée pour diluer les eaux usées et diminuer sa salinité. Les eaux de ruissellement de l’agriculture aquatique peuvent encore être utilisées comme une source de nutriments pour la production des algues, permettant ainsi une suppression totale et l'emploi des résidus organiques. La production d'algues peut être intégrée dans la partie solaire des serres à pente.

Pyrolyse, comme un polluant dans le circuit urbain de la matière, produisant un non-dégradable améliorateur de sol comme un sous-produit: Quand on regarde le flux de déchets après le cycle de vie du produit, les eaux usées ont déjà été mentionnées. Les déchets organiques solides peuvent être divisés en déchets agricoles qui par exemple peuvent être contaminés par les pesticides, et les déchets domestiques qui peuvent également contenir des constituants toxiques.

Le risque d'accumulation de polluants dans les circuits fermés de matière peut être minimisé par pyrolyse comme étant une méthode de traitement des déchets solides. À côté de la possibilité de production d’huile et de gaz avec cette méthode, les résidus issus du processus comme le charbon et le dioxyde de carbone peuvent être redirigés dans la serre.

Comment fonctionne la pyrolyse? Les résidus agricoles, les déchets domestiques solides et les
boues doivent être séchés, en utilisant l'énergie solaire. Cela peut être fait comme une méthode commune soit dans les champs ou dans les serres. La biomasse séchée est transportée vers un dispositif centralisé de pyrolyse, où elle est transformée en huile, gaz et charbon. L'huile peut être utilisée comme un produit d'exportation. Il a besoin de post-traitement, qui peut être fait dans une unité plus décentralisée. Le gaz peut être utilisé localement dans les unités de combustion, tandis que la production de dioxyde de carbone produit dans ces unités peut être utilisées pour l'alimentation en CO2 des serres fermées. Le charbon peut être utilisé comme un tampon du sol permanent, non dégradable dans les terres productives, qui, comme une rétroaction positive renforce la production de ressources biologiques.

Récupération combinée d'eau à partir de l'irrigation de serre et de l'eau de refroidissement à partir des stations l'énergie thermique solaire (CSP): A l'échelle d'une région, les zones de serres peuvent être placées sur le périmètre des villes, produisant des produits destinés à l'exportation et pour le marché local. L'électricité peut être produite en concentrant les stations d'énergie solaire, qui peuvent être utilisés en combinaison avec les serres, en utilisant le stockage commun de chaleur pour les fins de refroidissement, sans augmenter le volume de ces stockages, comme il est possible de simplement augmenter l'amplitude thermique, qui, pour les serres varie entre 25 et 40 °C et pour les stations électriques entre 40 °C ~ 45 °C. La chaleur stockée peut être utilisée en combinaison avec le dessalement d'eau de mer dans le solaire de la serre à pente ou dans les serres fermées pendant la nuit avec la condensation de l'eau à l'intérieur de la serre. La taille de la turbine à vapeur d'une station d'énergie solaire décline également la taille d'une unité de serre.

Agadir comme l'une des régions exemplaires: La structure centrale d'Agadir est déjà associée à des zones de serres dans les banlieues, qui pourraient être améliorées pour assurer les fonctions de l'eau et de la matière en milieu urbain. Pour la croissance future de la région urbaine, il est proposé d'avoir une sorte de concentration décentralisée au lieu d'une croissance à l'extérieur du centre. Il y a une zone côtière le long de la route principale avec plusieurs grands villages, il y a Biugra comme la plus grande ville satellite et il existe une chaîne de villages le long de la route de la ville de Taroudant. Ces domaines sont en contact direct avec le paysage environnant. Ils peuvent être développés pour l'intégration de circuits de la matière urbaine et les flux d'énergie, en fournissant une offre suffisante de main-d'œuvre, de nourriture, d'eau et d'énergie. Enfin, un système d'approvisionnement pour l'eau de mer est proposé. Il peut être utilisé comme une source additionnelle d'eau dans les zones de serres, qui permettra au système de production régionale d'être plus ou moins totalement indépendante des précipitations. Agadir, la région métropolitaine du sud du Maroc à l'orée du désert, par ce, pourrait être un exemple pour les nouvelles villes de la côte sud, et pour d'autres régions hyperarides du monde.

Recommandations de la recherche et des politiques: Le caractère innovateur, multifonctionnel des nouveaux systèmes proposés comme une unité de production de denrées alimentaires et non alimentaires et de l'eau propre, d'une part, et un système de traitement des eaux usées et l'eau salée, d'autre, exige un soutien politique et administratif pour accélérer la mise en œuvre de ces technologies. Des programmes de démarrage pour l'appui de la mise en œuvre de l'approche ECOSAN (y compris la séparation des eaux usées et la réutilisation saine) sont proposés. Sur la base de l'application des normes existantes sur la réutilisation des eaux usées, un appui au développement de normes adaptées pour la nouvelle génération de système de serres est discuté. Des recommandations pour les plans d'action régionaux, permettant la réutilisation des eaux usées sont donnés.
Pour le contexte de l'horticulture sous serres, un label pour une production agricole durable, y compris l'exploitation durable de l'eau est proposé. Les serres fermées en combinaison avec le traitement des déchets par pyrolyse doivent être officiellement confirmées en tant que puits de carbone dans le système de commerce international du carbone. La récupération de l'eau de refroidissement (y compris les concepts de surplus d'eau), des unités d'énergie solaire et des méthodes pour utiliser les déchets de l'énergie thermique pour les procédés de dessalement solaire dans les serres doivent être soutenus par des directives spécifiques de CSP et devraient être inclus dans des subventions relatives. Les réseaux d’approvisionnements côtiers en eaux salines peuvent être développés dans le cadre de la planification de l'infrastructure régionale. Les serres doivent être envisagées comme une catégorie spécifique dans les plans directeurs des zones urbaines ou plans de développement du paysage.

Pour les mesures à court terme, un certain nombre de modèles dans 10 domaines de recherche sont proposées, qui sont (1) recherche en serre fermée pour les cultures vivrières, (2), recherche en serre fermée pour les cultures non alimentaires, y compris la fermentation intégrée de l'état solide sous serre, (3) recherche en serre ouverte avec la convection naturelle, construite sur les pentes de montagne, en utilisant l'eau salée de la mer pour le refroidissement par évaporation, (4) agriculture aquatique intégrée pour la production des poissons et des algues en utilisant des eaux usées et les déchets solides provenant de la transformation du poisson, (5) la formation de zones urbaines modèles pour la présélection des eaux usées avec l’utilisation des eaux grises et des urines traitées dans des projets de serre (6) des systèmes de post-traitement des eaux usées adaptés à la réutilisation de l'eau et des éléments nutritifs de la plante dans les systèmes de production horticole (7), les systèmes de dessalement de l'eau saumâtre et de l'eau de mer adaptés à l’utilisation dans la production horticole, (8) le projet de modèle de pyrolyse pour le traitement des déchets urbains, des boues et des déchets agricoles avec du charbon comme principal produit destiné à être utilisé comme un redresseur du sol (9), la culture pluviale dans les zones arides basée sur l’apport du sol en charbon et la récolte de l'eau de pluie et (10) des projets de l'énergie solaire avec le recyclage de l'eau de refroidissement dans des serres fermées.
مشروع الدعم سايكلر «CYCLER» الذي يموله البرنامج السادس للاتحاد الأوروبي يهدف إلى جمع المعرف من مختلف مجالات البحث الذي تختص بالأساس تدفعة البيوت المكيفة، الدستورية وإدارة المياه لتفعيل إمكانات النمو في الغذاء عن طريق استعمال مصادر المياه الغير تقليدية.

يشمل ذلك من جهة، إنتاج المحاصيل باستخدام المياه في المناطق الحضرية واستغلال دورة المياه كقاعدة للماء والتنزه من جهة أخرى.

ومع ذلك، ينص استغلال التكنولوجيا لكلي مياه الأمطار وتحلية المياه.

هناك برنامج سياريو طويل المدى، يأخذ في الاعتبار التصور المستقبلي للتنمية المستدامة على قاعدة اقتصادية وتقنية 100% عن السطح في محيط المناطق الحضرية من المناطق النائية جدًا. يشمل هذا النباتات ذات الإنتاجية العالية خلال منظومة جديدة عالية الكفاءة للبيوت المكيفة المقتضبة لإستهلاك المياه.

وكل ذلك تعكس استعمال الأراضي المفتوحة التي يمكن تطويرها مثلاً: تغيير المحيط وإضافة الكاربون الغير قابل للتحلل الناتج كمخلفات للاستعمالات في الدورة الحضرية.

المثال الأول للتكنولوجيا الجديدة هي البيوت المكيفة واترجي «WATERGY» ذات بيئة المغلقة.

هناك منظمة داخلية تتلو هذه الهواء، مع ذوبان المياه الساخن والرطب إلى الأعلى نحو بربر مرتقي.

ويقع تبادل الهواء للأسفل داخل أنابيب نحو البيوت المكيفة. أما بالنسبة للماء الذي تخرج من النباتات داخل البيوت المكيفة فيقع تكثيفه باستخدام عملية تبريد بواسطة مربتات هواء على جوانب البيوت المكيفة.

هناك ميزرة محددة للبيوت المكيفة وهي أنه لا يمكن دخول الحشرات بما يسمح بالتخلي عن المبيدات.

بالإضافة إلى ذلك يمكن لثاني أكسيد الكربون المتراكم في نظام مغلق أن يستعمل كأساسة للنباتات. ينتج النباتات هذا النموذج، ويرجع ذلك أساساً إلى تخصيب ثاني أكسيد الكربون.

يتميز تزايد كميات أكبر من المحاصيل على مستوى أعلى من الجويدة ميزرة اقتصادية كبيرة للمزارعين.

نوع جديد آخر من البيوت المكيفة هي البيوت المكيفة المستخدمة لبيوت البحر، وقد وقع تطويرها من طرف شركة البريطانية «SEAWATER GREEN HOUSE» تمثل هذه المنظومة في نظام مفتوح مع سيريان هوائي نفطي، وتمته مروحية تقوم بصرف الهواء خارج البيوت المكيفة. الهواء النقي يدخل ثم يُبرد بمتصاعد تبخير عند دخول البيوت المكيفة وذلك باستخدام الماء القادم من البحر للتبخير. وهذا يعني أن يمكن إداد الهواء البارد بطرق رائعة في بيئة المحيطة ببيئة الملاحة المائية المتاخرة من النباتات بالإضافة إلى البخار الناتج من المنصات يمكن تكثيفه من الهواء باستعمال الجدران.

كذلك الهواء ممكن تدوير كميات كبيرة من المياه الداخلية في المنظومة.
لتجاوز مرحلة استخدام التهوية المستهلكة للطاقة يقترح تطوير نوع جديد من البيوت المحامية المحدودة التي يمكن أن تستعمل للحث على الطفو أثر تبادل الهواء مرة أخرى، من الممكن استخدام مياه البحر في المرادات الحرارية بالتبخير لتبريد الهواء القادم وناتج المحاصيل في المناطق المجاورة لليبيوت المحمية.

داخ الأحوال طوال المدخرات الجبلية يمكن استخدام ارتفاع درجات الحرارة لتبخير المياه من برك مياه البحر التي يمكن وضعها داخل العديد من المدرجات وتمكن ربط هذا الجزء مع أنتاج الطحالب، التي تتحمل درجات عالية من الحرارة والملوحة وأخيراً يقع وضع مياه حراري بسيط الهواء في المنفذ العلوي لتهدئة الجو الحر والرطب ولقوة التكييف يمكن لليبيوت المحامية الزراعية تغيير، على الهواء، أثر سطح وتفجيف الهواء المتعلق بها، مما يساهم في ماكافة التأثير السلبي على المناخ في المناطق الساخنة والتي تحول دون نزول الأمطار في المناطق الساحلية نظراً لعدم كفاءة الغطاء النباتي لتبريد السطح.

النظام الإنتاجي لاستخدام المياه في المناطق الجبلية:

* يمكن إزداد الحفاظ وندرة المياه خطراً عاماً في بلدان البحر الأبيض المتوسط وغيرها من المناطق القاحلة بالعالم والتي تؤدي على زيادة إمدادات الغذاء وأهم الصادرات الإنتاجية للكثير من المناطق.

وتؤدي عدم كفاءة معالجة مياه الصرف على تلوث المياه الجوفية وعده مشاكل ذات صلة بالأمراض.

ويمكن تصنيف مياه الصرف المعالجة من مجالات "CLEARAGE" بواسطة فلتر الحمي المحمد.

وعقل استعمال الصرف من خلال هذه الفلاتر لأغراض الري وإمدادات المياه للجيل الجديد من البيوت المحامية الزراعية.

تعرقل محاور تلوث الأغذية حتى الآن مثل هذه التدابير الوسطي في السياسة الزراعية الروسية.

ومن المتطلبات الأولى هي تقييم نوعية المياه قبل وبعد الفلتر الجديد من الحمي وداخل المحاصيل الزراعية النهائية من خلال دراسات معمقة.

وفي حال عدم كفاءة معالجة المحمية، يقترح استخدام الأغذية فائقة التنقية، والتي هي أكثر كتلة ونخفية من طريقة فلتر الحمي، ولكنه لا يزال أقل كلفة بكثير من تلقيحة المياه بتناسبية العكس.

كل من المنظومات لها ميزة معينة، ففن المغذيات النباتية تستطيع البقاء في المياه ويمكن أن تستخدم لإنتاج المحاصيل.

إمكانيات أخرى لاستخدام مياه الصرف وهي الفصل المباشر بين مياه الصرف والبول داخل البيوت مما يسمح بمعالجة 와واتي واستعمال فلتر الحمي أو استعمالها مباشرة لأغراض الري في البيوت المحامية الزراعية. وتمثل الأغذية الطازجة التي يمكن بيعها سواء في السوق المحلية أو الخارجية الناتج النهائي من المشروع.

في هذه الحالة، فإن فلتر الحمي أو السوير فلتر لا يسمح بزراعات ذات الجودة الكافية، كما يمكن استعمالها أيضاً في رو المحاصيل الغير الغذائية داخل البيوت المحامية الزراعية والتي يمكن استخدامها فيما بعد على سبيل المثال كقاعدة لمياه البناء. هنا لدينا مخاطر بشأن عدم كفاءة قيمة المنتجات غير الحيوية في هذه الحالة يقترح زيادة تطوير البيوت المحامية المتكاملة مع حالة تخمير الصلبة، التي تسمح بإنتاج المواد الخام الصناعية مثل المنتجات المحسنة والألبان، المواد التي لها قيمة أعلى بكثير من مجرد الكنية الحيوية.

يمكن للخزير تعويض القلق والمعالجة بطريقة بيولوجية لتعويض القسط ولكن كلا المنتجين يمكن إنتاجها مع انخفاض واضح للاستهلاك الطاقة والمياه بالمقارنة مع المنتجات التي يمكن تعويضها وأيضًا يمكن استعمالها.

التخمير على الحالة الصلبة أيضاً لإنتاج البروتين الغذائي من الزيت أو النباتية مثل محاصيل الفول السوداني، الآز أو البطاطس التي يمكن أن توفر دبلاً فيما للأسمك واللحم.

مرة أخرى، هذه المنتجات يمكن إنتاجها مع انخفاض واضح للاستهلاك الطاقة والمياه بالمقارنة مع المنتجات التي يمكن تعويضها. تبين هذه الأمثلة زيادة الإنتاجية للمساحات بمجرد استعمال الكثافة الحيوية
كمصدر للطاقة التي يمكن أن تصل تماما لأسواق جديدة للأعمال التجارية المتعلقة بالبيوت المحلية الزراعية.

* يتم توضيح أن المياه المالحة في دورة المياه للبيوت المحلية الزراعية.

يمكن استعمال مياه البحر كمصدر إضافي وخاصة بالمناطق الساحلية التي تسهم بالاستقلالية على مياه الصرف. وفي البيوت المحمية الزراعية المائية تستخدم مياه البحر لتحطيط الهواء في منطقة السفف وكذلك أثناء الليل وذلك باستخدام الطاقة الحرارية المكشوفة. وكما يمكن استخدام الطاقة الحرارية المكشوفة على سطح البيوت المحلية. أما بالنسبة للبيوت المحلية المحمية فستعمل ماء البحر لتحطيط الهواء الواقف وكذلك محاورة الدفعة الخلوية في الجزء المنحدر وراء مجال البيوت المحلية. بهذه الطريقة يمكن إدخال كمية أكبر من المياه بطريقة مستقلة عن إنتاج النباتات والكشفة الحيوية.

وإليك مشكليات محددة تخص المياه المستعملة في المناطق الساحلية وهي ناتجة عن توافد الأسلاف والصناعة التي تزيد من ملوحة مياه الصرف الصحي مما يمثل إشكالية إضافية لإعادة استخدامها في الري.

ومن هنا يقترح قدر هذا النوع من المياه المستعملة واستخدامها كمصدر للزراعة المائية للمواد الغذائية.

كما يمكن استعمال مياه البحر لخفض ملوحة المياه المستعملة. وتشتمل جولة إعادة مياه الصرف الزراعية على مياه مثبتة في الغازات المنحلة في إنتاج المحاصيل مما يسمح بزراعة كميات إعداد استعمال المخلفات العضوية ويمكن إدخال إنتاج المحاصيل باستخدام الطاقة الشمسية في البيوت المحلية المنحلة.

* الانحلال الحراري بالوعة المبئثات في دوائر المناطق الحضرية الغنية منتجة لتلك الكربون ومحسن

للمنتج إذا نظرنا إلى مجري النفايات بعد دورة حياته التوان والبيوت المستعملة يمكن تقنيق النفايات السلبة إلى نفايات زراعية التي يمكن أن تكون سبب مثل المبيدات والنفايات المنزلية التي يمكن أن تضم كميات مسموعة.

كما يمكن لخريج اللازميات في دوائر مغلفة أن يكون له حد أدنى من الانحلال الحراري بصفة عامة على طريقة معمولة النفايات الصعبة إلى جانب وجود إمكانية إنتاج منظمة بالنفس وكأن النفايات من الفروع مثل الضم وثاني أكسيد الكربون الذي يمكن توجيهها إلى المناطق الخفيفة.

كيف يعمل الانحلال الحراري؟ لا لدى المخلفات الزراعية والبكتيريا المنزلية الحيوية من أن تخف هي استخدام الطاقة الشمسية ويمكن أن يتم ذلك بسبب طريقة شائعة مع فتح المجالات أو في البيوت المحمية الزراعية المتغيرة.

يقع نقل الكشفة الحيوية المجهزة إلى جهاز مركزي للانحلال الحراري حيث تتم معالجتها إلى نقطة غاز أو فحم صلب.

وقد يتم استعمال النفايات كأنك لصورة تصديرية جديدة.

ويمكن ذلك إلى تجهيز يمكن القيام به في أكثر من عدة مركبات.

بالنسبة للغاز فيمكن استخدامه محليا في وحدات الاحتراق في حين أن إنتاج ثاني أكسيد الكربون من أحد الوحدات يمكن أن يستعمل لعرض ثاني أكسيد الكربون في البيوت المحلية المعطلة. ويستخدم الفحم النباتي كمصدر حنال للحرارة في الأراضي المنتجة التي لها عدد فعال إيجابية تعزز الإنتاج للعوارض البيولوجية.

الجمع بين الانتهاء من المياه من ري الدفعة وتبديد المياه من محطات توليد الطاقة الحرارية الشمسية

(2) : (SP)

على مستوى المنطقة بأسرها، يمكن وضع المناطق الدقيقة على محيط المدن وذلك لإنتاج الغاز، التصميم والسوق المحلية. ويمكن إنتاج الكربون عن طريق تركي محدود الطاقة الشمسية التي يمكن أن تستخدم في الجمع مع البيوت المحلية بالاستعمال المشترك للحرارة والمخازن لأغراض التبريد دون زيادة حجم هذه المصادر.

كما أن من الممكن زيادة درجة حرارة السعة والتي تتراوح بالنسبة للبيوت المحلية الزراعية ما بين 25 و 40 درجة منوية و 40 إلى 45 درجة بالنسبة لمحطات توليد الطاقة.
بأغادير واحده من الأماكن الترفيهية المثالية المميزة المريكي لمدينة أغادير بجنوب المغرب قد تم ربطه بالفعل بمساحات هامة من الصوامع المحيطة والتي يمكن تحسينها لتوفير وظائف دائرة مغلفة للمياه والموردة.

والمزيد من النمو في المناطق الحضرية من المنطقة يقترح أن يكون لها نوعا من الامركون يبدأ من تركيز النمو على سطح البلاد إذ أن هناك منطقة ساحلية على طول الطريق الرئيسي مع عدد من القرى الكبرى. ولهذا يكون أكثر من موجة تطويرها من أجل إعداد مواء المرشد الحضرية وتفوق الطاقة، وتطوير امدادات مياه البحر المنظومة المقتدحة إذ يمكن استعمالها كعنصر إضافي ومصدر للمياه في المناطق الدفلى، التي تسمح للنظام الإقليمي للإنتاج الزراعي بأن تكون مستقلة ولوضوع غير عام.

أما فيما يخص طول المساكن أو أغادير عاصمة جنوب المغرب، على أبابا الصحراء من جانب البحر، من جانب آخر، يمكن أن تكون مثل لمدن الجديدة الساحلية بالمنطقة والمدن القائمة في العالم.

*توصيات مبنية على البحث والسياسة.*

الطبع المبتكر، المتداعي الوظائف للمنطقة المخصصة الجديدة يتمثل في اعتبارها وحدة إنتاجية للأنشطة، والممارسات العذراء والمياه المعززة بالمياه المطلبة والماء من ناحية أخرى. ويتطلب تنفيذ هذه المنظمات دعما على مستوى السياسة العامة والإدارية للدراسات في تنفيذ هذه التكنولوجيات. وقد وقع اقتراب بدأ بتنفيذ برنامج لدعم تطوير أكواس ECOSAN الكبيرة، (مباشرة فصول مياه الصرف الصحي ومياه استخدام المياه المستعملة ودعم التنمية للمعايير المكافئة لنضم أبسط البحر من الصوامع. وقد وقع التأكيد على توصيات علم الإقليمية ضم من إعادة استخدام المياه المستمرة وفي إطار النشاط داخل الصوامع وفق اقتراب عامة للإنتاج الزراعي المستدام بما في ذلك الاستخدام المستدام للمياه.

وقد يكون جمع الدفقات المغلقة مع الإصلاحات الرسمية لمحاولة النفايات أحد المقومات الرسمية لبضاعة الكرتون في نظام التجارة الدولية للكاربون. ينبغي دعم توجيهات حضرية لانشئ مياه التبرد (ما في ذلك مقاومات خاص المياه) لوحدات الطاقة الشمسية، وأعمال استخدام نفايات الطاقة الحدودي للativllات التنغيمية الحيوانية داخل البيوت المحمية الزراعية.

ويمكن تطوير شبكات إمدادات المياه الملاحصة في المناطق الساحلية كجزء من التخطيط الإقليمي للبنية التحتية.

ويعتبر الأخ الأصغر في إحصاء البيوت المحمية كخناجر حديثة في خطط التنمية الطبيعية لتدابير مدى القرارات وفق اقتراب عشرة نماذج من مجالات البحث وهي (1) البحث حول البيوت المحمية المدمجة للإنتاج الزراعي (2) البحث في البيوت المحمية المغلقة للتنبئات الغفازية بما في ذلك تحمير الصلبة المتكافئة (3) الأبحاث حول البيوت المحمية المفتتحة مع الحملا الحراري الطبيعي (4) البيوت المحمية المغلقة على مساحات الأراضي الجزيرة استخدام المياه الملاحصة من اجتماعات التبرد والتساقط، (5) تشكيل نموذج لبيوت الصرف الصحي المحرر لاختيار ما يتصل بذلك من استخدام مياه اليد في مشاريع البيوت المحمية (6) نظم مكاني نسبة المياه المستعملة بعد تكييفها للاستخدام المستدام والمدى والبيئات التي في حل نظم الإنتاج في منظمات (7) الانتاج الزراعي (8) تحليل مياه البحر أو الجوفية المتكافئة للاستعمال في نطاق الإنتاج الزراعي (9) مشروع منظومة الإنتاج الحدودي لمعظم المياه المستعملة الحضرية مع الفحم كمصدر رئيس لإنتاج مصبات الناتجة (10) الزعوات箢ية في المناطق الساحلية على أساس توفير للنظام البيئي، الأمطار والصرف (11) مشاريع الطاقة الشمسية المزدوجة مع إعداد تدوين المياه والتدريب في البيوت المحمية الزراعية المغلقة.
Prices for agricultural products have been rapidly rising through the last months with dramatic consequences especially for developing countries. Exploding costs are caused by real physical shortages after a period of growing demand in emerging markets, that are more and more changing diets towards meat, while at the same time a number of bad harvests mainly caused by drought did reduce global supply.

Additionally, at present state, bio-fuels made out of sugar cane, can be produced at prices below the current price of oil. Production cots for sugar beat or corn also is close to the price of oil. This together means a total change of the situation: Agricultural production can face a de facto endless market on the demand site! Producers could sell as much as possible for a good price but how could they offer more?

Financial investments into agriculture should be a good deal in this context, but it is not that easy. While, for example, European policies try to subsidize the conversion of wheat into fuel, some Golf countries are promoting oil based desalination in order to grow wheat in the desert.

Pushing the productivity on existing agricultural land by the known methods of the green revolution (inorganic fertilizers, chemical pesticides, mechanisation, irrigation) or by the use of genetically modified crops is the most current area of financial investments, but in many areas, a decrease of productivity can be observed after decades of land overexploitation caused by just these methods. Further more, growing oil prices are increasing the costs especially for mineral fertilizers.

Irrigation is a key issue in arid climate to convert previously unused or unproductive land into areas of intense cultivation. Anyway, the business is so profitable that around available groundwater stocks, land use is growing so fast, that any source will be finally ended, even if using the today available sophisticated water efficient irrigation systems.

The dramatic decrease of rainfall and groundwater deficits due to water overexploitation in North African countries asks for some general new concepts towards water- and resource efficient agricultural practices. The common messages, that ask for crops that are more adapted to drought and to the original environment sounds reasonable, but do not very much address the real situation in these countries.

In the Mediterranean area, the production of fresh fruits and vegetables in greenhouses has dramatically grown during the last 20 years. In some areas, even for some national economies, horticultural production is already the most important economic branch! For morocco, this kind of production already has brought a number of great benefits:

- Greenhouse horticulture has generated a work load equivalent to more than 1 Million permanent jobs only in the greater area of Agadir.
- Beside crops that are exported, mainly to Europe, greenhouse technology allows more water efficient production and also contributes to the fact that many crops, that has been imported some years ago now are locally produced and now provides a cheaper food supply
- The strong controls of the export goods towards integrated crop protection also contributes of an increased quality of the local food supply.
Today, a strategy generally turning away from fresh crops like Tomato, Sweet pepper or Bananas towards Olives, Almonds or Cactus to manage growing water scarcity is not a real solution for the region, as it would destroy most part of the market like yet developed and would by this also destroy a source of human nutrition. Changing from “cash crops” to low income products implies the risk of massive breakdown of one of the most important areas of income in Northern Africa and in several regions of Southern European countries.

**Five steps of implementation**

The rising global food crisis is mainly caused by a lack of water and a more and more limited supply of plant nutrients. For a long term development with foreseeable further population growth, related increase of needed human supply and growing water scarcity due to climate change, a kind of quantum leap has to be considered, that should go far beyond the currently discussed measures of higher water efficiency in agricultural and urban water supply.

For arid climate, a much more resource efficient system should be implemented, that can be defined within five new paradigms:

- **The natural water cycle can be circumvented!** Water efficiency can be drastically improved by new greenhouse technologies, that provide condensed water regained after being evaporated by plants with recycling rates of up to 80% and reduced water consumption compared to open field intensive production of 95%.

- **Urban water and matter cycles, realised by specific wastewater and solid waste collection- and treatment technologies will allow to minimise nutrient losses, contamination of land and groundwater.** For the future, they can provide a real alternative to mineral fertilisers and to groundwater based irrigation water supply.

- **The natural carbon cycle can be circumvented!** Carbon dioxide from the atmosphere can be captured by vegetation and after the life cycle of biological products, can be transferred to charcoal by processes like pyrolysis or hydrothermal carbonisation. By this, carbon can be accumulated in the soils for very long periods and can allow to increase the water field capacity and related heat capacity of productive land.

- **Carbon dioxide produced by combustion or biological degradation of biomass or fossil fuels can be recycled into the air volume of closed greenhouses with enriched CO$_2$ content for extensive increase of plant productivity - without disputed methods like further plant breeding or genetic modification.**

- **The cooling water cycle of concentrated solar powers systems and geothermal power systems can be combined with solar seawater desalination as well as with new generation greenhouse systems to allow the use of sea- and brackish water sources for agricultural systems, especially in coastal areas.**
This document will describe within 5 steps the implementation of these new approaches. The concept consist of (1) the new generation greenhouse systems, (2) the formation of an urban water and matter cycle, (3) the accumulation of carbon in the urban perimeter (4) the use of saline water in combination with concentrated solar power generation and finally (5) the interaction of the previous approaches

Within the Annex, the localisation of the described measures within the exemplary regions of Agadir and Gabes is described. Finally, policy recommendations and an outline for ten research programmes as first steps of implementation are presented.
1. First step: New generation greenhouses as a solution for intensive agricultural production in arid and hyper arid areas

The new greenhouse generation here is defined as the ability of a greenhouse to gain condensed water from the water vapour of at least a part of the greenhouse volume and by that reducing the total water consumption to at least 60% of the original consumption of a standard greenhouse. This can be reached either by condensing the water evaporated by plants or by specific evaporation modules, fed with saline water or by a combination of both water sources.

There are actually three different approaches approved by different prototypes as being closed greenhouses (e.g. Watergy), Open greenhouse with evaporative cooling pads at the air inlet (e.g. “Seawatergreenhouse”) and Standard greenhouse with associated solar still (e.g. integrated in the greenhouse roof or in combination with covered sweet water storage tanks, solar ponds or thermal heat storage ponds).

Effects of the water condensation:

- All these types of greenhouses can achieve a higher water efficiency by providing a higher air humidity around the plants and by providing condensed water recycled from air humidity. At many regional situation, a reduction of 60 % already would mean to change from a situation of over - exploitation of groundwater stocks to a sustainable use of such a sources.

- The water efficiency can be further enhanced if collection and storage of rainwater from the greenhouse roof is provided. In situations of higher rainfall or high condensed water recycling rates, a total water autarky situation can be reached only by rainwater harvesting from the roof and condensed water recycling.

![Diagram](image-url)  
*Fig.: 1.1. Water efficiency by production of condensed water*
Fig. 1.2.: Water desalination using new generation greenhouse technology. The salt output goes with a concentrated brine if using air evaporators or with the biomass, if saltwater is used in irrigation and irrigation water is sufficiently diluted with condensed water and sufficiently salt tolerant plants are used.

- If using pre-treated urban wastewater or grey water, already a situation can be reached, where the greenhouse provides fresh water due to the high quality of treatment reached with distillation and by this works as a water producing device, while using the wastewater input on a very efficient way.

- Saline water can be used either to feed the evaporation cooling pad at the air inlet (Seawater greenhouse) or for post humidification of the air cycle in the closed greenhouse (Watergy) or during night cooling of the thermal storage (Watergy) or with an attached solar still or with a combination of different approaches.

- Also, saline water can be mixed to the irrigation water, if sufficiently mixed with the condensed water. At very high recycling yields (> 90%), even seawater can be diluted sufficiently to be used in the irrigation process. This method is only realisable, if the irrigation management is sufficiently organised (e.g. lower salinity for young vegetation, sufficiently organised drainage water disposal etc.)

Economics of improved water efficiency: In addition to the income from horticultural production, a further income can be achieved by the water technologies. Compared to a 100% horticultural profit, a total profit of additional 40% can be reached due to the water production. This can be achieved by the water recycling (5 %), by selling condensed water to urban areas (20 %), by income related to greywater disposal services (5%) and by lowered costs for mineral fertilisers due to the high nutrient content of the waste water. These profits can be enhanced up to more than 100%, if real prices for water as a rare resource would be paid and if the recent drastical increase of prices for mineral fertilizers are considered.
1.1. Closed greenhouses, The Watergy approach

1.1.1. Functioning of the Watergy system

A closed greenhouse system has been developed in two different prototypes for horticultural use in arid climate and building applications within the EU funded Watergy project. The main goals are space heating- and cooling, water recycling, advanced horticultural performance and solar thermal energy capture. (Buchholz 2004, Zaragoza 2007)

The Watergy system (Buchholz 2000) consists of a closed greenhouse connected with a solar tower. An air-water heat exchanger contained in a cooling duct inside the tower provides the climate control of the greenhouse. Air exchange is powered by the heat- and pressure difference between the upper and lower side of the tower. The efficiency of the heat exchange processes is enhanced by the utilization of latent heat. due to constant humidification/de-humidification of air in the process. Condensation associated with cooling of the nearly saturated air also provides distillation of water. Thermal energy released in the process is stored outside the greenhouse for being used for heating or further water distillation during the night.

Plants are an essential part of the process, being a means of water and air filtering and a source of humidification of the air. Together with water and heat, enhanced biomass production is the main output, as a closed greenhouse allows abundance of pesticides and efficient CO₂ supply for increased plant nutrition.
Fig. 1.4. : Closed greenhouse prototype of the Watergy project in Almeria /Spain.
A first prototype has been built near Almeria/Spain with the big success of a water recycling rate up to 90% without using energy consuming components like ventilators or heat pumps. This enables water autarky intensive horticulture production even for regions with only little more than 100 mm/a. A further success was crop production totally free of pesticides during 4 years.

A second prototype has been built in Berlin /Germany, being a closed greenhouse attached to a building façade. The aim of using the collector element for generation of heat has been proofed. The main advantage compared to conventional solar thermal systems is the use of an air-to-water heat exchanger to transport energy into a seasonal storage, where the same heat exchanger can be used for building space heating with very low supply temperatures between 22 and 28°C.

Main further developments of the system to reach the level of competitiveness are the use of more efficient and cheaper direct contact air-to-water heat exchangers.
Fig. 1.5. : Inside of the Watergy Greenhouse: Okra vegetation with cooling duct behind

Fig. 1.6. : Passive air circulation in the Watergy Greenhouse, driven by rising hot air and falling cooled air
1.1.2. Integration of Solid State Fermentation as a co-production process in the closed greenhouse.

A further technological possibility is the coupling of horticulture with Solid State Fermentation (SSF) (Buchholz 2002). The tropical indoor climate allows to cultivate and control fungal growth, as (1.) the humid air prevents the used substrates from drying out, (2.) the air circulation allows the withdrawal of processed CO2 as well as waste heat and (3.) the temperature optimum of the specific cultivated mushroom can be provided without extra energy input. Mushrooms can be cultivated to grow on biomass given as a substrate that will be degraded in a way that higher valuable products can be produced.

Using soybeans or peanuts as a substrate, the mushrooms can degrade the crops but at the same time produce high quality proteins, that can be used as a valuable meat or fish substitute, but with much higher processing speed and much lower thermal losses compared to aqua farming or diary practices. Steinkraus has investigated different vegetarian protein sources that can be used as a meat substitute with Tempe, a product produced by SSF having the most valuable quality (Steinkraus 2002).

A further application is the upgrading of non food fibre plants. Lignin is digested by the mushroom. The fibres are getting softer (more cotton like) and can be sold at higher value. Also the pre-treatment of wooden biomass for pulp and paper products can be applied, as the lignin of wood is removed. (Giovanozzi et al. 1998)

The solid state Fermentation process can also be used as a CO2 source in the closed greenhouse.
Fig. 1.8. Classification of Solid State Fermentation applications (Buchholz 2002)

Fig. 1.9. Specific economic advantages of closed greenhouses: Additional income from closed greenhouse related applications CO2 accumulation, biological pest control, and Solid State Fermentation (Horticulture = 100 %)
1.1.3. Specific benefits of closed greenhouses and potential for climate change mitigation and adaptation strategies:

**CO2 accumulation:** Closed greenhouses can be used for production with enhanced CO2 level, that is used as a specific fertilisers, and that can not be used in the open field or in only marginally in open greenhouses, as CO2 would always be diluted by the atmospheric air. At the Watergy prototype, already an increase of productivity of 200 % has been achieved. Further increases could be reached with more advanced cooling methods and with optimum light disposal (no use of shades for cooling).

**Pest control:** A further specific advantage of the closed greenhouse is the protection against insect (insects can not enter). Wirth abandoned use of pesticides, an additional income of about 50 % can be achieved due to the higher quality of the crops.

**High water efficiency:** The high water recycling rate of a closed system (approved up to 90%) will allow applications in hyper arid areas, including autonomous systems combined with rainwater harvesting from the greenhouse roof working below 200 mm yearly rainfall) Also seawater based irrigation systems are possible, as the source water can be sufficiently diluted with the condensed water. Theoretically, even a zero input water system with a totally sealed cover is imaginable (“Mars-Greenhouse”)

**Implementation of Solid-State-Fermentation:** As a co-production in the closed greenhouse, fermented food can be produced. As an alternative to meat, it can be produced on a fraction of time and fraction of source biomass. Kenaf, Hemp or Linen can be produced instead of cotton. In this way, a production method can be applied, that only needs a fraction of water, space, pesticides, etc.

**Cooling of the land surface temperature:** By storing daytime heat into a thermal active medium (into a water storage or into the humid soil), and by unloading this heat during night, the system allows a reduction of the land surface peak-temperature compared to adapted arid land surface structures like olive trees, cactus etc. This allows to decrease the ascending dry air current, which is the main reason of decreased rainfall, especially in arid climate coastal areas.

Taking together the closed greenhouse specific applications of CO2 accumulation, biological pest control and Solid State Fermentation, a total 400 % of value can be produced. This will allow to built up improved greenhouse systems, four times more expensive in terms of investment and running costs compared to conventional greenhouses.

Together with the higher water productivity and the benefit of night heating from the thermal storage, the production could be increased on the base of new applicable regions (colder and dryer zones) as well as new markets (tropical crops, fibre crops, fermentation crops like soy or peanut and final fermented products like meat and fish substitutes, textiles, cellulose, bio-enzymes etc.).

This is specifically interesting, if considering the global size of land for agriculture and forestry needed just to produce meat, textiles and paper, while the new system could
provide alternatives for these production methods on today usable land, that is too cold or too dry for conventional production.

The modification of the production process will allow to decrease this surface due to the higher efficiency (fermented food instead of meat, produced on a fraction of time and fraction of source biomass; Kenaf, Hemp or Linen produced instead of cotton, produced with a fraction of water etc.). The production process will further more allow to increase the cultivatable areas into now arid or even hyper arid land, which contributes much more to the current food crisis then just focusing on production methods with increased water efficiency.

Disadvantages and Risks: Specific disadvantages for the system are much higher investment costs for the cooling- and dehumidification instalments. Also, the concept until now works with over heating of the indoor atmosphere, which can be partially compensated with the CO2 accumulation, but that gives a limitation on the variety of usable crops, that have to be tolerant against high temperatures and high humidity.

The system works with a passive cooling strategy, that releases most of the heat through the outside foil. Further heat is stored and released through cooler night time temperatures. Both approaches are limited to certain climate with a limit regarding maximum allowed daytime and nighttime temperatures.

Further research can lead to improvements of the cooling system, that will allow an operation also at higher ambient air temperatures.

1.1.4. Further needed steps for implementation:

The cooling system in the watergy prototype consists mainly of a capillary pipe heat exchanger, a heat storage tank and a connection system with a pump and a number of insulated pipes.

The heat exchanger: The heat exchanger has been specially designed for the application but with special functions for the experimental status. The price of about 10.000 EURs (50 EUR/m²of related greenhouse surface) is about three times higher than a normal low budget greenhouse (compared to the related scale). A modified, more simple pipe heat exchanger (without the experimental extras) could be reduced in costs to about 50%, but still this would be much too expensive in comparison with the added values, given by the new system.

The same problem relates to the other main parts, the heat storage and the circulation pump. The investment costs for the pump (~1000 EURs) can only be reduced, if a lower resistance in the water flow can be reached.

The heat storage: For the storage, a number of four tanks have been installed, together having a price of about 7.000 EURs. A single tank could reduce the costs again by 50% but the relation to the normal greenhouse investment costs are still too high. A sealed pond could further reduce the costs.
For the heat storage, the lowest costs would arise if placing the storage volume into the greenhouse soil. The needed storage volume would be equivalent to a layer of 20-40 cm in the greenhouse soil. Different constellations for this solution are described in the “Report on reconstruction of existing greenhouses” (Deliverable 6).

The example of the most simple heat storage is the activation of humid soil in the greenhouse. For a layer of 40 cm, each 40 cm would be a pipe installed in the middle of this layer, heating (and cooling) the surrounding wet soil. For this example (within the existing prototype of 14x14m, a simple PVC pipe of 8 cm of diameter would cost about 0,50 EURs/m. A total length of ~500 m (14 x 14 m / 0,4 m distance) and a number of 70 T-Connectors (0,70 EURs each) would result in costs of 300 EURs, which is 1,5 EUR/m². The costs for the saturated soil layer with underlaying geo film will be a bit more expensive but similar to this figure.

**The circulation pump:** Smaller and less energy consuming circulation pumps could be used if using a direct contact air to water heat exchanger, where water is not pressed through small pipes but is only dissipated above a filling material. This procedure is explained in the next chapter. This only requires the lifting of the water, but no losses of resistance in pipes (the main need for power) will arrive.

**New approach for the heat exchanger:** To achieve more reduction of costs, a more radical solution has now been proposed by using a direct contact air to water heat exchanger. This kind of heat exchanger is usually only used within cooling towers, where hot water is cooled down by evaporation processes, where a part of the cooling water is released as water vapour.

In the case of this project, an inverse principle is required, where hot and humid air is chilled down by contact with cooling water, where a part of the water vapour of the air is condensing into the cooling water.

Such a heat exchanger can be realised with costs of 5 EURs/m² of greenhouse, if using industrial heat exchangers normally applied within cooling towers. This would be a reduction of factor 10 compared with the existing one. If using a low tech solution for this component, under use of local materials, this price could further more be approximately halved. Than the price of 2,50 would only be about 20% of a low budget greenhouse construction.

The heat exchanger consists of a number of parallel packed columns, where the air flows through horizontally. The cooling water from the thermal storage runs from the top to the bottom of the columns. The water from the bottom of the first column is pumped up to the top of the next column. The water from the bottom of the last column is pumped back into the storage.
Fig. 1.10.: Industry column filling for waste water treatment and as a cooling tower direct contact air to water heat exchanger (http://www.2h-kunststoff.de)

Fig. 1.11.: Packing with natural wooden material in a historical graduation house (Gradierwerk in Bad Orb, Germany, Saline water flowing over wooden packings, photo: Ulrich Stelzner, www.wikipedia.de, article on „Gradierwerk“)
New methods for closed greenhouse construction:

there are different criteria for a new construction principle:

- Foils have only little tensile strength. In comparison with textile membranes, they can only cover a small surface and have to be fixed from the perimeter of this surface. Methods from membrane architecture can not just be transferred to film constructions.

- The present development of film constructions in architecture mainly relies on double or multiple layer ETFE foil cushions, that are statically optimised by overpressure between the foil layers. This is not a valid way for greenhouses, as the insulation effect of the cushions is unwanted and the related costs are much too high.

- Material base in the long term should be wood and/or plastic

- A sufficient strong double curved surface allows minimisation of the construction and by this higher material efficiency, as wind forces are distributed much more equalized.

- The integration of a cooling tower should be possible under the foil to avoid high and slim building elements where wind forces can not be equalised sufficiently with resulting higher need of material.

Regarding these criteria, two main construction principles are proposed: a sphere like greenhouse and a radial tent like greenhouse. Both have the advantage of a double curved surface and the ability of distributing wind forces equally over the building, leading to lower material demand in the constructive parts and by this also allowing to use less stable materials other than steel.

Domes: A dome, as a segment of a sphere distributes the forces from a surface to its perimeter. This allows to put all or most of the constructive parts out of the greenhouse volume, when the foil is installed as a hanging structure under the construction. This has the large advantage, that corrosive parts (e.g. steal) or wooden parts that could be affected from fouling (e.g. bamboo) is not in contact with the humid interior air of the greenhouse, but is surrounded by the outside dry air. This can significantly extend the lifetime of the construction.

In a dome, the wall of the cooling tower can also be realised by foils, that are fitted as a hanging construction under the roof. The heat exchanger elements also can be constructed from the bottom to the top with light materials, as there are no wind forces within the volume.
Fig. 1.12. : Tensegrity dome structure, Bamboo material, Buckminster Fuller (from Sieden et al. 2000)

Fig. 1.13, 1.14. : Movable Dome, Buckminster Fuller, Radome, Buckminster Fuller 1950 (from Sieden et al. 2000)
Fig. 1.15. : Design for a large Bamboo greenhouse dome with details for node- and plug connexion. (Design: TU-Berlin, Min Ji Kang, Sarawut Nakpee, Kwang Sae-Lim)

Fig. 1.16. : Model of the bamboo greenhouse. (Design: TU-Berlin, Min Ji Kang, Sarawut Nakpee, Kwang Sae-Lim)
Fig. 1.17: Dome carried with overpressure of interior air. This method comes with a radical minimisation of constructive parts, but a constant providing of electric energy for the air compressor is needed. Problem: Hurting of the foil (e.g. by birds) may lead to constructive collapse. (Design: TU-Berlin, Anna Luisa Bories, Annina Wagner)
**Radial tents:** Radial tents have a high point in the middle, that is carried by a pillar. The paral greenhouse is similar to this type, as it has a number of pillars, acting as high points and between some low points that are stretched to the ground by ropes.

The cooling tower elements can be integrated in the pillar or can be arranged around the pillar.

The pillar is used to form a high point, that can carry a grid of cables that are used as a support structure for the foil. The cables can be stretched from lower parts in the bottom of the construction.

![Fig. 1.18.](image)

The pillars have integrated the cooling towers. The altitude of the tower helps to drive the internal air ventilation. Also smaller greenhouses of this type are imaginable. (Design: Luis Miguel Kann, TU-Berlin)
Fig. 1.19. : Intersection of the tent like construction (Design: Luis Miguel Kann, TU-Berlin)

Fig. 1.20. : This design is aimed at minimising the number of ropes. The hexagonal structure of the net hinders a concentration of grids at the highest point, which would occur in a radial grid. (Design: TU-Berlin)

**Modularity for large surfaces:** As providing radial shapes with both types of construction method, a further step has to investigate the possibility of a modular arrangement to realise multiple greenhouses, that can cover a larger surface.
The radial shape can form a circle, where in between the circles are some unused gaps. A more efficient structure comes with a hexagonal unit. An octagonal unit allows an arrangement with a few square intersections, which can be useful to allow to implement some openings on ground level (e.g. for emergency cooling of the volumes).

**Fig. 1.21.** Greenhouse with 4 square outline and connecting lentil shaped interim roofs. (Design: TU-Berlin, Lena Köppen, Stephanie Bock)

**Fig. 1.23.** Landscape appearance (1) (Design: TU-Berlin, Lena Köppen, Stephanie Bock)
1.2. Seawater-fed open greenhouses

Open greenhouse with evaporative cooling pads at the air inlet and equipped with a cooling pad within the greenhouse, that is powered with evaporative cooling (heat exchanger at the air inlet or external cooling duct) or with direct air to air heat exchangers at the greenhouse outlet.

1.2.1. The seawater greenhouse

The Seawater greenhouse process (Davies et al 2005) uses seawater to cool and humidify the air that ventilates the greenhouse and sunlight to distil fresh water from seawater. This enables the year round cultivation of high value crops that would otherwise be difficult or impossible to grow in hot, arid regions.

The entire front wall of the building is a seawater evaporator. It consists of a honeycomb lattice and faces the prevailing wind. Fans assist and control air movement. Seawater trickles down over the lattice, cooling and humidifying the air passing through into the planting area.

Sunlight is filtered through a specially constructed roof. The roof traps infrared heat, while allowing visible light through to promote photosynthesis. This creates optimum growing conditions - cool and humid with high light intensity.

Cool air passes through the planting area and then combines with hot dry air from the roof cavity. The mixture passes through a second sea water evaporator creating hot saturated air which then flows through a condenser.

The condenser is cooled by incoming seawater. The temperature difference causes fresh water to condense out of the air stream. The volume of fresh water is determined by air temperature, relative humidity, solar radiation and the airflow rate. These conditions can be replicated in the thermodynamic model and, with appropriate meteorological information, the detailed design and performance of the Seawater Greenhouse can be optimised for every suitable location and environment.

The air entering the Greenhouse is both cooled and humidified. High humidity and low temperatures (the Greenhouse operates at approx. 90% relative humidity) reduces plant transpiration substantially, by up to 80%. This reduces irrigation requirements. The irrigation rate in Tenerife averaged 1.2 litre/day/m² against 8 litres/day/m² used by local farmers. Of even greater importance is the effect the Seawater Greenhouse can have on reducing demand for mains water and reserves of ground water.

The Greenhouse is driven by solar and wind energy. Sunlight is separated into visible and infrared light. Visible light passes through the roof to drive photosynthesis. Infrared light is trapped in the roof canopy and is ducted from there to the seawater evaporator. Thus solar energy converts seawater to water vapour.

The structure acts as a ‘wind-catcher’. It faces into the prevailing daytime wind to assist ventilation. Fans are required under most conditions although these were unnecessary in Tenerife. The wind-fan combination moves air through the front evaporator and chills the sea water which then provides cooling for the rear condenser and, thus, the production of fresh water.
The electricity requirements are modest and, in the absence of grid power, can be provided by photovoltaic panels without the need for batteries, inverter or standby generator. The Tenerife Greenhouse was built on a wind farm with power supplied by the wind turbines on site. There are thus potential synergies between the Seawater Greenhouse and both wind and solar power.

The overall process is energy efficient. 1kW of electricity expended on pumping will remove 500kW of heat. Water can be produced at low energy costs (<3kWh/m3) (www.seawatergreenhouse.com)

Compared to the closed greenhouse approach, an open greenhouse is mainly cooled by water evaporation at the air inlet. This means that for the basic function of cooling, no thermal storage is needed which allows a more simplified and thus cheaper concept.

This type of greenhouse can only be more water efficient than a standard greenhouse, if seawater is used for evaporative cooling. This means seawater has to be easily available, which is the case in coastal areas or in flat areas connected to the coast (like e.g. the large sinks of the North African Shott areas), that allow the instalment of a saline water distribution system with low energetic effort.

Open greenhouses with salt water input can be used on places, where seawater in large quantities is easy available (without having relevant transport costs) as being directly on the coast, at plane areas connected to the coast or at regions under sea level.
1.2.2. Concept for slope greenhouses

A main synergism of open greenhouses will be achieved if coupled with slope greenhouses. Greenhouse evaporative cooling normally is achieved with so called “fan and pad” systems, the pad side wasting water, the fan side wasting energy. To use buoyancy forces for air movement, the greenhouse can be partially placed on a mountain slope or building façade. Already in 1990, a slope greenhouse for seawater desalination was proposed by Luboschik (Luboschik 1990)

In the proposed case, the slope part can be used to place tanks with seawater, that can be used as a solar still while storing heat for night operation. This function will allow higher air temperatures than horticulture. At the greenhouse outlet, can be a simple foil air-to-air heat exchanger, that cools down the air close to the ambient air to achieve condensation. The temperature level could be: Outside at the entry: 35°C, After the cooling pad: 18°C, After the greenhouse 40°C, at the mountain top 70°C, after the heat exchanger 35°C at ambient temperature of 30°C.

A co-function can be algae production in the ponds of the solar still in the slope part of the greenhouse with specific species of algae, adapted to higher temperatures and higher salinity. The major problem in algae production, being the dehumidification of the algae biomass can be solved by special containments that allows to run the drying process with the passing air stream.
1.2.3. Specific benefits of seawater fed open greenhouses and potential for climate change mitigation and adaptation strategies:

Cheap greenhouse cooling method: Seawater in principle will not directly be used for irrigation due to its high salt content. Anyway, it can be used for evaporation cooling in the greenhouse. In opposite to closed greenhouse systems, Seawater Greenhouse can be envisaged as an open system and as a further development of the greenhouse fan and pad system, where a fan sucks exterior air into the greenhouse that is humidified an by this chilled at the air inlet.

Desalination: If using a further cooling mechanism inside of the greenhouse, air humidity can be condensed out of the air stream, so there is a fresh water output, that can be used for irrigation or external (urban) use. Following this principle, the Seawater greenhouse system is a prototype for open greenhouse systems, that beside irrigation water having a salt water input and a fresh water output.

Humidification of ambient air: Beside the higher state of simplicity, related to lower costs, the main interesting potential of the open greenhouse is the higher rate of humidification of the surrounding atmosphere, as only a lower part of the evaporated water is condensed and always a part of the evaporated water escapes from the system. Per surface, this can be as high than a well developed tropical forest. While the closed greenhouse only contributes to a decrease of the daytime peak-temperature, the open system also contributes to a higher humidity of the surrounding air, which reduces the air dew point temperature that is a major factor according to the potential of condensation and resulting rainfall in the area. This process is further described in chapter 1.4.
Surface cooling, addition of air humidity, finally increased rainfall: Applied at large scale, the humidification together with the cooling of the surface can help to increase the rate of natural rainfall. Especially in coastal areas, there is sufficient humidity in the air but the high surface temperatures of dry regions together with the missing additional humidity from surface evaporation recently leads to a decrease of rain. This process can only be changed with concepts, that will cover a large part of the total surface and only will work at sufficient total size.

Disadvantages and Risks: High energy demand for greenhouse ventilation may hinder the applicability. Because of this, passive ventilation strategies should be further developed. Especially interesting is the placement of greenhouses on slope areas, inducing free buoyancy driven air flow. Another method is using solar chimneys. Other than wind energy, solar chimneys allow ventilation in parallel to the cooling demand. Its specific advantage is higher simplicity of the technology and the high rate of evaporative cooling and humidification of ambient air according to effects on the regional climate.

The seawater fed open greenhouse could allow horticultural and algae production combined with seawater desalination. The outgoing humid air can be considered as a water loss, but applied at sufficient scale, a change of the regional climate can be achieved by the cooling of large surfaces and the intense humidification of ambient air. The goal will be to initiate additional rainfall, that would allow to re-change a growing fraction of the land to more simple open-field agriculture. It can be considered as a land-repair method for breaking the vicious circle of increasing drought and subsequent decreasing rain.
1.3. Standard greenhouses with attached solar still

The limited water resources in arid areas have led to use a low-quality irrigation water in agriculture which may reduce crop yields and derange the environment. This study is focused on a greenhouse water desalination considered for small scale applications at remote locations in areas where only saline water is available.

In this greenhouse the roof light transmission is reduced as solar radiation is absorbed by a layer of flowing water on a top glass. Fresh water is evaporated, condensed on the top glass and collected at the roof caves.

The main objective of this research work is to analyze the fresh water production as well as the crop growth capacity and water demand for the concept. Included are theoretical and experimental studies with a focus on the total system performance and design.

For the theoretical analysis simulation models with high accuracy have been developed for the water desalination, the light transmission into the greenhouse, the greenhouse climate and for the crop growth and water demand. A prototype was construct and tested.

![Diagram](Image)

**Figure. 1.28.** Principle of the solar system of desalination integrated into a greenhouse.

1.3.1. Specific benefits of greenhouses integrated solar stills:

Especially for hot arid areas, it maybe useful to use a part of the solar radiation in the roof zone before entering the vegetation zone in order to reduce the need of cooling in the greenhouse. This additional energy pulse can be used for distillation of seawater in an air
space separated from the greenhouse volume in order not to have too much humidity in the vegetation’s environment.

Saline water is not only a topic if using seawater. Brackish water is available in very much environments as the only water source available, so all potential desalination methods related to greenhouses should be observed. Also waste water implies salinity problems, that finally need strategies for desalination.

Possible concurrence of light distribution (flexible shading) to allow optimum light supply to the plants should be regarded.

A very important application is the combination of the solar still with an open water surface as having at water storages, heat storages or water transportation ditches. In this case, the large water body can be used as a heat source for the operation during night, while the cover of the solar still hinders the evaporation of the water from the surface.
1.4. Polarised development with high productive greenhouses on one side and adapted open field agriculture, based on rainwater harvesting, soil improvement and short term use of treated wastewater on the other side.

The main local reason for declined rainfall is the decreased evaporative cooling of the landscape surface, that finally ends up in a vicious, self enhancing circle of less cooling and less rainfall. The role of a small water cycle is important, as water evaporated from the surface can contribute to further rainfall, as the total relative humidity grows. A secondary effect is the diminished thermal buoyancy wind, that turns the movement of external humid air and clouds away from the surface.

Fig. 1.29. Expansion of deserts or semi-deserts with the breakdown of the small water cycle (Kravcik et. al. 2008)

The reason for less evaporative surface cooling is mainly based on two phenomena, being overexploitation of the land surface and overexploitation of groundwater and collection of surface water, which leads to decreased regeneration of groundwater stocks. In total, the water is more and more evaporated in relative small spots of intensive production like e.g. greenhouses or citrus fruit culture, while the rest of the landscape turns dryer and dryer due to falling groundwater levels.
Having the perspective of much more water efficient greenhouses or greenhouses that can even generate water, there is the chance of using the available surface water or larger fractions of available unconventional water sources again on the whole surface of the landscape to increase the total load of evaporative cooling and decrease of the average surface temperature.

For the future, there shall be a rule, that the available water (groundwater, unconventional water sources, potential surplus water generated by the greenhouses) should be used dissipated on the whole surface with vegetation adapted to the area instead of having singular intensive production spots with high water consumption. High water consuming crops should be damned into the new generation greenhouses!

Fig. 1.30. Water holding measures on the edge of critical areas: Their role is to harvest and hold water from the small water cycle from adjacent lands, water from the large water cycle (even in deserts it rains occasionally). The period in which the water cycle is renewed depends on circumstances (the hydrological and pedological conditions, success of the growth of protective vegetation, etc.). (Kravcik et. al. 2008)

It has been reported in the previous sections, that the new generation of greenhouses can contribute to the lowering of the surface temperature, as a large fraction of solar load is either reflected or stored into the soil and released during night. For open greenhouses, using seawater in coastal areas for evaporative cooling, there is even the effect of an extensive increase of air humidity which from a certain size applied, could contribute to more rainfall.
Fig 1.31: Decreasing areas of desert with self enhancing activation of the small and the large water cycle (Kravek et. al. 2008)

1.4.1. Rainwater harvesting

Climate change is widely acknowledged as one of the greatest environmental challenges facing the worldwide community. Even though the causes remain controversial, it is generally agreed that the planet has warmed over the last century. During the last thirty years, the global average surface temperature increased by 0.5 °C (Mrabet, 2008)

The world's drylands are facing not only increasing temperatures with climate change but more importantly also disruptions to their hydrological cycles resulting in less and more erratic rainfall that will exacerbate the already critical state of water scarcity and conflicts over water allocation. In West Asia and North Africa (WANA) region, water scarcity is a well-known and alarming problem because water in this region is the scarcest in the world and water-related issues have become extremely acute and even critical. This problem became one of the highest priorities for national government and local as well as international research institutions. In WANA countries, agriculture is consuming over 75% of the total consumption of water. However, the increasing industrialization and urbanization will require an increasingly water reallocation away from agriculture.

The average annual per capita renewable supplies of water in WANA countries is well below the world average and most countries had per capita water availability less than the threshold of poverty.

Most of the agricultural area in WANA is rainfed and a large proportion of the region’s agricultural livelihood is based on dryland farming systems. In these areas, agricultural
production and livelihoods can be sustained only if priority is given to improving water

Under the Mediterranean-type climate, precipitation is characterized by low annual amount, unfavourable distribution over the growing season, and great year-to-year fluctuations. Rainfall amount in the dry areas is much lower than crop water requirements for economic production. Large variation in the distribution of rainfall within a season coupled with great year-to-year variation make predictions very difficult. As a result of unfavourable rainfall pattern, soil moisture does not satisfy crop needs over the growth season. Therefore, looking for special sources of water is a must under the prevailing stressful conditions that the entire world is experiencing.

Rainwater may be harvested from roofs, ground surfaces as well as from intermittent or ephemeral watercourses. Instead of leaving runoff to cause erosion, it is harnessed, stored and utilized. In the semi-arid and drought-prone areas, water harvesting enhances yields and reliability of production while also conserving the soil. In many parts of the world, rainwater harvesting provides a source of water for household use, for institutions such as schools and community centres, for agriculture where it provides full or supplemental irrigation, environmental conservation and prevention of flood damage.

Water harvesting on croplands may be achieved through micro-catchment or macro-catchment systems or through floodwater farming. Under micro-catchment systems, runoff is collected close to the crop growing area and used to replenish soil moisture. Under the same systems, overland flow is harvested from short catchment lengths, about 1-30 metres long, and having a catchment to cultivated area ratio of about 1:1 to 3:1. Since micro-catchments handle small flows, they normally have no provision for overflow.

Macro-catchment systems, also known as external catchment systems, handle large runoff flows diverted from some source such as a road, home compound, pasture or hillside. The usually 2:1 to 10:1. The runoff may be allowed to infiltrate into the soil profile where a crop catchment is usually 30 - 200 metres in length while the ratio of catchment to cultivated areas is grown. Alternatively, runoff is channelled into storage structures such as ponds, tanks or

Fig. 1.32: Measures of rainwater harvesting by change of surface relief (ICARDA 2008) productivity and enhancing the efficiency of water procurement. In this case, more food, feed and fibber must be produced using less water.
Fig. 1.33. Measures of rainwater harvesting (ICARDA 2008)
groundwater aquifers for various uses, including supplementary irrigation. Due to the large
volumes handled, provision for overflow is made.

Floodwater farming is practiced when water flow is diverted from a valley or wade onto
cropland which is subsequently cultivated. In this case, floodwater systems must have
overflow structures to handle unexpected flows. The catchment is usually large, and thus the
ratio of catchment to cultivated area may exceed 10:1.

Water harvesting techniques are used to improve farmers’ income in drier environment where
rainfall is too low to support any economical dryland farming. Jordan, Syria, Yemen and
Tunisia are advanced in these techniques.

Various rainwater harvesting systems are found all over these different countries. Apart of the
modern techniques that have been recently introduced into the region, all the indigenous
water-harvesting systems used in WANA evolved over the centuries, according to the dictates
of the agro-ecological and socioeconomic factors, and because of modifications made as a
result of the experience gained by people in each country.

Different techniques and rainwater harvesting systems developed and used in most of the
WANA region are documented and well described (Oweis and al. 2004; Ben Mechlia and
Ouessar, 2004; Fardous and Jitan, 2004; Karrou and Boutfirass, 2004, 2007; Soumi and
Abdel Aal, 2004; Alghariani, 2004; Al-Khafaji, 2004; Salem, 2004; Ghaleb and Bamatraf,
2004; Shahid, 2004).
1.4.2. Improved rainwater harvesting using non-degradable organic matter from the urban matter circuit

For productive landscapes, especially in the neighbourhood of urban areas, there is the big chance of increased water keeping capabilities due to the activation of organic matter coming from the solid waste stream. In chapter 3, it is described, how organic material from agricultural waste, municipal waste and sludge can be transformed into charcoal, then being available in a form that can not be degraded by micro-organisms. This charcoal will be a waste material from an energy recovery process and by this can will be available for free of at least for low cost.

Used in the combination with measures of rainwater harvesting, it will allow to minimise water losses to the sub ground and will allow plants to have water available for longer periods, also in a fresh estate, where the vegetation is not able to exploit larger volumes of the ground or reach to groundwater levels. For a restructuring of the landscape, this method can help to speed up the process of vegetation based cooling structures in the landscape.
1.4.3. Short term use of treated wastewater for irrigation with treated wastewater (TWW) with Emphasis on Fodder Crops

Even if the use of treated wastewater in the open field is problematic, due to the long term accumulation of salt and problematic substances like heavy metals or organic micro compounds, it should be used extensively, at least as long as the new generation greenhouses are sufficiently developed to cover the total load of the treated wastewater in a controlled way.

Disposing wastewater into the landscape or removing it to the sea is a much more problematic disuse.

Crops for Irrigation with TWW

The crops that may be irrigated with TWW are crops in which plants or plant parts are not consumed raw by humans. They include the following:

1. Industrial crops such as cotton, "alfalfa", forest trees, etc.;
2. Crops used for landscaping (roadside, golf courses, etc.);
3. Trees, such as olive trees, or fruit trees such as citrus trees where consumed fruit or fruit parts do not come in direct contact with TWW;
4. Crops that are either sun-dried or subjected to heat before they are consumed, such as cereals;
5. Fodder crops that are not directly grazed, but rather harvested and sun-dried (hay) or ensiled.

For all crops, basin or flood irrigation is relatively safe and easy to implement. Drip irrigation is most safe and is therefore recommended, especially for fruit trees and high-value crops, while sprinkler irrigation is to be avoided because of associated high contamination risk of the agricultural product, the farmer, and the surrounding environment.

The Case of Fodder Crops

Fodder crops that may be irrigated with TWW include herbaceous species (such as barley, oats, sorghum, alfalfa, etc.), shrubs, and cacti.

Herbaceous species: The need to increase livestock production requires the intensification of forage production which itself necessitates water resources. Treated wastewater may be used to increase forage production provided precaution measures are taken to avoid dissemination of feces-borne pathogens harmful to animals, livestock keepers and consumers.

The use of TWW for irrigation of green forage must be avoided, except perhaps for cattle raised for meat. For milk production, the forage must not be grazed or fed green, but must be either dried or, better ensiled, before it is fed to animals. The silage transformation, a reaction that takes place at relatively high temperature in an acid anaerobic environment, assures a quasi-total elimination of harmful pathogens. Grass species, such as oats, barley and sorghum are particularly suitable for such transformation.
Although drying and ensiling are excellent for pathogen elimination, TWW must be checked for absence or acceptable low level of harmful chemicals (like heavy metals) before it can be used for irrigation of forage crops.

**Shrubs:** Certain shrub species – known as halophytic shrubs - are very tolerant to drought and produce palatable leaves, suitable for animal feeding. Several saltbush species, belonging to the genus *Atriplex* have been used in Australia and in West Asia and North Africa for small ruminant feeding (Figure 1). Examples are the species: *Atriplex nummularia, Atriplex halimus, Atriplex leucoclada*, etc. These species are also tolerant to salinity, which makes them very suitable for irrigation with TWW, to produce 15 tons of dry matter per hectare.

**Cacti:** Cactus species (cacti) are plant species having fleshy and succulent stems, called pads, and leaves reduced to spines, making these species very resistant to drought and therefore adapted to arid and pre-desert areas.

*Opuntia ficus indica* is the cactus species most commonly found in Tunisia - and generally in North Africa - where it is grown in arid and semi-arid areas for erosion control, and for its fruit appreciated by local people (which gave it the common name of prickly pear). However, its drought resistance makes of its pads a suitable feed resource in arid regions where other feed resources are scarce or unavailable. Cactus productivity is highly increased under irrigation. Like other forage species, prickly pear can be irrigated with TWW if proper
precaution measures are taken to avoid contamination of pads. In an intensive irrigation-based production system, pads are planted in rows spaced 1.5 m apart with 30-cm spacing within rows (Figure 2). Cutting may be done several times a year for a crop irrigated with 4000 m$^3$ ha$^{-1}$ to produce 20 t DM ha$^{-1}$ per year. Cactus plantations should be located near a wastewater treatment plant to minimize transportation cost.
2. Second step: Urban water and matter circuit

2.1. Marginal-quality water resources

Marginal-quality waters consist of: (1) wastewater generated by domestic, commercial and industrial uses; (2) drainage water generated by irrigated agriculture and surface runoff that has passed through the soil profile and entered the drainage system; (3) groundwater from different sources, such as underlying saline formations, seawater intrusion in coastal areas, recharge of agricultural drainage, storm water runoff from urban areas, and/or infiltration from wastewater-irrigated areas. Marginal-quality waters contain one or more impurities at levels higher than in freshwater, including salts, metals, metalloids, residual drugs, organic compounds, endocrine-disrupting compounds, and the active residues of personal care products and/or pathogens. These constituents may have undesirable effects on soils, crops, water bodies, or human and animal health.

2.1.1. Wastewater from domestic, municipal, and industrial activities

Population growth coupled with the provision of goods and services that allow higher living standards have increased the demand for good-quality water to provide for the needs of the domestic, municipal, and industrial sectors in water-scarce countries. Consequently, greater amounts of wastewater are being generated. After treatment, and in conjunction with suitable management practices, this could be reused for a variety of purposes. Urban wastewater consist of a combination of some or all of the domestic effluent produced (black water and grey water), water produced by commercial establishments and institutions (including hospitals), industrial effluent and storm water which has not infiltrated the soil, as well as other forms of urban runoff (Van der Hoek, 2004).

Estimates of the extent to which wastewater is used for agriculture worldwide reveal that at least 2 _ 106 ha are irrigated with treated, diluted, partly treated or untreated wastewater (Jimenez and Asano, 2004). The use of untreated wastewater is intense in areas where there is no or little access to other sources of irrigation water. Few databases are available that describe the extent to which wastewater is used for agriculture at the national or regional levels (Minhas and Samra, 2003; Van der Hoek, 2004). Owing to the variable quantities of water available for human consumption in water-scarce countries, estimates of the per capita generation of wastewater vary, ranging from 30 to 90 m3 yr^-1. The volumes of wastewater generated in some countries of Central and West Asia and North Africa (CWANA) are presented in Table 1. A significant part of the wastewater generated in these countries is used to supplement the freshwater needs of a variety of crops.

The rate at which populations are increasing means that wastewater treatment and its sustainable use is an issue that requires more attention and investment. Most developing countries have not been able to build wastewater treatment plants on a large enough scale and,
Table 2.1. Volume of wastewater generated annually in some countries of central and West Asia and North Africa

<table>
<thead>
<tr>
<th>Country</th>
<th>Reporting year</th>
<th>Wastewater volume ($10^6$ m$^3$ yr$^{-1}$)</th>
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</thead>
<tbody>
<tr>
<td>Algeria</td>
<td>2004</td>
<td>600</td>
</tr>
<tr>
<td>Bahrain</td>
<td>1990</td>
<td>45</td>
</tr>
<tr>
<td>Egypt</td>
<td>1996</td>
<td>10012</td>
</tr>
<tr>
<td>Iran</td>
<td>2001</td>
<td>3075</td>
</tr>
<tr>
<td>Jordan</td>
<td>2004</td>
<td>76</td>
</tr>
<tr>
<td>Kuwait</td>
<td>1994</td>
<td>119</td>
</tr>
<tr>
<td>Kyrgyzstan</td>
<td>1995</td>
<td>380</td>
</tr>
<tr>
<td>Lebanon</td>
<td>1990</td>
<td>165</td>
</tr>
<tr>
<td>Libya</td>
<td>1999</td>
<td>546</td>
</tr>
<tr>
<td>Morocco</td>
<td>2002</td>
<td>650</td>
</tr>
<tr>
<td>Oman</td>
<td>2000</td>
<td>78</td>
</tr>
<tr>
<td>Saudi Arabia</td>
<td>2000</td>
<td>730</td>
</tr>
<tr>
<td>Syria</td>
<td>2002</td>
<td>825</td>
</tr>
<tr>
<td>Tunisia</td>
<td>2001</td>
<td>240</td>
</tr>
<tr>
<td>Turkey</td>
<td>1995</td>
<td>2400</td>
</tr>
<tr>
<td>United Arab Emirates</td>
<td>2000</td>
<td>881</td>
</tr>
<tr>
<td>Uzbekistan</td>
<td>2004</td>
<td>170</td>
</tr>
<tr>
<td>Yemen</td>
<td>2000</td>
<td>74</td>
</tr>
</tbody>
</table>


in many cases, they were unable to develop sewer systems fast enough to meet the needs of their growing urban populations. As a result, in several countries, particularly in Sub-Saharan Africa (SSA), the sanitation infrastructure in major cities has been outpaced by population increases, making the collection and management of urban wastewater ineffective. In many large cities (for example, Accra in Ghana), only a small part of the wastewater produced (<10%) is collected in piped sewerage systems for treatment (Drechsel et al., 2002). Owing to the gradual addition of contaminants into freshwater bodies, and the awareness of their possible impacts, wastewater treatment is now receiving greater attention from the governments of several water-scarce countries and organizations such as World Bank, the Food and Agriculture organization of the United Nations (FAO), and the United Nations Development Programme (UNDP), among others. There is now more scope in the water and environment sector to develop and implement wastewater treatment technologies that: (1) need low levels of capital investment for construction, operation and maintenance; (2) maximize the separation and recovery of by-products (such as nutrients) from polluted substances; (3) are compatible with the intended reuse option in that they yield a product of an appropriate quality in adequate quantities; (4) can be applied at both very small and very large scales; (5) are accepted by farming communities and the local population. Bearing in mind that treated wastewater could be used for agricultural, environmental, recreational and industrial purposes, it is important to realize that such wastewater must be adequately treated and used appropriately. This is important for several reasons:

- The discharge of untreated wastewater into surface water bodies affects the quality of both the water it enters and the water further downstream.
Treated wastewater could be used to provide a reliable source of irrigation water in urban and peri-urban areas, providing water for parks, play and sports grounds, and roadside greenery. Its other uses may be environmental (providing water for wetlands, wildlife refuges, riparian habitats, urban lakes and ponds), or industrial (used in cooling, boiling, and the processing of materials). It could also be used as a source of non-potable water to provide for many needs (fire fighting, air conditioning, dust control, and toilet flushing). It may also be used for aquaculture and groundwater recharge, a use, which has received considerable attention in recent years as it needs proper legislation and periodic monitoring of the aquifer quality.

The treatment of wastewater before discharging it into surface water bodies helps to safeguard existing (scarce) sources of good-quality drinking water and protects the environment.

Using treated wastewater for irrigation decreases the demand for freshwater in agriculture.

If it is treated and managed appropriately, treated wastewater can be used to provide several nutrients essential for plant growth. This directly benefits farmers because they have to make little or no investment in fertilizer (a significant farm input) or its application. The benefits of using treated wastewater must also be considered against the human health, economic, and environmental costs of not using it. For example, treating and using wastewater would reduce the discharge of untreated wastewater into the environment (so reducing water pollution and the contamination of drinking water supplies), and would improve the socioeconomic situation of farmers, and thus their health and that of their families.

Based on different parameters, various guidelines (Ayers and Westcot, 1985; WHO, 1989; Blumenthal et al., 2000; Carr et al., 2004; WHO, 2006) are available for wastewater use in agriculture (Tables 2 and 3). However, in many developing countries these guidelines are not followed and most farmers use untreated wastewater in an unplanned manner to irrigate a variety of crops. Most cities in these countries have networks of open and covered interconnected channels located within and around urban premises. In general, these channels carry a mixture of wastewater generated by domestic, municipal, and industrial activities. The farmers divert untreated wastewater from these channels to provide irrigation water as and when it is needed. Although farmers irrigate a range of crops with wastewater, they often prefer to grow high-value vegetables as a market-ready product, which will generate a higher income (Qadir et al., 2000).

In some cases, the authorities implementing government regulations periodically expel these farmers from their fields (Keraita and Drechsel, 2004) or uproot wastewater-irrigated vegetables.

In other cases, however, the administrators do not make any efforts to check the use of wastewater in this way. Rather they regard this farming practice as a viable option for wastewater disposal. The farmers consider such untreated wastewater to be a reliable source of irrigation, which involves less cost than other sources of irrigation water such as groundwater pumping (Van der Hoek et al., 2002).
<table>
<thead>
<tr>
<th>Category</th>
<th>Wastewater use condition</th>
<th>Exposed group of communities</th>
<th>Irrigation method</th>
<th>Intestinal nematode (arithmetic mean, no. per 1000 mL)(^b)</th>
<th>Faecal coliforms (geometric mean, no. per 100 mL)(^a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Unrestricted irrigation (all crops, including vegetable and salad crops eaten uncooked, sports fields, public parks)(^a)</td>
<td>Workers, consumers, public</td>
<td>Any</td>
<td>&lt;0.1(^f)</td>
<td>&lt;10(^a)</td>
</tr>
<tr>
<td>B</td>
<td>Restricted irrigation (cereal crops, industrial crops, fodder crops, pastures, and trees)(^a)</td>
<td>B1 workers, children &gt; 15 years, nearby communities</td>
<td>Spray or Sprinkler</td>
<td>≤1</td>
<td>≤10(^b)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B2 same as B1, children of all ages, nearby communities</td>
<td>Food or Farrow</td>
<td>≤1</td>
<td>≤10(^b)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>None</td>
<td>Trickle or drip</td>
<td>Not applicable</td>
<td>Not applicable</td>
</tr>
<tr>
<td>C</td>
<td>Localised irrigation (crops in category B, but without exposure of workers and communities)</td>
<td>None</td>
<td>Trickle or drip</td>
<td>Not applicable</td>
<td>Not applicable</td>
</tr>
</tbody>
</table>

Modified from Blumenthal et al. (2000) and Carr et al. (2004).\(^a\)

\(^a\) In specific situations, these guidelines may be modified according to local epidemiological, socio-cultural, and hydrogeological factors.

\(^b\) Assam and Tribhuvan species and hookworms. The guideline values are also intended to protect against risks from parasitic protozoa.

\(^c\) During the irrigation period; routine monitoring is not required if wastewater is treated in waste stabilization ponds (WSP) or wastewater storage and treatment reservoirs (WSTR).

\(^d\) During the irrigation period; the faecal coliform counts should preferably be done weekly, but at least monthly.

\(^e\) Local epidemiological factors may require a more stringent standard for public lawns, especially hotel lawns in tourist areas. A guideline of 400 faecal coliforms 100 mL\(^-1\) is appropriate for the lawns.

\(^f\) This guideline value can be increased to ≤1 if conditions are hot and dry and surface irrigation is not used, or if wastewater treatment is supplemented with anti-helmintic chemotherapy campaigns in areas of wastewater use.

\(^g\) In the case of fruit trees, irrigation should stop 2 weeks before fruit is picked, and no fruit should be picked up from the ground. In addition, sprinkler irrigation should not be used.

### Table 2.2. Guidelines for microbiological qualities of treated wastewater for irrigation

<table>
<thead>
<tr>
<th>Element</th>
<th>RMC (mg L(^-1))</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>5.00</td>
<td>Can cause non-productivity in acid soils (pH &lt; 5.5), but move alkaline soils at pH &gt; 7.0 will precipitate the ion and eliminate any toxicity</td>
</tr>
<tr>
<td>Arsenic</td>
<td>0.10</td>
<td>Toxic to plants varies widely, ranging from 12 mg L(^-1) for rice to less than 0.05 mg L(^-1) for grass.</td>
</tr>
<tr>
<td>Beryllium</td>
<td>0.10</td>
<td>Toxic to plants varies widely, ranging from 5 mg L(^-1) for kale to 35 mg L(^-1) for burr beans.</td>
</tr>
<tr>
<td>Cadmium</td>
<td>0.01</td>
<td>Toxic at concentrations as low as 0.1 mg L(^-1) in nutrient solution for beans.</td>
</tr>
<tr>
<td>Chromium</td>
<td>0.10</td>
<td>Not generally recognized as an essential plant growth element.</td>
</tr>
<tr>
<td>Cobalt</td>
<td>0.05</td>
<td>Toxic to tomato plants at 0.1 mg L(^-1) in nutrient solution.</td>
</tr>
<tr>
<td>Copper</td>
<td>0.20</td>
<td>Toxic to a number of plants at 0.1–1.6 mg L(^-1) in nutrient solution.</td>
</tr>
<tr>
<td>Iron</td>
<td>5.00</td>
<td>Non-toxic to plants in aerated soils. Can contribute to soil acidification and loss of availability of phosphorus and molybdenum.</td>
</tr>
<tr>
<td>Lithium</td>
<td>2.50</td>
<td>Tolerated by most crops up to 5 mg L(^-1), limits in soil. Toxic to citrus at low concentrations with recommended limit of &lt;0.075 mg L(^-1).</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.20</td>
<td>Toxic to a number of crops at a few-tenths to a few mg L(^-1) in acid soils.</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>0.01</td>
<td>Toxic to plants at normal concentrations in soil and water. Can be toxic to livestock if forage is grown in soils with high concentrations of molybdenum.</td>
</tr>
<tr>
<td>Nickel</td>
<td>0.20</td>
<td>Toxic to a number of plants at 0.5 to 1.0 mg L(^-1); reduced toxicity at neutral or alkaline pH.</td>
</tr>
<tr>
<td>Lead</td>
<td>5.00</td>
<td>Can inhibit plant cell growth at very high concentrations.</td>
</tr>
<tr>
<td>Selenium</td>
<td>0.02</td>
<td>Toxic to plants at low concentrations and toxic to livestock if forage is grown in soils with relatively high levels of selenium.</td>
</tr>
<tr>
<td>Zinc</td>
<td>2.00</td>
<td>Toxic to many plants at widely varying concentrations; reduced toxicity at pH ≥ 6.0 and in fire-affected or organic soils.</td>
</tr>
</tbody>
</table>

Modified from Ayers and Westcot (1985).\(^*\)

\(^*\) The maximum concentration is based on a water application rate, which is consistent with good irrigation practices (0.000 m\(^3\) ha\(^-1\) yr\(^-1\)). If the water application rate greatly exceeds this, the maximum concentrations should be adjusted downward accordingly. No adjustment should be made for application rates less than 10,000 m\(^3\) ha\(^-1\) yr\(^-1\). The values given are for water used on a long-term basis or one site.

### Table 2.3. Recommended maximum concentration (RMCs) of selected metals and metalloids for irrigation water
Other benefits to the farmers include the fact that farmers have to invest nothing, or very little, in fertilizer purchase and application, while benefiting from greater levels of crop production than are obtained via freshwater irrigation. In addition, they enjoy higher incomes as a result of cultivating and marketing high-value crops. These benefits help the farmers to ensure that their families receive better levels of nutrition and that their children benefit from better educational opportunities. For all these reasons, farmers take health risks and use untreated wastewater when the opportunity presents itself (Ensink et al., 2002; Matsuno et al., 2004).

Surveys and research studies carried out in different countries revealed that fields irrigated with untreated wastewater yielded more than those irrigated with freshwater (Shende, 1985; Minhas and Samra, 2004). In addition, economic analyses based on the cost of production of different crops have shown attractive economic returns from wastewater-irrigated fields in Syria (Qadir et al., unpublished data). The analyses revealed that each US$ invested in the production process gave a return of US$ 5.31 in the case of wheat (Triticum aestivum L.) irrigated with wastewater and US$ 2.34 in the case of wheat irrigated by groundwater. In addition to the higher wheat yields provided by wastewater-irrigated plots, there were savings with regard to fertilizer use. In comparison with those growing groundwater-irrigated wheat, the farmers using wastewater to irrigate wheat saved US$ 95 ha⁻¹. Similar economic return trends were obtained for faba bean (Vicia faba L.). However, in the case of cotton (Gossypium hirsutum L.), there was little difference between the returns from wastewater irrigation (US$ 5.17) and groundwater irrigation (US$ 5.23) for each US$ invested. This is because wastewater resources in the area during the long summer growing season of cotton are not sufficient to provide the crop with its needs. Therefore, the wastewater-irrigating farmers also use fertilizers and pump groundwater as and when needed. The cultivation of vegetables – which are grown on only 7% of the wastewater-irrigated area because of government restrictions – produced the highest economic returns from wastewater irrigation: US$ 7.48 for each US$ invested. This was much greater than in the case of vegetables irrigated with groundwater, where the return was US$ 3.29 per US$ investment (Qadir et al., unpublished data). Although these crop yield and economic analyses indicate that communities who use untreated or partly treated wastewater clearly benefit financially, there is a need to carry out comprehensive analyses of the potential environmental and health implications and their costs. These must be weighed against both the short- and long-term benefits of wastewater use.

Owing to the low literacy rate found amongst farmers in developing countries, limited and inappropriate information gathering and reporting, insufficient public pressure, most farmers using polluted water in low-income countries remain uninformed about the health and environmental consequences (Hussain et al., 2002). Moreover, farmers and authorities have insufficient knowledge about the technical and management options available for reducing the environmental and health risks associated with wastewater use. Depending upon the levels of contaminants present, the continued and uncontrolled use of untreated wastewater as an irrigation source could have a variety of implications. These include the following:

- Groundwater contamination through the movement of high concentrations of a wide range of chemical pollutants (Ensink et al., 2002). This is particularly true in the case of wastewater that contains untreated industrial effluent. The pollutants reaching groundwater in this way have the potential to impact upon human health when groundwater is pumped for direct human consumption. Pathogens have also been found to accumulate in the groundwater found immediately beneath wastewater-irrigated fields (Ensink et al., 2002).
The gradual buildup, in the soil solution and on the cation exchange sites of soil particles, of ions such as Na\(^+\) and a range of metals and metalloids which are deleterious to the soil. In this way, potentially harmful metals and metalloids may reach phytotoxic levels (Qadir et al., 2005). The accumulation of excess Na\(^+\) in the soil can have numerous adverse effects, including changes in exchangeable and soil solution ions and soil pH, the destabilization of the soil structure, the deterioration of the soil’s hydraulic properties, and an increased likelihood of crusting, runoff, erosion and aeration. It can also have osmotic effects and specific ion effects in plants (Sumner, 1993; Qadir and Schubert, 2002).

The accumulation of potentially toxic substances in crops and vegetables which will, ultimately, enter the food chain, so damaging human and animal health. For example, leafy vegetables irrigated with untreated wastewater containing metals and metalloids can accumulate higher levels of certain metals, such as cadmium (Cd), than non-leafy species (Qadir et al., 2000). Excessive exposure to this metal has been associated with various illnesses in people, including gastroenteritis, renal tubular dysfunction, hypertension, cardiovascular disease, pulmonary emphysema, cancer, and osteoporosis (Wagner, 1993). Numerous illnesses are also associated with the ingestion of excessive levels of other metals and metalloids. Similarly, pathogens may enter the food chain via the same pathway. However, in most cases, industrial pollutants in the form of a variety of metals and metalloids can cause greater and longer lasting health effects in people than pathogenic organisms.

The health risks associated with the presence of parasitic worms, and viruses and bacteria. These have the potential to cause disease in farming families exposed to untreated wastewater for extended periods. Such diseases also raise the issue of the financial consequences associated with treatment. Farmers using untreated wastewater for irrigation demonstrate a higher prevalence of hookworm and roundworm infections than farmers using freshwater for irrigation. Hookworm infections occur when larvae, added to the soil through wastewater use, penetrate the skin of farmers working barefoot (Van der Hoek et al., 2002).

Bearing in mind the challenges associated with the use of wastewater for irrigation, studies carried out by the researchers at the International Water Management Institute (IWMI), Sri Lanka have proposed a number of options to maximize the benefits and minimize the risks involved in the use of untreated wastewater for agriculture (Scott et al., 2000; Ensink et al., 2002; Van der Hoek et al., 2002; IWMI, 2003; Matsuno et al., 2004; Scott et al., 2004). These options include: (1) the use of suitable irrigation techniques and the selection of appropriate crops that are less likely to transmit contaminants and pathogens to consumers; (2) the use of protective measures such as boots and gloves to control farm workers’ exposure to pathogens; (3) the implementation of a medical care program through the use of preventive therapy such as anti-helminthic drugs; (4) the post-harvest management of vegetables, through washing and improved storage; (5) the conjunctive use of wastewater and freshwater to dilute the risks and increase the benefits by supplying nutrients to a larger area; (6) upstream wastewater management and appropriate low-cost treatment; (7) education and increased awareness among farmers, consumers, and government organizations; (8) the implementation of monitoring programs for key environmental, health, and food safety parameters.

The Hyderabad Declaration on Wastewater Use in Agriculture made on 14 November 2002 (available at http://www.iwmi.cgiar.org/health/wastew/hyderabad_declaration.htm) – which resulted from a workshop organized by IWMI and the International Development Research
Center, Canada – stressed the need to “safeguard and strengthen livelihoods and food security, mitigate health and environmental risks and conserve water resources by confronting the realities of wastewater use in agriculture through the adoption of appropriate policies and the commitment of financial resources for policy implementation”. The management options used should include raising public awareness, using safer irrigation methods, minimizing human exposure, restricting the types of crops irrigated with wastewater, disinfecting produce, ensuring institutional coordination, increasing land tenure, and increasing funding (Scott et al., 2004). In view of the fact that it is not possible to simply ban wastewater use in many developing countries, the World Health Organization (WHO) is considering the realities faced by these countries while revising guidelines for wastewater use in agriculture (WHO, 2006).

2.1.2. Role of plant nutrients in the wastewater

While water is the main element in the public discussion, there is no doubt that plant fertilizers also constitute as a major limitation factor in global nutrition. Production of fertilizers, especially nitrogen is very much dependent on energy prices. Potassium and Phosphorus are fossil resources and as a raw material currently more limited then oil and also dependent to oil as related mining requires lot of energy.

![Graph showing fertilizer sales gross margins](data:image/png;base64,iVBORw0KGgoAAAANSUhEUgAAABAAAAAQCAYAAAAf8/9hAAAABGdBTUEAALGPC/xhBQAAAABJRU5ErkJggg==)

**Fig. 2.1.**: Growth rates of fertilizer sales gross margins at Saskatchewan Inc. due to growing global demand at decreasing supply (2007=100). (Data source www.reportonbusiness.com, April 24, 2008)

With standard wastewater systems, also a large part of embedded energy and carbon is released within the canalisation systems, producing a lowered oxygen demand for the following treatment and producing (unusable) process-heat.
A real urban water and matter circuit is needed to allow a sufficient reuse of plant nutrients, carbon and embedded energy. The realisation of such a system is directly dependent on new filter and irrigation methods, that will totally overcome the current wastewater treatment systems, that does not treat the urban output as a resource but as garbage. Nutrients disappearing to the air or mixed with toxic constituents being dumped on waste deposits today are not considered as a loss of a resource but as a solution for a waste management problem.

A new concept has to provide a solution for wastewater treatment systems, that allows to reallocate water sufficiently clean to be used for irrigation in agriculture and at the same time to keep the nutrient content of the wastewater as high a possible.

A development shall be done in two steps:

1. Post treatment of water from existing treatment plants to allow the use of the cleared water for irrigation of crops or at least non-food crops.
2. Installation of modified wastewater systems with separation of different wastewater streams at the user side. This includes separated collection of greywater, urine and faecal in the households but also separated wastewater cycles to certain commercial users (e.g. fish industry, hospitals, hotels)

2.1.3. Greenhouse horticulture as a filter element in the urban water cycle

Global phenomena like growing drought and over-exploitation of groundwater stocks provokes a fundamental change of water management including a more efficient use of given freshwater resources and as a more and more important topic, the use of unconventional water sources.

For agricultural purposes in arid countries, greenhouse horticulture allows a much more efficient use of the water per biomass produced. This is especially understandable, if not only looking for production rates in kg/m2 of cultivated land but in kg/m3 of water irrigated. The background for this is, that greenhouses increase the production by providing higher mean temperatures. Further more, higher air humidity in the greenhouses allows a decrease of evapotranspiration of the plants. In the Watery greenhouse, only 2 litres of water is needed for irrigation per day and m². While producing condensed water, this amount can be lowered to about 0,5 litres if mixing the external sources with the condensed water. (Zaragoza 2007)

While not only looking at the increased water efficiency of greenhouse cultivation, also numerous potential applications regarding the reuse and the further treatment of unconventional water sources become possible in the greenhouse context like:

- Lower uptake of nitrogen, at lower total water uptake per produced biomass which is especially important as today, nitrogen over-fertilisation is one of the main reasons against using the existing wastewater.
- Lower uptake of salt (NaCl) at lower water uptake per produced biomass.
- Lower uptake of bioaccumulative pollutants at lower water uptake per produced biomass.
All these possibilities together are giving strong reasons to form an expert group to collect and disseminate the present state of art regarding these applications and to devise measures for better implementation of existing methods and to specify the areas of further needed research. A further main focus of such a project should be to promote the message, that wastewater reuse in agriculture can be considered as both: an unconventional water source AND a sound, cheap and simple water treatment method, that can be easily applied by local farmers if clear safety guidelines will be followed.

2.2. Post treatment of water from existing treatment plants for use in irrigation

Using wastewater in irrigation includes the risk of contamination of the greenhouse inner volume and the contamination of the crops with remaining pathogens or heavy metals. A pre-treatment has to avoid these problems.

Pre-treatment strategies are based on the supply of oxygen to bacteria films to grow under aerobic conditions, producing bacterial biomass that have to be separated, dried and used within the solid waste stream.

If the wastewater is used in hydroponic irrigation systems, it has to be pre-treated to avoid problems related to anaerobe processes. Anaerobic conditions will lead to rotten stench and further health problems. Further more, it causes denitrification and loss in nutrients (that is normally volitional in waste water treatment, but of course not in crop irrigation).

The general mix of urban wastewater forces to give priority to secure healthy conditions in the production process as well as to crop security. The post-treatment gives the chance to concentrate polluting substances in the discharge of the bacteria sludge.

The sludge drainage concentrates non usable and dangerous substances. On the other hand, the treatment section has to keep the usable fractions of nutrients in the irrigation water. The pre-treatment should provide a constant quality of usable water. It could be organized in several methods, of which two of them are pointed out in this scenario as cheap and proofed, reliable methods, suitable for the situations found in Gabes and Agadir: Aerated ponds, Periodically flooded gravel filters (unplanted or planted with vegetation). A more expensive but more intense way of post treatment is the technology of membrane micro-filtration. It should only be used, if field tests show that the gravel filter is not able to guarantee certain basic levels of pathogenic content, heavy metals or toxic organic compounds.

Post filtration of treated wastewater

Treated wastewater, and primarily domestic treated sewage can be reused for a large pattern of possibilities, primarily for agricultural irrigation (Salgot et al., 2006). The major drawbacks of Treated Municipal Wastewater (TMWW) use are the high capital investment in the treatment and reclamation facilities, Current efforts of wastewater reclamation focus on pathogen removal. However, for sustainable agriculture production and in order to maintain high quality ground water additional treatment phases have to be undertaken in order to remove the dissolved solids and mineral pollutants.

Fehler! Es ist nicht möglich, durch die Bearbeitung von Feldfunktionen Objekte zu erstellen.
Fig. 2.2. Anaerobic lagoon as a primary treatment of wastewater

2.2.1. Sand filtration percolation Plant

Wastewater treatment and reuse plants in the great Agadir seeks to reduce the impact of pollution and to realize water savings through the reuse of treated effluents. Prior to the completion of these Wastewater treatment plants, discharges of untreated wastewater in the Region of Agadir polluted ground water and coastal beaches, emitted unpleasant odors, and were a threat to public health.

The plant layout considers the uses of anaerobic lagoons as a primary treatment (fig 1) followed by a sand filtration system as a secondary treatment (fig 2). The Drarga plant also includes a tertiary treatment using reed beds to eliminate nitrates that could threaten ground water. This pilot project includes a storage basin for the treated wastewater and a system to distribute the treated effluents to farmers. Treated effluents will be distributed and sold to farmers to irrigate food crops (alfalfa, corn, vegetable crops and cereals). With a population of over 850,000, the rapidly growing Greater Agadir faces an increasing need for wastewater treatment and an increasing demand for water supplies. The two main discharges of raw sewage — one into the port area, the other into the bed of the Souss River within a few kilometers of its mouth — are incompatible with a valuable tourist attraction.

In a cooperative project between Morocco and France and USAID, wastewater treatments through dune sand infiltration–percolation are already operating in Lamzar and the rural commune of Drarga respectively.

The initial chemical oxygen demand (COD) of raw sewage is 1190 mg/l, and the first treatment is by anaerobic stabilization pond. These plants treat wastewater by infiltration–percolation treats 750, 50 000, and 1000 m3/day respectively of highly concentrated effluents in several infiltration basins each, consisting of 2 m thick Aeolian sand. The anaerobic stabilization pond (for a theoretical residence time of 2 days; depth of 3–4 m) is used to reduce suspended solids (40–50 %) and organic matter (50–60 %), increasing the rate of infiltration and reducing the surface area necessary for the infiltration basin. The basin is submerged for 8 hours and remains dry for 16 hours.
Fig. 2.3. and 2.4. Sand filter system as a secondary treatment of wastewater. The wastewater is infiltrated at the rate of 1 m/day. Nearly 100% of suspended solids and 95% of COD are removed; 85% of nitrogen is in oxidized form and 56% is removed. Microbiological quality of raw sewage, pond effluent and percolated water are shown in Table 1. The percolated water will be used in irrigating the public gardens and future golf courses.

Factors such as the increased demand for water, coupled with increased water stress, water scarcity and the compliance measures towards environmental legislation, are likely to increase the drive towards the use of treated wastewater. The future of treated wastewater reuse can be viewed as a climate change adaptation solution as well. In some cases it can also be viewed as a climate change mitigation solution where water is reused locally with a lower energy cost than importing freshwater, exporting treated wastewater, reducing the investment in developing new water sources, sewerage and storm water infrastructure. The benefits of treated wastewater reuse are very evident even though some risks have to be taken into account. Treated wastewater reuse is vital in the widely promoted concept of “integrated urban water management

Table 2.4. Microbiological quality of raw sewage, pond effluent, and percolated water (Bennani et al. (1992))

<table>
<thead>
<tr>
<th></th>
<th>Raw sewage</th>
<th>Pond effluent</th>
<th>Percolated water</th>
<th>Overall removal efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fecal coliforms (No./100 ml)</td>
<td>$6 \times 10^6$</td>
<td>$5 \times 10^5$</td>
<td>327</td>
<td>4.26 logs</td>
</tr>
<tr>
<td>Fecal streptococci (No./100 ml)</td>
<td>$2 \times 10^7$</td>
<td>$1.6 \times 10^6$</td>
<td>346</td>
<td>4.78 logs</td>
</tr>
<tr>
<td>Nematode ova (No./l)</td>
<td>139</td>
<td>32</td>
<td>0</td>
<td>~100%</td>
</tr>
<tr>
<td>Cestode ova (No./l)</td>
<td>75</td>
<td>18</td>
<td>0</td>
<td>~100%</td>
</tr>
<tr>
<td>Total helminths ova (No./l)</td>
<td>214</td>
<td>47</td>
<td>0</td>
<td>~100%</td>
</tr>
</tbody>
</table>
2.2.2. Aerated pond

This method is already used in the project areas since it is easy to install and to maintain. On the other hand the loss of water by evaporation is high as well as the operating costs for the aeration of the water. The produced biomass will mainly not be harvested. It sinks on the ground of the pond. The duration of water in the pond varies, but needs to be much higher than in the described second method. A further disadvantage is the denitrification of nitrogen due to partially existing anaerobic zones in the pond.

The method should be considered as an easy to build and maintain technology with the disadvantage of higher energy costs and lower nutrient efficiency.

2.2.3. Gravel bed filter

A constructed gravel bed is related to the treatment process of constructed wetlands. The following descriptions are reported with respect to the experience from systems working in Berlin. Main differences between common constructed wetlands and the here described gravel beds are flow and retention rates as well as the material used as the substrate. Gravel beds have a lower inner particle surface than sandy substrates with the disadvantage of lower surface of bacterial films but the high advantage of larger air spaces between the particles that help to aerate the particle surface and helps to remove the growing bacterial film to prevent clogging of the system. This helps to reduce the effort of maintenance during the regeneration and cleaning of the filter.

Second difference is the absence of iron material, that in constructed wetlands are mainly responsible for the removal of phosphorous. The loss of phosphorous in the pre-treatment process would be negative as phosphorous is one main limiting factor for the crop production. Iron material has to be avoided in gravel beds used as pre-treatment for irrigation in crop production.
Functioning of the filter: The wastewater is periodically pumped into the planted gravel bed. The gravel surface keeps constantly wet and works as an interface between air and waste water. The cleaning process is related to bacterial growth on the gravel. To avoid soil clogging from extra-cellular polymeric substances (EPS), known as a main problem in constructed wetlands with vertical flow (Marciel 2004), bacteria has to be discharged constantly out of the gravel. Compared to constructed wetlands, where the infiltrative capacity regenerates through the interruption of the wetland operation for several weeks, parts of the biofilm has to be discharged periodically out of the gravel.

The resulting sludge could either be disposed, dried and treated as solid waste, or used again as a fertilizer or soil substrate in horticultural systems. As not only nutrients but also heavy metals and other polluting substances are concentrated in the sludge, the quality of the sludge has to be supervised and might be used only for non- food production (biomass). The process of pre-treatment in a gravel bed has to be optimised for two variables, the inner surface of the gravel filter and the retention time of waste water in the filter. The resulting cleaning capacity is a product out of both variables.

The gravel particles have to be sufficiently large to enable the discharge of the sludge to prevent soil clogging. Instead of a sandy soil known for constructed wetlands (0-2 mm), the gravel filters in Berlin used two types of gravel out of 1-3 mm and 4-8 mm. The total particle surface of a gravel filter is much smaller than a sandy or loamy soil, as well as the retention capacity for water, which both reduces the cleaning capacity. Anyway, experiments for different types of filter material showed that in sand substrates, a non reversible soil clogging takes place which smashes the whole system and leads to cost intensive permanent maintenance work.

A second important difference between gravel filters and conventional constructed wetlands is the reduction of nitrogen by anaerobic degradation of the biofilm. In constructed wetlands, nitrogen is forced to be discharged to air as N₂ and by this gets lost for fertilization of the greenhouse systems.
Compared to constructed wetlands with a conventional wastewater load of about 30 l/(m²*d) the treatment capacity in the above mentioned filter systems is 6 up to 100 times higher. Due to lower quality standards for the treated water (this water is used for irrigation and to flush toilets) the resultant treatment capacity does not really figure out a significant nutrient removal but reduction in oxygen demand. This works similar to the main goal of the Cycler project.

The above mentioned filter systems are used to treat first flush rainwater runoff of public streets. A third filter system was established at the Potsdamer Platz in the centre of Berlin. This filter was adapted to already existing filters in Lankwitz and UFA-Fabrik. It has a total filter surface of 1100 m² and is used to treat rainwater runoff from 19 buildings in the centre of Berlin. All filter systems are mainly planted with Phragmites and other plants used to grow on wetlands.

<table>
<thead>
<tr>
<th>Field Capacity</th>
<th>Filter surface</th>
<th>Water retention</th>
<th>Wastewater load</th>
<th>Wastewater load</th>
<th>Retention time</th>
<th>Retention time</th>
</tr>
</thead>
<tbody>
<tr>
<td>[Vol %]</td>
<td>[m²]</td>
<td>[Liter]</td>
<td>[m³/d]</td>
<td>[l/(m²*d)]</td>
<td>[min]</td>
<td>[h]</td>
</tr>
<tr>
<td>Expanded clay 8/16</td>
<td>14,3</td>
<td>2,5</td>
<td>214,9</td>
<td>9,9</td>
<td>3960</td>
<td>31,3</td>
</tr>
<tr>
<td>Gravel 4/8</td>
<td>5,2</td>
<td>2,5</td>
<td>78,4</td>
<td>9,9</td>
<td>3960</td>
<td>11,4</td>
</tr>
<tr>
<td>Expanded slate 1/3</td>
<td>24,7</td>
<td>25,0</td>
<td>4823,3</td>
<td>4,8</td>
<td>192</td>
<td>1447,0</td>
</tr>
</tbody>
</table>

Tab 2.5. Two natural treatment filter systems used in Berlin in comparison for the used filter material and resultant treatment retention time
Infiltrative capacity regeneration: The interruption of the filter operation of constructed wetlands is a main part of the process. It has the goal to decrease the EPS concentration significantly while hydraulic permeability increases. Such interruption lasts for several weeks. Filter systems have to be divided into several sections to allow a continuous operation of the treatment process, while having interrupting phases in parallel. During the interruption, the biofilm is not feeded with new fertilizing elements and by this consumes the accumulated EPS. N₂, CH₄, CO₂ and H₂O are released out of the system. Anaerobic conditions take place.

The gravel filter systems in opposite might be flushed continuously (once a day or once a week). Sludge is disposed out of the gravel intersections by completely filling the bed and then suddenly let it out from a big drainage outlet. The permanent water outlet can be forwarded to the main greenhouse plantations.

Construction, treatment capacity and water loss: The gravel beds in Berlin are constructed in both variables: inside and outside of buildings. In case of the Cycler Project, the implementation in an open greenhouse is recommended to avoid a significant water loss by evaporation. The cleaning process is recommended for a daily minimum value of 30 mm, these are 30 litres per square meter and day.

The evaporative loss in an open greenhouse are estimated at a value of 10 mm. A closed greenhouse would minimize the water loss to 2mm, but in this case, a circulation of oxygen from the crop production area to the treatment facility is recommended. The implementation of this method has to be scientifically proofed in an additional model project. For all further calculations, the treatment facility is calculated for the case of being implemented in an open greenhouse system.

Biomass production in the treatment section is exclusively reserved for non eatable purposes. The production might be heavily contaminated with the above mentioned pollutants like heavy metals etc. The biomass of the sludge would be affected even higher. For a further use, the quality has to be supervised.

A treatment capacity of 30 mm per day could supply an area of crop production almost 10 times larger if closed greenhouse systems are used. The resulting relation between crop...
Tab 2.6. Comparison of pre-treatment and crop production area for a wastewater amount of 1000 m³ per day production and pre-treatment area would be 10:1, a quite comfortable rate. The rate for open field agriculture would melt to a ratio of ~2:1 – pre-treatment area versus production area. The production area would need a certain over-irrigation, otherwise the high evaporation loss would concentrate a huge load of pollutants like heavy metals and an overnutrification, leading to salt accumulation in the soil.

### 2.2.4. Membrane ultra-filtration

Membrane ultra-filtration becomes a more and more accepted, cheap and reliable technology for the treatment of wastewater, for drinking water supply systems in case of emergency needs, for water reuse and eco-sanitation concepts. In a market-survey in the EU-Techneau-Project (www.techneau.eu) 204 water companies were contacted to characterise costs for investment, operation and maintenance. The notable reduction in energy requirements per cubicmeter of treated water of these meanwhile improved systems forces to include the technology into innovative new concepts for agricultural production facilities. Membrane technology has to be divided into different types of materials, organic and ceramic, and different filtration types (see fig.). The ultra filtration is the most common system in the market (Techneau 2008).

Reverse osmosis (RO) is about to be established but principally in the context of desalinisation of sea- or brackish water. The energy consumption is 5 kWh for a desalinisation via RO, which is much less than in the past.

For membrane ultrafiltration an even much lower energy consumption is required. The energy amount needed for membrane technology is related to the pressure difference between the wastewater and the effluent. For Reverse osmosis a difference in pressure of 10-100 bar is needed (100-1000 meters), ultra filtration is satisfying working at 0,1-5 bar (1-50 meter water column). Standard ultra filtration membranes work with a water column of 2-3 meters.

For the pre-treatment of wastewater for agricultural production the ultra-filtration process is recommended. It filters bacteria and viruses, but keeps the important dissolved nutrients inside the usable effluent. This means a nearly optimised treatment process for the goal of water reclamation for crop production.
Solids might be removed in an adapted pre-filtration process to prevent clogging of the membranes. The above mentioned pre-treatment- with gravel filters might be combined with the ultra-filtration membrane to meet the requirements for a sufficient performance of the membranes and finally to achieve an optimised irrigation water quality.

Membrane ultra-filtration is a quite new technology compared to conventional wastewater treatment processes. The disadvantage of membrane technology is the relatively “high tech” technology due to operation and maintenance requirements and dependence on producers that in most cases are not locally represented. Monitoring requirements are to be mentioned as well as education/ formation. Monitoring needs are mainly justified due to problems of clogging and further membrane dysfunction. Secure maintenance friendly filtration and operation diagnostic tools have to be implemented. Detailed information on membrane technology is available on the website http://www.mbr-network.eu/

2.2.5. Problem of micro-pollutants (all filters)

Membrane ultra-filtration has the highest option to keep nutrients inside the usable fraction of the filtration. Unfortunately this process does not remove all dissolved components, e.g. the salt and endocrine substances etc. Due to this fact there are some further requirements, e.g. in the pre-treatment process. The pre-treatment for the membrane systems itself is another unsolved problem.

All micro-pollutants have to be monitored for the treatment success. Some of them like heavy metals which are combined on the suspended solids are removed in the ultra-filtration process. In gravel filters they are concentrated in the bacteria and can be removed with the sludge. A combination of the different treatment options would create the best result in case of water quality security for crop production. On the other hand the nutrients have to be kept into the percolation, this represents a clash of targets.
Wastewater recycling for crop production has to be considered as risky when using municipal wastewater including industrial production facilities without restriction in the use of certain chemicals which might effect the pre-treatment process and/or the quality of the crops. The evapotranspiration-condensation process in the “Waterny”-closed greenhouse system gives a high security in the production process. A further alternative is the preselection of water qualities. The mix of the different water and nutrient resources into municipal wastewater is a badly arranged situation and should be avoided. The following chapter describes the potential for a pre-selection of water resources to improve the conditions for crop-production by solving the problems of micro-pollutants and reclaiming the dissolved nutrients at the same time.

2.3. Sustainable Use of Saline Water for Irrigation in Arid and Semi Arid Regions

This chapter examines potential management practices capable of minimizing damages to crops under saline conditions, with special references to the control of the root salinity below permissible levels through irrigation (method, amount, interval and water quality) and the use of irrigation water of different quality (blending or alternate application of good and saline water for different crops, at different growth stages, to reduce the effective salinity). The experience gained during more than ten years of research carried out at the Mediterranean Agronomic Institute of Bari on saline water practices and its management aspects will be also discussed in this paper.

The goal of sustainable development should be to make sure that the unlimited natural resources are available for future generation. Sustainable development of water resources requires that we respect the hydrologic cycle by using renewable water resources that are not diminished over the long term by their use. In many countries of the Middle East and the Mediterranean regions, specially those in the arid climate zone with high rates of population growth, urbanization and industrialization, water is becoming a scarce resource. The increasing competition for water shall greatly affect the water supply for irrigated agriculture in these countries. Generally, available quantities will be reduced and costs will be increased. There is now growing realization that an increasing number countries in those regions are approaching full utilization of their surface water resources and that the quantity of good water quality supplies available to agriculture is diminishing. What is left is water of marginal quality and agriculture have to cope with this situation.

In this regard, the question which yet remains to be answered is: can agriculture make use of marginal water in a way that is technically sound, economically viable and environmentally non-degrading? In other words, is it a viable proposition to use marginal quality water for agriculture production?

2.3.1. Assessing the suitability of saline water for irrigation

The evaluation of a source of saline water is complex and has to be done individually for each region, depending on local conditions. Nevertheless, for simplification some general schemes of water classification have been proposed and used (U.S. Salinity Laboratory Staff, 1954; Thorne and Thorne, 1954; Doneen, 1967; Ayers and Westcott, 1976).
The disadvantage of such simplified schemes is in their neglect of the other factors influencing water suitability. Consequently a source of water may be rejected where it is usable or accepted where it should not be used because of unfavourable local conditions. This illustrates the limitation of generalized water-classification schemes and the need for a more quantitative means of assessing water suitability; one that takes into account the specific conditions of use. To ensure that the quality of water available is put for the best use, in assessing the suitability of saline water for irrigation it is important to take into considerations the followings (BOX 1):

In this regard, much work has to be done with much emphasis on how to manage such water and how to manage soils and crops irrigated with such water rather than on how to judge the water quality.

BOX 1
Assessing the Suitability of Saline Water for Irrigation

- cropping system: crop tolerance to salinity must be known on a quantitative basis for all specific ecological conditions of concern;
- prevention of salt accumulation in the soil; the dynamic of salts in the soil must be quantitatively known for all specific soils, climatic and hydropological conditions of concern. Furthermore, the interrelationship of leaching to crop response must also be understood;
- use of advanced irrigation and drainage technology: irrigation methods must be adjusted to the use of brackish water and must be very efficient, technically as well as economically; a drainage system must be provided when necessary;
- research programmes should be modified from the individual to the integrated ones where crop rotation, water management and soil amendments are all combined;
- more emphasis should be given to development of appropriate models, criteria and standards under non-steady state conditions.

2.3.2. – The potential of using saline water in irrigation

Although the number of documented reports on successfully using brackish water for irrigation are relatively limited, enough exist to support the premise that water, more saline than conventional water classification schemes allow, can be used for irrigation (BOX 2).

Recent research development on plant breeding and selection, soil crop and water management, irrigation and drainage technologies enhance and facilitate the use of saline water for irrigated crop production with minimum adverse impacts on the soil productivity and the environment. Extensive reviews of the world literature conducted on this topic, include those by Bressler (1979), Gupta (1979) and Gupta and Pahwa (1981).
The assessment of saline water suitability for irrigation, combined with these latter cited worldwide references, give the evidences for the relatively high potentiality for using saline water for irrigation.

2.3.3. Management practices under saline irrigation water

The management practices must prevent excessive salt and sodicity building up and accumulation in the soil surface and in the root zone and control the salt balance in the soil-water systems. The crop type, the water quality and the soil properties determine to a large degree the management practices required to optimize production.

BOX 2

The Potential of Using Saline Water in Irrigation

- In the USA, extensive areas (about 81,000 ha) of alfalfa, grain sorghum, sugarbeet and wheat are irrigated (by gravity flood and furrow methods) in the Arkansas Valley of Colorado, with water salinity not less than 1,500 mgL\(^{-1}\) and up to 5,000 mgL\(^{-1}\). In the Pecos Valley of Texas, groundwater averaging about 2,500 mgL\(^{-1}\) of total dissolved salts, but ranging far higher, has been successfully used to irrigate cotton, small grains, grain sorghum and alfalfa, for three decades.

- Cotton is successfully grown commercially in the Nahal Oz area of Israel with saline groundwater (EC of 5 dS/m\(^{-1}\) and SAR of 26). The soil is treated annually with gypsum and National Carrier water (non-saline) is used (usually during the winter) to bring the soil to field capacity to a depth of 150 to 180 cm prior to planting.

- In Egypt, 3 to 5 thousand million m\(^3\) of saline drainage water are used for irrigating about 405,000 ha of land. About 75 percent of the drainage water discharged into the sea has a salinity of less than 3,000 mgL\(^{-1}\). The policy of the Government of Egypt is to use drainage water directly for irrigation if its salinity is less than 700 mgL\(^{-1}\); to mix it 1:1 with Nile water (180 to 250 mgL\(^{-1}\)) if the concentration is 700 to 1500 mgL\(^{-1}\); or 1:2 or 1:3 with Nile water if its concentration is 1,500 to 3,000 mgL\(^{-1}\); and to avoid reuse if the salinity of the drainage water exceeds 3,000 mgL\(^{-1}\).

- The saline Medjerda river water of Tunisia (annual average EC of 3.0 dS/m\(^{-1}\)) has been used to irrigate date palm, sorghum, barley, alfalfa, rye grass and artichoke. The soils are calcareous (up to 35% CaCO\(_3\)) heavy clays which crack when dry.

- Salt tolerant cereal crops, vegetables, alfalfa and date palms are being successfully irrigated with water of 2000 mgL\(^{-1}\) TDS in Bahrain, 2400 to 6000 mgL\(^{-1}\) in Kuwait and 15000 mgL\(^{-1}\) in the Tagoru area of the Libyan coastal plain. Forest plantations have been established in the United Arab Emirates using groundwater with up to 10000 mgL\(^{-1}\) TDS.

- Extensive use of saline groundwater from shallow aquifers (106,000 hectare-meters per year) is being undertaken in nine districts of Haryana State in India. In four of the districts, the brackish water is used directly for irrigation, while in the remaining five it is used after blending with fresh canal water, or by alternating between the two supplies (FAO 1990)
There is usually no single way to control salinity in irrigated land. Several practices (BOX 3) can be combined into systems that function satisfactorily depending upon the economic, climatic, social and hydrogeological situation. Thus, management measures should not be considered in isolation but should be developed in an integrated manner to optimize water use, minimize drainage and increase crop yields within limits of the physical and social environment.

The general management strategies seems practical: (a) control salinity within permissible levels, (b) change conditions to improve crop response, (c) change management to maintain yield at the field level when salinity causes damage at the plant level. All three can be used together, but the first one is the most commonly used. Emphasis will be given to irrigation practices for soil salinity control and management of saline water.

BOX 3

Management Practices Using Saline Water for Irrigation

- Hydraulic Management:
  Leaching (Requirement, Frequency)
  Irrigation (System, Frequency)
  Drainage (System, Depth, Spacing)
  Multiple water resources (Alternating, Blending)

- Physical Management
  Land levelling
  Tillage, Land preparation, Deep ploughing
  Seedbed shaping (Planting resources)
  Sanding
  Salt scarping

- Chemical Management
  Amendments
  Soil conditioning
  Fertility, Mineral Fertilization

- Biological Management
  Organic and Green Manures
  Crops (Rotation, Pattern)
  Mulching

- Human Management
  Farmer
  Socio-Economic Aspects
  Environmental Aspects
  Policy
2.3.4. Irrigation practices

Irrigation practices which are important in the management of saline water are: Irrigation scheduling (amounts and interval); Leaching scheduling (amount and timing); irrigation method, and management of multi-source irrigation water of different qualities (Shalhevet, 1984).

Irrigation Scheduling

The irrigation scheduling should allow both good crop yields and adequate leaching of the soil when saline irrigation is practiced. Irrigation scheduling is complicated under saline water application mainly due to: i) information of consumptive use of many crops under saline water irrigation is not available and ii) under saline water practices the leaching requirements (LR) of the crops related to the salinity level of water must be calculated and included in the crop water requirements.

Successful saline irrigation requires a new production functions that relates crop yield to water consumption with acceptable irrigation intervals for the various crops. Several models to simulate crop-water production functions have been recently developed (Feinerman et al., 1984; Letey et al., 1985; Bressler, 1987). The results of Bressler's model (1987) suggest full compensation between irrigation water amount and salinity for a relatively wide range irrigation water salinities. However, the results of the model of Letey et al., (1985) suggest that increasing the amount of irrigation water compensates only partially for the irrigation water salinities.

The dynamic models of Bressler (1987), Van Genuchten (1987), Hanks et al. (1977) can be used to stimulate seasonal crop water production functions for various irrigation schedules, if appropriate input data for the given model is available. Solomon (1985) and Letey et al. (1985) presented seasonal water-salinity-production functions based on our current understanding of the response of crops to water, the salt tolerance of crops and the leaching process.

Both the dynamic models and the seasonal ones assume a unique relationship between yield and ET for a given crop and climate that is independent, regardless of whether the water stress leading to the reduced ET is caused by deficit water supply, excess salinity or both. Beginning with this premise, Solomon (1985) stated the following: - for any given amount and salinity of irrigation water, there will be some point at which values for field ET, leaching and soil salinity all are consistent with one another. The yield at this point is the yield to be associated with a given irrigation water quantity and salinity.

In the statistical/econometric approach, for production function estimation, the parameter values are inferred from observations on alternate levels of yield and inputs and not relying on actual parameters measurements (dynamic and seasonal models). Therefore, the statistical models can predict the conditions under which they are estimated reasonably well but will likely be less transferable to other areas.

There is no doubt that substantial progress has been made in developing empirical models that can be used to relate crop yields and irrigation management under saline conditions. However, further work is needed before these empirical models can be reliably applied under a wide variety of field conditions. Further work also is required on the relation of ET to soil and environmental conditions. Nonuniform applications of water and spatial variations in soil parameters significantly affect seasonal water production functions. To date, little or no work
has been done to estimate transient production functions under nonuniform conditions. Procedures for estimating uniformity distribution on a scale relevant to the plant also are needed. Variations in the environment affect the growth of the plant, so random effects related to the weather need to be included in models of the growth of plants under saline conditions.

**Irrigation Interval**

Plant growth is a function of the osmotic and matric potential of soil water; osmotic potential can be controlled by leaching, whereas matric potential is controlled by adequate and timely water application.

The question arises of whether it is necessary to narrow the watering intervals to keep the soil solution concentration low (to diminish harmful effects of the salt) or whether it is possible to lengthen the interval and to apply large amounts of water.

Analysing the process that occurs when evapotranspiration reduces soil water content between waterings shows that as the soil dries, the matric potentials -as well as the soil solute potential- decreases (increases of soil solution concentration). Because of the decreased soil solute potential, beneficial effects from decreasing the irrigation intervals as soil salinity increases could be reasonably expected (Allison, 1964; Ayers and Westcott, 1967). This process is counteracted by the effect of irrigation intervals on the shape of salt distribution in the soil profile and on the overall level of salinity. Under steady state conditions, increased irrigation results in an upward shift of the peak of the salt distribution profile, thereby increasing the mean salt concentration in the upper main root zone. Furthermore, ET increases as irrigation becomes more frequent, leading to additional water applications and an increase in the salt load (Van Schilfgaarde et al., 1974). The effect of irrigation intervals on the final crop yield was studied by several workers (Bernstein and François, 1975; Hoffman et al., 1983; Hamdy, 1990a). The data obtained indicated that increasing irrigation frequency did not significantly benefit crop production and may increase, rather than decrease, the effect of salinity.

Irrigation scheduling is a major parameter for assessing an appropriate saline irrigation management. However, this subject did not receive the attention of researchers in this field. A frequent constraint to improving on-farm water use is the lack of information of when an irrigation is needed and what capacity of replenishment is available within the root zone. Most of the methods used to determine the onset of stress including both direct and indirect measurements suffer the limitation of needing an empirical determination of the set-point for irrigation. Furthermore, measurements of soil water content or matric potential cannot be used (at least not conveniently) to assess or control the leaching fraction as is required to prevent an excessive build-up of soil salinity. Saline water irrigation scheduling require some methods of assessing the water availability to the crop with sufficient lead time to provide for a water application before significant stress occurs.

**Irrigation Method**

Proper choice of the irrigation method greatly facilitates reduction in drainage volume, uniform leaching and use of poor quality water. Poor selection of irrigation method not only aggravates salinization but may also create drainage problems. Utilization of saline water
resources in the long term, calls for scientific knowledge of soil-water-plant relationships and its modifying influence on irrigation techniques.

The method used for saline water irrigation may be guided by:
- the distribution of salt and water under different irrigation methods;
- crop sensitivity to foliar wetting and the extent damage to yield, and
- the ease with which solubility and matric potential can be maintained in the soil.

In the case of border or basin irrigation, salinity will increase in the top layer during the irrigation interval and decrease during watering more or less homogeneously if the land is well graded.

Under saline irrigation, the period of germination and emergence of the seedlings is the most critical stage of crop growth. A failure at this stage leads to a poor stand and a considerable yield decrease. Failures recorded where saline water was used can often be attributed to failures during germination and emergence and not to excessive soil salinity at a later stage (Hamdy, 1990b and Hamdy et al., 1993). Salt accumulation can be especially damaging to germination and seedling establishment when raised beds or ridges are used and "wet-up" by furrow irrigation. Seed bed shape and seed location should be managed to minimize high salt effects. For soils irrigated with saline water, slopping beds are the best where the seedling can be safely established on the slope below the zone of salt accumulation (Bernstein et al., 1955; Bernstein and Fireman, 1957).

Under flood or sprinkler irrigation where water and salt transport is downward and away from the seedling, limited pre-planting leaching of the upper soil strata may take care of the germination and establishment inhibition. Under furrow and drip irrigation there is downward component of water and salt transport, but another component is lateral and upward in the spaces between furrows or laterals. With these methods the adjustment of the soil surface contour and seedling or planting position according to the expected salt distribution can limit significantly this damage.

Irrigation by sprinkling allows close control of the amount and distribution and is often used on land where the slope is too great for other methods. In addition, both in soils with a high infiltration rate and those with soil structure problems sprinkling may provide alternative. The principal problem encountered with sprinkler irrigation using saline water is wetting of foliage with consequent tip and marginal burning of the leaves and ultimate defoliation. Provided foliar burn is avoided, sprinkler irrigation has the advantageous that salt-removal efficiency with sprinkler irrigation tends to be substantially higher than with flood or trickle irrigation.

Evaluating the ability of the irrigation method under saline water practice, the prevailing moisture conditions under the drip methods provides the best possible conditions of total soil water potential for a given quality of irrigation, besides avoiding leaf injured. The roots of the growing plants tend to cluster in the leached zone of high moisture near the trickles, avoiding salt that accumulates at the wetting front. Moreover drip irrigation offers the advantage of supplying water on a nearly daily base, in that way keeping the water content of the soil and the salinity of soil solution at a stable level. The only problem with this method is the need to remove salts that accumulate at the wetting front.

Subsurface systems provide no means of leaching the soil above the source. Continuous upward water movement and evaporation cause salt to accumulate near the soil surface.
Unless the soil is leached by rainfall or surface irrigation, salt levels will certainly become toxic. Generally, this system, is not suitable over the long-term, especially when salts are high in water supply.

**Leaching Management for Salinity Control**

The frequency and amount of leaching depend on water quality, climate, soil and crop sensitivity to salinity, the crop seasonal period as well as the accumulated salts in soils.

For efficient leaching management, it is questionably desirable to use extra water to every watering to leach the soil, at the same time increasing the peak requirements of an irrigated area or, on the contrary, to apply less water and to apply less leaching complements when more water is available. This will greatly depend on the salt distribution, which is related to the growing season. Leaching during a period of peak, consumptive use means that not only are greater amounts of water applied but also that greater amounts of salts are brought into the soil. Moreover with permanent leaching there is greater risk of water stagnation and suffocation of the crops. On the other hand, seasonal leaching during a period of low consumptive use can also draw advantage from rainfall, at least in the Mediterranean area and the Middle East where rainfall occurs during the winter.

The findings of Bernstein and François (1973), François (1981) and Hamdy (1990c) support the idea that applying the required leaching when salt accumulation becomes excessive - periodically rather than at every irrigation- is a better strategy for short-season crops. However, the point still needs to be settled: if leaching should be practiced periodically, at which growing stage should leaching be administrated and what is the appropriate leaching fraction?

Hamdy and Nassar (1991) concluded that for maximum utility and better saving of fresh water, leaching should be carried in accordance with the salinity tolerance of the growing stage and in proper quantities (L.F.). In this regard, the extent to which leaching can be minimized is limited by the salt tolerance of the crops being grown, salt composition of irrigation water and soil characteristics. Increase efficiency or reducing leaching under the proper circumstances can result in more effective water use in the first instance, a reduction in the salt load needing disposal and a substantial reduction in the volume of drainage water.

To increase the efficiency of leaching and reduce the amount of water needed, the following practices are suggested (BOX 4):

**Management of the Multi-Quality Water Resources**

Operation strategies that permit an optimal increase in cropped area and maximize the use of all available water of different qualities can be outlined under the following two major operational techniques:

A) Blending water (network dilution): different quality waters are mixed in the water supply permitting the predetermined of water quality for every field according to the tolerance of each crop to salinity. This procedure may increase the total quantity of water available for irrigation but at the same time will lower the quality of good water available. So far, results of studies show that this practice is not costly, more economic and easier to implement on large farms than other alternatives uses of water.
BOX 4

**Efficient Leaching Practices**
- Leach during the cool season (rather than during the warm season) when ET losses are lower;
- Use sprinklers at lower application rate than the soil infiltration rate to favour unsaturated flow, which is appreciably more efficient for leaching than saturated flow;
- Use more salt-tolerant crops, which require a lower LR and thus a lower water demand;
- Use tillage to slow overland water flow and reduce the number of surface cracks which bypass flow through large pores and decrease leaching efficiency; and
  - Where possible, schedule leachings for periods of low crop water use, or postpone leaching until after the cropping season.

Nevertheless, an extensive reuse of saline water, on the long-term, applying this technique could lead to detrimental effects on both soil productivity and crop production. Consequently, the necessary precautions concerning drainage, leaching and crop selection should be cautiously implemented.

**B) Alternating use of good and poor quality water (recycling-alternation):**

i) soil dilution: crops are irrigated by alternating between water resources so that the dilution occurs in the root-zone;

ii) sequential application: the water source is changed during the season according to the specific salt tolerance of the crops at each growth stage.

This technique is centering on the possibility of applying alternatively fresh and brackish water according to the varying tolerance of crops during growth stages. This reuse strategy that avoid blending has been demonstrated in field projects to be viable and advantageous in well-managed irrigation projects (Rhoades, 1984; 1988 and Rhoades et al., 1988).

The experimental studies carried out by Bari Institute to evaluate the forementioned two water application strategies favoured more the alternate water application than the blending one (BOX 5).

Although cyclic strategy has more potential flexibility than the blending one, there may be difficulty in adopting the cyclic strategy on small farms. In addition, application implies a double distribution system of water -both saline and fresh- to farms.

However, the matter is not simply the alternation of water resources. A suitable cropping pattern is also required that allows the substitution of saline water by normal water to irrigate certain crops in a suitable tolerant growth stage. Indeed, the timing and amount of possible substitution will of course, vary with the quality of the two waters, the cropping pattern, the climate, certain soil properties and the irrigation system.
**BOX 5**

**Alternating Use of Good and Poor Quality Water (Advantages)**

- Avoiding the deterioration of the good water quality. This water could be used at the time it should be most needed, for instance at the germination and seedling stages which are very sensitive to the salinity level of irrigation water as well as to satisfy the leaching requirements which requires water of relatively good quality;

- With the plants which are sensitive to the salinity level in irrigation waters, satisfactory production could only be achieved with water of good quality through alternative application modes. The disadvantages appearing under mixing could be completely eliminated and offer a free-hand possibility in using the different water resources according to the prevailing conditions;

- The cyclic use of water of low and high salinity prevents the soil from becoming too saline while permitting, over a long period, the substitution of brackish water for a substantial fraction of the irrigation needs.

- Cyclic strategy provides a vast choice of the crops to be included in the crop rotation as compared with the blending technique where crop selection is limited to the tolerant ones.

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**Concluding remarks and recommendations**

Saline water is a potential source of irrigation water. Recent research developments on salt tolerance of various crops, water, soil and crop management, irrigation and drainage methods and the reuse of drainage effluents, will enhance and increase its potential use for irrigation.

Recognizing the importance of saline water for irrigation, it is recommended the following actions which imply strong need for technological research:

- integrated management of water of different qualities at the level of farm, irrigation system and drainage basins with the explicit goals of increasing agriculture productivity, achieving optimal efficiency of water use, preventing on-site and off-site degradation and pollution, and sustaining long-term production potential of land and water resources;

- further research is needed in developing and use of mathematical and computer simulation models to relate crop yield and irrigation management under saline conditions so far that those empirical models can be reliably applied under a wide variety of field conditions;

- at present, there is no clearly defined policies and strategies on the use of saline water and/or the reuse of drainage water for irrigation. To arrive at these policies and strategies, monitoring programs are required on both water quantities and qualities, as well as on soils;

- much important and useful research on potentials and hazards of the use of saline water in irrigation were undertaken in relative isolation and no mechanism existed for coordinating the research work and to utilize effectively the research findings. In this regard it is needed, (1) to establish working relationships on national, regional and international institutions dealing with this subject through the formulation of networks, (2) to conduct and foster a comprehensive multi-disciplinary basic and applied research programme in coordinating fashion on the sustainable use of saline water in irrigation and related problems and obstacles and (3), to provide facilities for research workers and to train associated personal in techniques and methods for dealing with saline water practices and related salinity problems.
2.4. Wastewater separation

Decentralised urban situations with lower density allow to integrate horticultural production units in the direct surrounding of the consumers. The easiest way of providing waste water for irrigation is the separation of different wastewater streams, as faecal contains the most energy and a part of the plant nutrients on one side and most of the hygienical problematic particles, it is worth to collect and to treat separately. Faecal can be collected separately in compost or vacuum toilets with decentralised tanks. The total yearly volume of a waterless vacuum toilet is less than 100 litres per year and person. Decentralised solar drying of faecal and post treatment with solid waste is the adequate treatment method in hot and arid regions.

Urine contains the most plant nutrients and is responsible for odour problems. A separated collection is worth, as hygienic control is much easier than if mixed with faecal. It can be later used as a liquid fertilizer in automated irrigation systems. Urine separation from the faecal (so called black water) allows to easily collect around 80-90% of this fraction with simple gravity based collection systems for the urine. Another aspect is the future shortage in nutrients, especially phosphorous, that can be supplied directly. A treatment process will always reduce the available phosphorous and the re-separation of phosphorus out of dried sludge is complicated and cost intensive. The reclamation process won’t be as effective as a separated wastewater collection/ urine separation.

Greywater is easy to treat and contains the largest water content. It can be upgraded as irrigation water. Separated collection of faecal (with dry toilet systems) and grey water allows a household to spare about 20-30% of its total water consumption.

Within this system, the pre-treatment is much less delicate and for grey water, a direct input into the irrigation system is possible without pre-treatment or (depending on the sources) in combination with a gravel filter.

Fig. 2.11. Volume and nutrient content of different wastewater streams (Source: Anton Fröhlich 2003, based on figures from Otterpohl 2000)
The decentralised aspect allows a better control of the effluents’ total hygienic quality and by this enables the use of grey water for crop production. As well, it is a crucial base for supply autarky of food for a village from its direct surrounding.

Within this concept, again, solutions with grey water use for irrigation only (open field), recycling of drainage water e.g. for irrigation of public parks or water flush toilets (esp. gained from conventional greenhouses) and recycling by condensation processes (closed greenhouses) can be compared with the difference to the centralised systems being that the people of a neighbourhood can recycle their own water without having to pay for it (monetary) but can use their own labour to earn water directly.

**Decentralised approach:** This scenario is especially interesting for areas without or with only marginal existing waste water disposal! As well as for completely new urban areas. A further advantage is the improved quality of the waste water that will be used for irrigation in responsibility of the direct neighbourhood. These mechanisms might provide the local producer with a higher water quality that has not necessarily to be pre-treated.

**Disadvantages and risks:** The main disadvantage of the closed water and nutrient cycles is the missing pollutant sink. Direct conversion of urine into fertilizer is very easy and sufficiently hygienic but does not consider accumulation of micro pollutants in the system. For the case of faecal, composting is the most simple and common practice for the treatment, but in the same way as for urine, there is no pollutant sink embedded in the system.

Because of this, such a simple system can only be used with systematic control of specific pollutants and a regular operation of such a system can only be run with sufficient low values of heavy metals, micro pollutants etc. This may not be a problem in the MED countries, as the main source of the micro pollutants in Urine is from medicaments, and consumption here is relatively low.

**Fig. 2.12.** Urban water cycle between buildings and closed greenhouses (www.watergy.de)
<table>
<thead>
<tr>
<th>no.</th>
<th>System name</th>
<th>Waste flowstreams</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Wet mixed systems with on-site or off-site treatment</td>
<td>- mixed wastewater flowstream</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- faecal sludge flowstream</td>
</tr>
<tr>
<td>2</td>
<td>Wet blackwater systems (blackwater separated from greywater)</td>
<td>- blackwater flowstream</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- faecal sludge flowstream</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- greywater flowstream</td>
</tr>
<tr>
<td>3</td>
<td>Wet urine diversion system</td>
<td>- urine flowstream</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- brownwater mixed with greywater flowstream</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- faecal sludge flowstream</td>
</tr>
<tr>
<td>4</td>
<td>Wet urine &amp; greywater diversion system</td>
<td>- urine flowstream</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- brownwater flowstream</td>
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<tr>
<td></td>
<td></td>
<td>- faecal sludge flowstream</td>
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<tr>
<td></td>
<td></td>
<td>- greywater flowstream</td>
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<tr>
<td>5</td>
<td>Dry greywater separate system</td>
<td>- excreta flowstream</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- greywater flowstream</td>
</tr>
<tr>
<td>6</td>
<td>Dry urine &amp; greywater diversion system</td>
<td>- urine flowstream</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- faeces flowstream</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- greywater flowstream</td>
</tr>
<tr>
<td>7</td>
<td>Dry all mixed systems</td>
<td>- excreta mixed with greywater flowstream</td>
</tr>
</tbody>
</table>

**Tab. 2.7.** Main two criteria for subdividing sanitation systems are WET <-> DRY as well as the various degrees of separating waste flowstreams.

For both, urine and faecal, there are a number of more advanced treatment technologies, that allows a handling of problematic substances, which are described in the next chapter.

A sanitation system - contrary to a sanitation technology - considers all components of adequate management of human waste. Each system represents a configuration of different technology components at the different spatial levels with their various management, operation and maintenance conditions. This section attempts to systematize distinct sanitation systems focusing on possible reuse options in greenhouses. The here presented information have been gathered and systemized in the EU project NETSSAF (www.netssaf.net).

Various systems need and produce different amounts and pollution grades of wastewater. For potential reuse options and application within the Cycler concept, the quality and needed further treatment steps have to be considered.

The systems take into account the individual waste flowstreams depending on the degree of separation. The flowstream of stormwater drainage (rainwater) although shown in the system description is only referred to if required necessary. The following chapters briefly describe the various systems and their main characteristics. For each system the various relevant flowstreams are listed.
Excreta | urine and faeces
---|---
Faeces | solid human excrement
Urine | liquid human excrement
Mixed Wastewater | mixed flow stream including greywater, urine, faeces and flushing water
Greywater | domestic wastewater without urine or faeces
Blackwater | faeces, urine and flushing water
Yellowwater | urine and flushing water
Brownwater | faeces and flushing water

**Tab. 2.8. Nomenclature of wastewater separation**

### 2.4.1. System Description

The Wet mixed wastewater system collect, transport and treat all wastewater flowstreams which are created by households, institutions, and commercial and industrial establishments without stream separation. The system is characterised by flush toilets (full/low/pour flush toilets) for collection. This mixed wastewater can be treated either close to where it is generated (on-site-treatment) or transported via a network of pipes and pumping stations to a larger centralised treatment plant (off-site-treatment). These two options of off-site and on-site treatment are described below as two subsystems. It is however obvious that a mix of these two subsystems is also feasible.

There are different technologies available for collection of mixed wastewater. These can be by full, low or pour flush toilets. After collection, mixed wastewater may be transported with different technical options to the treatment plant. Transport technologies may be in pipes with gravity flow, pressure flow, or using vacuum systems. The system shown below (Figure 1) describes a separate sewer system where drainage of rainwater is not fed into the sewer. Including rainwater from stormwater drainage into the sewer system - call mixed sewer system - may also be an option, however is not recommended as it significantly increases complexity of the system (pipe diameters and treatment plants).

There are different technology options for wastewater treatment. Typically, sewage treatment involves up to three stages, called *primary*, *secondary* and *tertiary* treatment. During the primary (mechanical) treatment the solids are separated from the wastewater stream. The dissolved biological matter is progressively converted into a solid mass (faecal sludge or biosolids) by water-borne flora in the secondary (biological) treatment. *Effluent* discharged by the wastewater treatment plant can be either reused (irrigation purposes) or discharged into the environment depending on the level of treatment and legal requirements. In certain cases the effluent from one treatment plant may be further treated (e.g. by lagoons, wetlands or micro-filtration).

The *biosolids* (sludge) from the wastewater treatment plant can either be disposed of (e.g. disposal or incineration) or undergo further treatment (e.g. composting) and be re-used (agriculture).
Figure 2.13. Wet mixed wastewater system with centralised wastewater treatment.

The “On-site-treatment” subsystem - similarly to the off-site-treatment - is characterised by flush toilets (full, low, or pour flush toilets) for collection. Here however, a treatment plant is located close to the source of waste generation. Transport is limited to short distances mostly by gravity sewers. There are various technology options for on-site wastewater treatment which differ from those typically used for off-site centralised technologies. Examples are septic tanks, anaerobic baffled reactors, biogas plants, and others.

Relevant Flowstreams

**Mixed wastewater flowstream:** Mixed wastewater flowstream consists of a mix of urine, faeces, flushing water, and greywater. As mentioned already above, rainwater from stormwater drainage may or may not be diverted into the sewer and mixed with wastewater. A sewer which includes rainwater from stormwater drainage is known as mixed sewer system. On the other hand a separate sewer system is one in which stormwater is kept away from the sewer pipes. Mixed wastewater flowstream involves collection using toilet facilities which use water as flushing and transport media. This collected mixed wastewater is then transported to the treatment facility which can either be on-site (close to the source of waste generation) or off-site (in a centralized treatment plant). Wastewater treatment will produce biosolids which must undergo further management (collection, transport and treatment). This is comprised in the faecal sludge flowstream as described below. Finally effluent (liquid fraction exiting the wastewater treatment plant) can be either reused or discharged into the environment.
Figure 2.14. Mixed wastewater system with on-site wastewater treatment. Faecal sludge flowstream: In a wet mixed wastewater system, sludge or "biosolids" are the byproduct of the treatment of domestic wastewater in a wastewater treatment plant. This sludge can be further treated to reduce pathogens and vector attraction by a variety of methods. Sewage sludge which derives not only household wastewater but also industrial wastewater may contain high levels of toxic chemicals which are not removed during treatment. Depending on their level of treatment and resultant pollutant content, biosolids can be used in regulated applications ranging from soil conditioning to fertilizer for food or non-food agriculture or distribution for unlimited use.

2.4.2. Wet blackwater system

This system collects, transports and treats urine, faeces and flushing water (blackwater) together, however keeps greywater separate from this toilet wastewater. As greywater accounts for 60% of the wastewater produced in homes this separation simplifies the respective blackwater management. Separated greywater contains little or no pathogens. Because of this, it does not require the same treatment processes as blackwater or mixed wastewater. Greywater can be recycled for irrigation, toilet flushing, and exterior washing, resulting in water conservation. Most frequent practice in developing countries shows that greywater - if kept separate from blackwater - is discharged either indiscriminately onto soil where it either infiltrates into the subsurface or runs off as surface water into a neighboring stormwater drain or water body. Blackwater on the other hand - similar to mixed wastewater described above - is collected, transported and treated on- or off-site. Again here faecal sludge management must be taken into account and effluent from the treatment process may be reused or discharged into the environment.
Figure 2.15. Wet blackwater system where greywater is transported, treated, reused or disposed of separately.

Relevant Flowstreams

**Blackwater flowstream:** Blackwater flowstream consists of a mix of urine, faeces, and flushing water. Lack of greywater in this flowstream may limit self-cleansing velocity in a sewer network given the reduced liquid content. Blackwater may also be stored/treated on-site. On-site storage/treatment most often entails settling of the solid fraction, and partial treatment of the liquid as well as solid fraction. The liquid fraction may then be transported further to treatment plants, infiltration, reuse, or discharged whereas the solids remain to be handled separately in the faecal sludge flowstream.

**Faecal sludge flowstream:** In a wet blackwater system, faecal sludge, or "biosolids," as mentioned in the previous system, can be the byproduct of the treatment step or else result from intermediate blackwater storage. The accumulating sludge in these facilities must be emptied, treated and reused on-site or transported to an off-site treatment plant and then reused or simply disposed. Treatment of faecal sludge has the objective of reducing pathogens and stabilizing the organic matter. With regulated treatment, applications may range from soil conditioning to fertilizer for food or non-food agriculture or distribution for unlimited use.

**Greywater flowstream:** Greywater is wastewater from kitchen, bathtub, cleansing facilities, sinks, and laundry and dish washing. Greywater accounts for 60% of the outflow produced in homes. It contains little or no pathogens and 90% less nitrogen than blackwater (toilet water). Because of this, it does not require the same treatment processes as blackwater or mixed wastewater. Greywater can be recycled for irrigation, toilet flushing, and exterior washing, resulting in water conservation. When planned into habitat construction, the home's wastewater treatment system can be significantly reduced, resulting in cost and space savings. Often, in existing practice greywater is discharged indiscriminately into open drains, onto
Figure 2.16. Wet blackwater system where greywater is transported, treated, reused or disposed of separately.

land for infiltration or fed into soak pits or infiltration trenches. Greywater treatment and reuse systems generally consist of a preliminary treatment to hold back sand, grit and fat with a subsequently treatment technology followed by infiltration into subsurface, discharge into surface waters or irrigation purpose.

2.4.3. Wet urine diversion system

This system collects transports and treats faeces and flushing water and greywater together however keeps urine separate from this toilet wastewater (i.e. brownwater with greywater). The diversion of urine from the other flowstreams needs specific sanitary installations at the household (known as urine diverting toilets). The separation of urine has the objective of keeping the nutrient rich urine, free of pathogens to thus facilitate its reuse. In this wet urine diverting system, the faeces are flushed with water. Urine, after separation may either be used directly (with dilution) however it is recommended that urine be stored (which can be considered as a treatment step) before reuse. Brownwater mixed with greywater, which comprises faeces, flushing water and greywater is of similar nature than mixed wastewater. However, given the lack of urine which contains most nutrients, brownwater mixed with greywater will obviously have much lower nutrients values than mixed wastewater or blackwater.

Relevant Flowstreams

Urine flowstream: Urine diverting systems avoid urine coming into contact with faeces thus eliminating potential pathogen contamination and enhancing safe reuse opportunities. Urine is collected separately in a reservoir or canister and stored, and treated and/or transported before
reused in agriculture. Urine is an excellent fertilizer. Urine is rich in nitrogen, potassium and phosphorus. The nutrients and minerals, which plants need for growing, are available in a good balance. Separated urine of a healthy person does not contain pathogens. However urine may still be contaminated easily by traces of faeces. For safety reasons it is recommendable to store urine for 1 - 6 months before application. Depending on the diet, human urine collected during one year (ca. 500 liters) contains 4 -5 kg nitrogen, but faeces (ca. 50 kg) only approx. 0,5 kg nitrogen. The urine from 30 persons collected during one year can fertilize one-hectare farmland, which is equal to an application of 120 –150 kg Nitrogen per hectare. Or in other words, the daily urine from one person contains enough nutrients for fertilising approximately 1 m2 field. Nitrogen characteristics of urine are comparable with that of artificial fertiliser and therefore there is a danger to apply too much or too concentrated urine to plants.

**Brownwater mixed with greywater flowstream:** Brownwater consists of faeces and flushing water without urine. In this system this flowstream is mixed with greywater. By separation of urine, brownwater contains less nutrients. This aspect is further enhanced by mixing with greywater with even lower nutrient contents.

**Faecal sludge flowstream:** Similar to the systems already described in the previous chapters, in this wet urine diverting system faecal sludge, or "biosolids," will be the byproduct of the treatment step or else result from intermediate excreta storage facilities. At on-site facilities, this sludge must be emptied, treated and reused on-site or transported to an off-site treatment plant and subsequently reused or disposed. Treatment of faecal sludge has the objective of reducing pathogens and stabilizing the organic matter. With regulated treatment, applications may range from soil conditioning to fertilizer for food or non-food agriculture or distribution for unlimited use.

### 2.4.4. Wet urine & greywater diversion system

The system uses flushing water and separates all flow streams (urine, faeces and greywater), which can be treated on-site and/or off-site. It presents a reuse potential (with urine as fertiliser, faecal sludge as soil conditioning and greywater for irrigation or water service), even when some process products (treated wastewater and sludge from the faeces on-site treatment) could be disposed. Greywater can be treated separately or together with rainwater.

**Relevant Flowstreams**

**Urine flowstream:** Urine diverting systems avoid urine coming into contact with faeces thus eliminating potential pathogen contamination and enhancing safe reuse opportunities. Urine is collected separately in a reservoir or canister and stored, and treated and/or transported before reused in agriculture. Urine is rich in nitrogen, potassium and phosphorus. The nutrients and minerals, which plants need for growing, are available in a good balance. Separated urine of a healthy person does not contain pathogens. However urine may still be contaminated easily by traces of faeces. For safety reasons it is recommendable to store/treat urine for 1 - 6 months before application. Urine can be used for self use on small plots, on-site, for also off site on large agricultural areas. For off-site reuse a transport (by truck) and centralized storage may be necessary before large scale application. Depending on the diet, human urine collected during one year (ca. 500 liters) contains 4 -5 kg nitrogen, but faeces (ca. 50 kg) only approx. 0,5 kg nitrogen. The urine from 30 persons collected during one year can fertilize one-hectare
Figure 2.17. Wet urine and greywater diversion system where each flowstream is handled separately.

Farmland, which is equal to an application of 120 – 150 kg Nitrogen per hectare. Or in other words, the daily urine from one person contains enough nutrients for fertilising approximately 1 m² field. Nitrogen characteristics of urine are comparable with that of artificial fertiliser and therefore there is a danger to apply too much or too concentrated urine to plants.

**Brownwater flowstream**: The brownwater flowstream consists of faeces and flushing water. “Drop and store” latrine types are mostly used for this flowstream. Storage can result in partial dehydration and thus characterize a treatment process. Nevertheless, brownwater can also be collected and transported to an off-site centralized treatment facility. However, assuring transport with only flushing water as transport media may in some cases result in limiting flow velocities especially when sewer pipes are not ideally laid and flushing volumes are low.

**Greywater flowstream**: Greywater is wastewater from kitchen, bathtub, cleansing facilities, sinks, and laundry and dish washing. Greywater accounts for 60% of the outflow produced in homes. It contains little or no pathogens and 90% less nitrogen than blackwater (toilet water). Because of this, it does not require the same treatment processes as blackwater or mixed wastewater. Greywater can be recycled for irrigation, toilet flushing, and exterior washing, resulting in water conservation. When planned into habitat construction, the home’s wastewater treatment system can be significantly reduced, resulting in cost and space savings. Often, in existing practice greywater is discharged indiscriminately into open drains, onto
land for infiltration or fed into soak pits or infiltration trenches. Greywater treatment and reuse systems generally consist of a preliminary treatment to hold back sand, grit and fat with a subsequently treatment technology followed by infiltration into subsurface, discharge into surface waters or irrigation purpose.

**Faecal sludge flowstream:** In a wet urine and greywater diverting system faecal sludge will be fairly dry as faeces are only mixed with flushing water. or "biosolids," can be the byproduct of the treatment step or else result from intermediate excreta storage facilities. This sludge must be emptied, treated and reused on-site or transported to an off-site treatment plant and subsequently reused or disposed. Treatment of faecal sludge has the objective of reducing pathogens and stabilizing the organic matter. With regulated treatment, applications may range from soil conditioning to fertilizer for food or non-food agriculture or distribution for unlimited use.

**Dry greywater separate system**

Dry systems are those which do not use water for flushing. Nevertheless some water may be used for anal cleansing. Dry greywater separate systems collect, transport and treat all flow streams which are created by households, institutions, and commercial establishments, whereby faeces and urine are mixed and greywater is the only stream separated. As the lack of flushing water does not allow generation of blackwater and thus hinders possible transport in pipes, the system is typically characterised by “drop and store” latrine types. The separate greywater can be treated either close to where it is generated (on-site-treatment) or collected and transported via a network of pipes or by motorized means of transport to a larger centralised treatment plant (off-site-treatment). The excreta fraction (urine in combination with faeces) may be to some extent treated off-site as well (in the faecal sludge flowstream). Generally, this off-site treatment process is only performed to increase the level of hygienization of the material, since all types of collection infrastructure have some on-site treatment included. Proper use, and taking into account the issues in the areas of operation and maintenance are influencing the performance of these facilities significantly. The reuse of resources (greywater and/or treated excreta/sludge) can as well be performed.

**Relevant Flowstreams**

**Excreta flowstream:** As a dry system without flushing water this flowstream consists of faeces and urine. Given the low liquid content technology components comprise on-site storage and treatment facilities. In rural non-densely populated areas where availability of space is not an issue, the drop and store facilities are closed when full and new pits are constructed. In areas of higher density with scarcity of space, either double pits are often observed which are used alternately or an emptying service of excreta must be ensured. Excreta can be co-treated together with solid waste (co-composting), or dried in order to eliminate pathogens before reuse.

**Greywater flowstream:** Greywater is wastewater from kitchen, bathtub, cleansing facilities, sinks, and laundry and dish washing. Greywater is collected and can be treated and recycled for irrigation and washing. Often, in existing practice greywater is discharged indiscriminately into open drains, onto land for infiltration or fed into soak pits or infiltration trenches. Greywater treatment and reuse systems generally consist of a preliminary treatment to hold back sand, grit and fat with a subsequently treatment technology followed by infiltration into subsurface, discharge into surface waters or for irrigation purpose.
2.4.6. Dry urine & greywater diversion system

Dry urine and greywater diversion systems are characterized by the diversion of urine, faeces and greywater into three different flow streams. The rationale behind this flowstream diversion is based on the different character of the fractions, when it comes to volumetric flow, nutrient and pathogen content and handling characteristics. The diversion into flow streams facilitates adaptive treatment and end use of the different fractions.

The first unit in the system is a toilet with two outlets. Through the front outlet the urine is collected and conveyed to a storage container (a tank in larger or more expensive systems or a jerry can in smaller, simpler systems) or possibly a soak pit, if the urine is not brought to use. The front outlet is sometimes equipped with a flushing device for rinsing the urine bowl. Through the rear outlet the faeces is collected in a container located underneath the toilet. Wiping material, such as tissue paper or similar, can be dropped through the rear outlet. Where water is used for anal cleansing an additional outlet is provided for collecting anal cleansing water.

The urine can be used as a fertilizer for crop production. Hygiene and sanitation guidelines on how urine as a safe fertilizer for crop production has been published by WHO. In larger systems the urine needs to be sanitized through storage, while in one family systems, the urine can be used directly but the time from fertilizing until harvesting the crop should be at least one month.

The faecal fraction needs to be sanitized, go through a secondary treatment, before being used for crop production. The secondary treatment can be either on-site or off-site. Guidelines how faecal fractions can be sanitized and used in an hygienic way has been published by WHO. The sanitization of the faecal fraction can be combined with the treatment of the organic solid waste fraction.
The greywater can be treated either on-site or off-site after which reuse for irrigation purposes, following the WHO guidelines. This system is more common in single housing settings but functions also for apartment complexes.

**Relevant Flowstreams**

**Urine flowstream.** Urine diverting systems avoid urine coming into contact with faeces thus eliminating potential pathogen contamination and enhancing safe reuse opportunities. Urine is collected separately in a reservoir or canister and stored, and treated and/or transported before reused in agriculture. Urine is an excellent fertilizer. Urine is rich in nitrogen, potassium and phosphorus. The nutrients and minerals, which plants need for growing, are available in a good balance. Separated urine of a healthy person does not contain pathogens. However urine may still be contaminated easily by traces of faeces. For safety reasons it is recommendable to store urine for 1 - 6 months before application. Depending on the diet, human urine collected during one year (ca. 500 liters) contains 4 -5 kg nitrogen, but faeces (ca. 50 kg) only approx. 0,5 kg nitrogen. The urine from 30 persons collected during one year can fertilize one-hectare farmland, which is equal to an application of 120 –150 kg Nitrogen per hectare. Or in other words, the daily urine from one person contains enough nutrients for fertilising approximately 1 m² field. Nitrogen characteristics of urine are comparable with that of artificial fertiliser and therefore there is a danger to apply too much or too concentrated urine to plants.

**Faeces flowstream:** The faeces flowstream consist of faeces only. In some cases anal cleansing water may also be included in this flowstream. The relative low liquid content of this flowstream give rise to technologies of storage. Storage may result in dehydration and thus characterize a treatment process. Other on-site treatment steps can be conceived such as composting together with organic solid waste.
Greywater flowstream: Greywater is wastewater from kitchen, bathtub, cleansing facilities, sinks, and laundry and dish washing. Greywater accounts for 60% of the outflow produced in homes. It contains little or no pathogens and 90% less nitrogen than blackwater (toilet water). Because of this, it does not require the same treatment processes as blackwater or mixed wastewater. Greywater can be recycled for irrigation, toilet flushing, and exterior washing, resulting in water conservation. When planned into habitat construction, the home's wastewater treatment system can be significantly reduced, resulting in cost and space savings. Often, in existing practice greywater is discharged indiscriminately into open drains, onto land for infiltration or fed into soak pits or infiltration trenches. Greywater treatment and reuse systems generally consist of a preliminary treatment to hold back sand, grit and fat with a subsequently treatment technology followed by infiltration into subsurface, discharge into surface waters or irrigation purpose.

2.4.7 Dry all mixed system

This system is characterized by mixing of urine, faeces and greywater in the same facility and can be very frequently observed in rural and peri-urban areas of West Africa. The system is applied in areas where water is scarce or not reliable water supply in sufficient quantity is available. As a dry system it does not use flushing water however may contain anal cleansing water if used in the specific socio-cultural context. Given the lack of flushing water, such a system is not based on waste transport by water and most often the facilities consist of “drop and store” latrine types where the liquid fraction infiltrates into the subsurface. In rural non-densely populated areas where availability of space is not an issue, the drop and store latrine facilities are closed when full and new pits are constructed. In areas of higher density with scarcity of space, either double pits are often observed which are used alternately or regular emptying of faecal sludge must be ensured. Collected sludge then needs be handled in the faecal sludge flowstream.
Relevant Flowstreams

**Mixed excreta and greywater flowstream:** This flowstream consist of mixing of urine, faeces and greywater in the same facility and can be very frequently observed in rural and peri-urban areas of West Africa. Drop and store facilities will need high infiltration rates to avoid rapid filling and overflowing through large volumes of greywater. In areas of higher density with scarcity of space, either double pits are often observed which are used alternately or an emptying service of excreta must be ensured. Faecal sludge, if removed from the pit can undergo specific treatment in faecal sludge treatment plants. Co-treatment together with solid waste (co-composting), dewatering, dehydration, humification, or treatment in pond systems are viable options.

### 2.4.8. Flowstreams and technology assessment

This section lists the identified relevant flowstreams which can be observed in different systems. These flowstream can be occurring in different systems depending on the level of separation. The following flowstreams have been identified:

<table>
<thead>
<tr>
<th>Waste flowstreams</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>mixed wastewater flowstream</td>
<td>Mixed wastewater flowstream consists of a mix of urine, faeces, flushing water, and greywater. Rainwater from stormwater drainage may or may not be diverted into the sewer and mixed with this flowstream (mixed sewer system or separate sewer system)</td>
</tr>
<tr>
<td></td>
<td><em>in: System 1 (chapter 2.4.1.)</em></td>
</tr>
<tr>
<td>blackwater flowstream</td>
<td>Blackwater flowstream consists of a mix of urine, faeces, and flushing water. Lack of greywater in this flowstream may limit self-cleansing velocity in a sewer network given the reduced liquid content. Blackwater however may also be stored/treated on-site in appropriate facilities. Such on-site storage/treatment most often entails settling of the solid fraction, and a partial treatment of the liquid as well as solid fraction. The liquid fraction may then be infiltrated into the subsurface or be transported further to treatment plants, and subsequently , reused, or discharged whereas the solids remain to be handled separately as faecal sludge flowstream.</td>
</tr>
<tr>
<td></td>
<td><em>in: System 2 (chapter 2.4.2.)</em></td>
</tr>
<tr>
<td>brownwater mixed with greywater flowstream</td>
<td>Faeces, flushing water and greywater are the components of this flowstream. Given its composition it is similar to a mixed wastewater flowstream with the exception of the missing urine. Thus, on-site treatment or else transport by a sewer and off-site treatment can be options for treatment before reuse of the effluent. On-site storage/treatment facilities most often entail settling of the solid fraction, and a partial treatment of the liquid as well as solid fraction. The solid fraction (faecal sludge) must then be further managed in the faecal sludge flowstream. By separation of urine, brownwater contains less nutrients (as nitrogen and phosphorous is mainly contained in the urine). This</td>
</tr>
</tbody>
</table>
### Brownwater Flowstream
Brownwater consists of faeces and flushing water without urine or greywater. Given the relative lack of liquids, on-site “drop and store” latrine types are mostly used for storage/treatment of this flowstream. Long term storage may dehydrate and treat the solid fraction. This dehydration and treatment can be enhanced through sunlight (heat), dewatering facilities or by adding solid waste for co-composting. Nevertheless in areas where space is scarce, solids might need to be emptied and treated further (faecal sludge flowstream).

*in: System 4 (chapter 2.4.4.)*

### Faecal Sludge Flowstream
In various sanitation systems sludge, or "biosolids," are the byproduct of the treatment of wastewater in a wastewater treatment plant. In on-site sanitation systems which often entail settling of the solid fraction and separation from the liquid fraction, the sludge may be stabilized through storage (on-site systems such as pits, latrines, or septic tank facilities). Collection of this sludge and its treatment can reduce pathogens and vector attraction by a variety of methods. Sewage sludge which derives not only household wastewater but also industrial wastewater may contain high levels of toxic chemicals which are not removed during treatment. Depending on the origin of the wastewater the level of treatment and resultant pollutant content, sludge can be used in regulated applications ranging from soil conditioning to fertilizer for food or non-food agriculture or distribution for unlimited use.

*in: System 1 (chapter 2.4.1.); System 2 (chapter 2.4.2); System 3 (chapter 2.4.3); System 4 (2.4.4); and System 7 (2.4.7)*

### Greywater Flowstream
Greywater is wastewater from kitchen, bathtub, cleansing facilities, sinks, and laundry and dish washing. Greywater accounts for 60% or more of the outflow produced in homes. Often, in existing practice greywater is discharged indiscriminately into open drains, onto land for infiltration or fed into soak pits or infiltration trenches. Greywater treatment and reuse systems generally consist of a preliminary treatment to hold back sand, grit and fat with a subsequently treatment technology followed by infiltration into subsurface, discharge into surface waters or irrigation purpose.

*in: System 2 (chapter 2.4.2); System 4 (2.4.4); System 5 (2.4.5), System 6 (2.4.6)*

### Urine Flowstream
Urine diverting systems avoid urine coming into contact with faeces thus eliminating potential pathogen contamination and enhancing safe reuse opportunities. Urine is collected separately in a reservoir or canister and stored, and treated and/or transported before reused in agriculture.

*in: System 3 (chapter 2.4.3); System 4 (2.4.4); System 6 (2.4.6)*

### Excreta Flowstream
Excreta flowstream results from a dry system without flushing water. This flowstream consists solely of faeces and urine. Given the low liquid content, technology components comprise
on-site storage and treatment facilities. In rural non-densely populated areas where availability of space is not an issue, the drop and store facilities are closed when full and new pits are constructed. In areas of higher density with scarcity of space, either double pits which are used alternately or an emptying service of excreta must be ensured. Excreta can be co-treated together with solid waste (co-composting), or dried in order to eliminate pathogens before reuse.

in: System 5 (chapter 2.4.5)

faeces flowstream

The faeces flowstream consist of faeces only. In some cases anal cleansing water may also be included in this flowstream. This flowstream resembles the excreta flowstream however with less liquid content (as urine is missing). The relative low liquid content of this flowstream give rise to technologies of storage or composting. Storage may results in dehydration and thus characterize a treatment process. Treatment options may also involve addition of solid waste.

in: System 6 (chapter 2.4.6)

excreta mixed with greywater flowstream

This flowstream consists of mixing of urine, faeces and greywater in the same facility. In areas of higher density with scarcity of space, either double pits are used alternately or an emptying service of excreta (faecal sludge) must be ensured. Faecal sludge can be co-treated together with solid waste (co-composting), or dried in order to eliminate pathogens before reuse.

in: System 7 (chapter 2.4.7)

2.5. Greenhouse irrigation systems allowing the use of treated wastewater

As Water is a scarce and valuable commodity, and in order to optimize yield per drop of water, the term water use efficiency (WUE) is commonly used to quantify this fact. WUE can be defined in four different ways: (i) photosynthetic WUE as the ratio of leaf net assimilation (μmol CO2 m-2s-1) and leaf transpiration (μmol H2O m-2s-1); (ii) transpiration WUE as the ratio of cumulative harvested biomass (g) to cumulative transpiration (T) used by the crop; (iii) evapotranspiration WUE as the ratio of harvested biomass (g) to cumulative evapotranspiration (ET); (iv) effective WUE of the cropping system, which is the harvested biomass, divided by the total amount of water supplied to the crop (Steduto, 1996).

Hydroponics under protected cultivation was designed to maximize yield per surface area (or greenhouse volume), because this is generally in horticulture the limiting factor to expand production as long as all other inputs, including water is in abundance (Bradley and Marulanda 2000). Most of the hydroponics systems today can be found in temperate climates for various reasons. While technical literature and recommendations of hydroponics for before mentioned situation is plentiful, research results and technology recommendations for hydroponics with emphasis to WUE can hardly be found (Schwarz et al., 1998). Without any doubt, there remains an enormous gap of knowledge concerning the methods for how to improve and how to manage WUE in hydroponics.
The combination greenhouse hydroponics is a clear example of how horticulture could meet the objectives of a sustainable horticulture, with a more efficient use of inputs: water and fertilizers (Tognoni et al., 2001). The yield-related water use efficiency can be increased by three main ways:

(i) By increasing the physiological and transpirational efficiencies, by manipulating the environment (greenhouse, soilless culture) in order to get a faster growth and development with the same amount of transpired water.

(ii) Reduce the evaporation component of ET, by mulching, or by using artificial substrates in containers or bags, that reduced significantly the area of evaporating soil.

(iii) Reduce the water loss due to drainage and run-off, by recycling part or totality of the nutrient solution (Baille, 2001).

Nutrient use efficiency can be expressed by several ways. “Mosier et al. (2004) described agronomic indices commonly used to describe nutrient use efficiency: partial factor productivity (PFP, kg crop yield per kg nutrient applied); agronomic efficiency (AE, kg crop yield increase per kg nutrient applied); apparent recovery efficiency (RE, kg nutrient taken up per kg nutrient applied); and physiological efficiency (PE, kg yield increase per kg nutrient taken up). Crop removal efficiency (removal of nutrient in harvested crop as % of nutrient applied) is also commonly used to explain nutrient efficiency.” (Roberts, 2008)

Optimizing Nutrient Use Efficiency means applying nutrients at the right rate, right time, and in the right place as a best management practice (BMP) for achieving optimum nutrient efficiency. Most crops are location and season specific — depending on cultivar, management practices, climate, etc., and so it is critical that realistic yield goals are established and that nutrients are applied to meet the target yield. Over- or under-application will result in reduced nutrient use efficiency or losses in yield and crop quality (Roberts, 2008).

2.5.1. Use of wastewater in irrigation

Under the arid climate in the region of Agadir, several studies have been performed on the irrigation of crops with wastewater. This principle has been tested on various crops such as forage crops, cereals, and high added value greenhouse crops.

Generally speaking, all these studies confirm the merits of this practice which ensures interesting results from both an agronomic and economic standpoint while guaranteeing, provided irrigation is performed in a suitable manner, a satisfactory sanitation quality. Trials performed on Greenhouses vegetables and flower crops showed an optimum water use, and also demonstrated the efficiency of irrigation by drip irrigation pots, which not only gives the same results of fresh water, but also has a favourable impact on the protection of the environment and crops from a sanitation point of view.

The comparison of the irrigation of two forage crops (oats and sorghum) with treated wastewaters and with supplemented clear water shows that for oats, yields showed no significant difference for the two treatments. However, for forage sorghum, there was a slight increase in yields for the first re-growth.
Irrigation trials for market garden crops using secondary effluents (Infiltration decantation), showed that whatever the type of produce harvested (root, fruit developed in contact with the soil or fruit developed at a certain distance from the soil), its sanitation quality is equivalent to that obtained by irrigation using groundwater tables.

The monitoring of the quality of treated water by the infiltration-percolation system and its effects on the performance of a tomato crop has led to the following conclusions.

The sanitation quality of treated wastewaters corresponds to category A and therefore is allowed for irrigation, according to the WHO standards, and provided certain precautions are taken to protect the user from any contamination and that an appropriate technique is applied, treated wastewaters can also be used to irrigate market garden and ornamental crops.

However, the agronomic quality of the treated wastewaters presents certain risks of soil salinity especially in heavy textured soils. Consequently, precaution measures must be taken in the management of salinity resulting from irrigation in order to avoid an accumulation of salt in the root zone.

The richness of wastewaters reduces fertilization requirements while ensuring a higher quality and quantity of yields than those obtained by irrigating with well water supplemented with fertilizer. The contamination risks of the groundwater table by nitrates must be taken into account especially in the case of light textured soils.

The recycling of both types of treated wastewater (by infiltration-percolation and by the hydroponics technique) for the irrigation of high added value crops such as melon and carnation provide an opportunity which has given satisfactory results both regarding agricultural production and the preservation of the environment, by reducing the quantities of effluents (treated or untreated) discharged into water courses and by conserving conventional water resources. However, irrigation using wastewaters treated by the infiltration-percolation system poses risks of possible pollution of underground aquifers and the use of wastewaters treated by the hydroponics technique combined with drip irrigation leads to severe clogging of the latter through suspended matter and accumulated bacteria. A tertiary treatment of infiltrated effluents would reduce their nitrate content. This treatment could be carried out using the hydroponics technique which has been shown to have a high nitrate purifying capacity.

The comparison of results obtained on eggplants and sorghum with well water and treated wastewater, both supplemented with different doses of nitrogen, give interesting results. Wastewater gives on average yields of eggplants 10% higher than with well water supplemented with 150 units of nitrogen. Similarly, on sorghum, non supplemented wastewater give similar results to well water supplemented with 150 units nitrogen. Conversely, trials have shown that the supplementation of wastewater with nitrogen does not increase yields significantly and in proportion to the nitrogen units added.

Along different lines, the results of trials carried out on forest crops have shown that localized irrigation with treated wastewater leads to more rapid growth and development of different species and can be used without danger for the irrigation of plants destined for reforestation and biomass production. When wastewater is used for irrigation, no significant changes occur at soil level concerning pH, phosphorus, ammoniac, nitrates, calcium and heavy metals. However, these experiments revealed an increase of the soil content of potassium, minor elements and electric conductivity.
Regarding the physical quality of soils, there has been a substantial improvement of the latter when irrigated with wastewater.

Concerning the impact of the recycling of treated wastewaters on health, it has been shown that localized irrigation is quite suitable for the irrigation of vegetable crops. Moreover, the production of forage irrigated with treated wastewater respecting regulations and the consumption by animals of these wastewaters has no detrimental effect on the health of small breeds.

Other work investigated the response of vegetable crops under the greenhouse to evaluate the effect of treated Wastewater these crops Grown on Soilless Technique using Sand, coconut fiber and on Soil Condition, irrigated by treated Wastewater (water having an electrical conductivity of 3 dS/m). The objective of this work is to determine the water and mineral balance; thus, to determine the impact of the two substrates on the growth and production of green beans using treated Wastewater.

Plants are grown in a gullies with a Volume corresponding is 240 litres of the substrate for 48 plants which correspond to 5 litres/plant. Also as shown in the figure 1, two other layers of 40 litres gravel (5 cm each one) were installed within the lower part to allow a good infiltration as well as a good drainage.

Sand culture presented high mineral use efficiency and production efficiency; this can be due primarily to the high porosity of the sands substrate, which avoids any accumulation of salts in the culture medium.

The obtained values of yield, water use efficiency along with the measurements of plant growth parameters indicated that both sand and coconut fibre are more appropriate than soil for growing the vegetable crops under saline conditions.

A further method of wastewater supply could be the dissipation of water into a soil with high organic content, that allows the capture of large amounts of water and acts as a sponge, balancing differences of water supply and demand. Soils can be upgraded with compost or charcoal for this purpose.

Dissipation of the water can be managed in open ducts, that are placed with certain distances to the plants between rows. Water transport to the roots then can be organised within the soil. The water storage capacity of the organic material hinders a flow of wastewater into the subsoil, that would lead to contaminations of groundwater and also to nutrient losses.

This method has the advantage of not needing any plastic components in the soil. The increase heat capacity of the soil water contributes to the cooling of the greenhouse during daytime (while emitting heat during night). The distance between the above ground water dissipation and the plants hinders a contact between wastewater and used organic matter.

The method needs sufficient experience with the related irrigation practices, to hinder an overloading of the soil storage capacity.

The methods of growing plants in Aggregate culture (e.g. rockwool, pumice, perlite, sand culture, gravel culture etc.), where the nutrient solution is supplied to plants via an irrigation system through the media; the excess solution is allowed to run to waste (open system) or the solution is recycled (close system).
• Inert substrates with open systems (sand culture in beds, in containers, rockwool culture)

• In an open system the surplus of nutrient solution applied to the medium in which the plants grow is drained off as waste. Because the nutrient solution is not recycled, such open systems are less sensitive to the composition of the medium used or to the salinity of the water. This in turn has given rise to experimentation with wide range of growing medium and development of lower cost designs for containing them. In addition to wide growing beds in which a sand medium is spread across the entire greenhouse floor, troughs, trenches, and bags are also used, as well as, slabs of porous horticultural grade rockwool (Abou–Hadid and El-Behairy, 1999).

• Inert substrates closed systems (gravel culture)

In this system the nutrient solution which runs-off after each application is collected and recirculated to be used in successive watering. It is important that the pH and electrical conductivity (EC) of the nutrient solution is measured frequently to determine the acidity or alkalinity and total dissolved solids of the solution (Romer, 1993). The sustainability of substrates and materials used in closed systems is very important. So, materials, which can be recycled after their use, are preferred. Various studies have shown that water and fertilizer consumption and hence waste of fertilizers into the environment could be substantially reduced: between 15% to 29% and 15% to 48% for the Chrysanthemum, rose and cucumber (Van Os, 1999). However closed systems have some disadvantages such as the complexity of the nutrient solution management (Pardossi et al., 1994), the risk of pathogens diffusion and the accumulation of organic substance and phytotoxic metabolisms (Van Os and Stanghellini, 2001).

• Natural organic substrates

For more than 30 years organic substrates, such as sphagnum peat moss, pine bark, straw, etc., have been the dominating bulk material for growing plants. It is clear that organic substrates decay quickly due to microbiological actions and also they react chemically with the nutrient solution. Therefore it is necessary to interfere in the growing process, to adjust the frequency of the nutrient solution application, the
Fig 2.23., 2.24. Cultivation of tomatoes in different substrates and recycling of the drainage changes in the EC, pH and the levels of the trace elements. If the soilless system is closed, then more frequent chemical analysis of the solution is required (Benoit and Ceustermans, 1994).

However these organic rooting media have the advantages of low cost, ease of use and provide a buffering capacity serving as a storage mechanism for the essential elements. It is common practice to add a mixture of other materials including vermiculite, perlite and sand to the organic substrate to provide desired characteristics, such as, increased porosity, water holding capacity or weight. Numerous formulas for preparing organic soilless mixtures have been proposed; the two most widely used and accepted are the “peat-lite” and the “Mix formulas” (Benton Jones, 1983).

A number of materials are used to construct the Soilless growing systems, the most common are: polyethylene, polypropylene, PVC, polystyrene foam, aluminum, steels, asbestos corrugated sheets and concrete. The materials should be sustainable Van Os, 1994 describe the specification that these materials must have:

- No leakages during installation and use and possibility of measuring possible leakages.
- No damaging volatilization of damps or substances.
- Resistance to steam sterilization, solar radiation and pesticides.
- Taking back of materials after use and a guarantee of primary recycling by the suppliers.
- Low costs

A very important aspect of establishing Soilless culture is the selection of the proper growing media. The main criteria for selection of a particular substrate should be based on (Olympios, 1996):

- Agronomic characteristics of the substrates
- Technical level of cultivation
- Environmental conditions which can be provided (structure, controls and other facilities)
- Effect of substance on crop susceptibility to diseases
- Economic situation of the farm business
Fig. 2.25., 2.26. Soilless culture with a gravel bed for sub-ground treated wastewater dissipation and a sand layer as the growing medium.

- Scientific support to the grower or level of education of the grower
- Availability of the substrate (local or imported)
- Cost of substrate
- Environmental effect of the substrate (pollution, etc.)
- Marketing prospects in remunerative prices of the produce

The interest for the growing crops on artificial substrate is mainly due to the strong dependence of plant production on environmental conditions, and to the fact that optimum growing conditions are rarely met under open field conditions because of a poor water and mineral availability. In particular, the root system environment being better controlled in soilless cultures, water and mineral excess and deficiencies (saline stress and root anoxia) can be restricted and more generally, a closer management of water and mineral inputs in time and space is possible with respect to the plant needs during the successive vegetative stages. Most of the Soilless crop substrates are porous and granular media such as perlite and pouzzolane, or fibrous media like rock or stone wools. All are acting as hydraulic and mineral reservoirs and mechanical supports for plants but with physical and chemical characteristics which can strongly vary (Bougoul, 2005).

The knowledge of the physical properties of these substrates should allow for a better management of water and mineral supply to maintain optimal growth conditions (Bougoul, 2005).

According to the bulletin of FAO (1990), the ideal substrate must have the characteristics, which are presented in the table 1.
Impact of Irrigation water quality on substrate container culture

In general, water quality is a complex concept. However, compared to hydrological definitions, water quality in hydroponics can be limited to the concentrations of specific ions and phytotoxic substances relevant for plant nutrition as well as the presence of organisms and/or substances that can clog the irrigation systems (Tognoni et al., 1998).

High quality irrigation water is a prerequisite for both soil and soilless culture. In soilless culture, in particular, high alkalinity, salinity, or pH, creates problems. In practice, most waters, the salinity of which does not exceed 2500 mg/L, are suitable for the soilless growth of crop. Some waters do, however, contain small amounts of certain toxic elements, which would inhibit or fatal effects up on plant life. In addition, water can be contaminated by organic and inorganic constituents and can carry diseases (Adams, 1999). It is, therefore, always desirable to test the quality of the water before using (Douglas, 1990). Thus such water may require treatment before use, or if possible, another water source should be located. Water analysis should be done in order to define its composition, which will serve to calculate the nutritive solution (Adams, 1999).

The elements particularly involved in the build up of salinity in the slabs include sodium and chloride. These ions are frequently present in the water supply, but are required by most plants in quite small quantities. Calcium may also be present at high concentration, as in hard waters, but this should rarely become a problem provided that the formulation of the nutrient solution is adjusted proportionally (i.e., less calcium nitrate is included and required nitrate level is maintained with other nitrogen sources).

Irrigation water should be tested periodically to determine its quality. It may contain essential nutrients such as iron at high enough concentrations to justify a reduction in the levels applied in the fertilization program. The parameters that should be carefully considered in assessing the water quality are (1) ph, (2) TDS (Total dissolved salts) and (3) Cations and anions.

Table 2.8. Characteristics of ideal substrate, Source: FAO, 1990

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apparent density</td>
<td>0.22 g/cm³</td>
</tr>
<tr>
<td>Specific density</td>
<td>1.44 g/cm³</td>
</tr>
<tr>
<td>Total porosity</td>
<td>85%</td>
</tr>
<tr>
<td>Solid matter</td>
<td>10 - 15%</td>
</tr>
<tr>
<td>Pores filled of air</td>
<td>20 - 30%</td>
</tr>
<tr>
<td>Water available</td>
<td>20 - 30%</td>
</tr>
<tr>
<td>pH</td>
<td>5.5 - 6.5</td>
</tr>
<tr>
<td>CEC</td>
<td>10-30 meq/100 g dry weight</td>
</tr>
<tr>
<td>Soluble salts</td>
<td>200 mg/L</td>
</tr>
</tbody>
</table>
Subirrigation use

Recently particular attention was given to Soilless cultivation and the area under Soilless culture expanding rapidly because of the various advantages of this system. However, Soilless culture requires frequent irrigation and high fertilization rates and, when used with free drainage (open system) can result in possible contamination of ground and surface water sources (Van Os, 1999). The development of closed growing systems offers excellent prospects in terms of limiting the problem of water and nutrient loss (Siddiqi et al., 1998; Van Os, 1999; Avidan, 2000). The adoption of a closed cycle has besides the major initial cost of the equipment for collecting and pumping drainage water, two principal problems: need for carrying out a disinfection of the nutritive solution and a major complexity in the management of the mineral and water requirements of the plant, since its composition tends to change during the cycle, especially with poor quality water (Incrocci et al., 2007).

Various types of closed Soilless systems have been developed for container crops. The most widely used are the surface system (drip-irrigation) and the subirrigation system (ebb-and-flow benches, capillary mat, trough benches and flooded floors) (Reed, 1996). The drip-irrigation is the most popular system used in hydroponics (Schröder and Lieth, 2002). However, in the last few years, subirrigation systems (Fig 4) have gained attention in greenhouse container crop production, since they offer many advantages, namely labor saving, crop uniformity, and higher productivity (Uva et al., 1998) as well as the fact that they can be totally automated (Reed, 1996). In addition, Compared to the traditional one, ZRS systems, also referred to as zero runoff subirrigation (Uva et al., 1998), have several advantages: uniformity in administration of nutrient solution, lower substrate compression, significant savings in water and fertilizers (Biernbaum, 1990, 1992).

With all these advantages provided, subirrigation can improve the production with closed systems. With the trough benches subirrigation technique the substrate has a crucial role. It must allow continuous supply of water and nutrients, must allow an adequate water movement in the upward direction through capillarity (Elia et al., 2003), good water retention capacity and finally good aeration. These conditions are guarantee by the distribution inside the substrate

![Figure 2.27.](source)

**Figure 2.27.** Simplified model of nutrient solution flow, capillarity rise and the typical stratification of humidity and salts in a subirrigated pot with the trough bench technique. (Source: Montesano et al., 2007)
of “capillary holes” (diameter< 0.3 mm) and “none capillary holes” (diameter > 0.3 mm) (Montesano et al., 2004).

2.5.2. Integration of a heat storage into the irrigation- and soil-system

An external water tank has been used in the watergy prototype as a heat storage to provide daytime cooling and regeneration of cooling capacity during the night. Anyway, a tank is expensive and would increase the investment costs for such a system between 30 and up to 80 EUR/m². A soil integrated pond would be somehow lower, especially in an area with low labour costs.

As a major part of cost reduction of the entire system, it is proposed to integrate the heat storage into the greenhouse soil. This can be done with an open water body that is filled into a gravel bed. For that, the whole greenhouse soil is sealed with a plastic foil. Water is pressed by gravity with a drive pipe into the lower level of the gravel at one side of the greenhouse and is pumped out at the other side. Free water in the soil is transported through the area once during daytime and twice during night, according to the modes of greenhouse cooling and regeneration of the coolant.

A variation of this system is the indirect loading of the submerged water zone with a number of parallel tubes, where the hot water runs through and heats up the water relatively synchronously. This method allows a more hygienic procedure, if the water volume consists of wastewater and should not be in contact with the above ground air to water heat exchange procedure.

Also, with the separation it is possible to lead saline water through the pipes during night to allow evaporation of the heated water in the greenhouse with having a condensed water yield on the interior walls of the greenhouse. The pipe system can also be used in combination with soil water in the organic material, where the activated water volume is not submerged in the soil above a foil, but just hold by the biomass.

Fig. 2.28. Soil integrated heat storage with indirect heating from parallel pipes and supply of wastewater from covered ditches.
3. Third step: Accumulation of carbon in the urban perimeter

3.1. Treatment of solid waste as a pollutant sink in the urban matter circuit

3.1.1. Pyrolysis

It is proposed to separate and collect all organic waste, mainly being organic waste and collected sludge from households, sewage sludge and agricultural waste, as it is possible to use efficiently its energetic content as well as the embedded carbon, that can be used as a soil enhancer after processing.

This method can not be considered as a circle. It is a linear flow from CO2 from atmosphere and generated CO2 from combustion units into biomass by photosynthesis, while being used either as food or as regenerative material. After the project lifecycle, the waste biomass shall be collected and dried decentralised. For the arid area, solar drying in the open environment is the easiest way of weight reduction and preparation for further processing. Only a mixing of the waste has to be provided. In areas, where the smell of the process may be disturbing, the drying process can be performed inside of a greenhouse (which is also the preferred method for more humid climate).

Though, pyrolysis systems had been in operation to treat all waste constituents, this approach was not very successful in terms of safe operation and economics (Kügler 2004). Anyway, separation of organic waste from other waste helps to reduce the hygienical problems of a proper waste separation and use of the remaining waste constituents. For most of the remaining waste like especially glass and plastic, today there are more sophisticated reuse strategies than conversion with only energetic use.

For the processing, a central biomass pyrolysis unit is proposed with sufficiently large quantity of operation of at least 300,000 t/a to allow an economic operation. (Gerdes 2001) This device can be operated in order to transform 100 kg of dry biomass into about 65 kg of oil, 15 kg of gas and 20 kg of charcoal. The oil has to be further processed in order to be used as a fuel or chemical raw material. This has to be done even more centralised (e.g. one unit within Morocco/Tunisia or as being sold as an export product an a site within the import country). The charcoal can be used as a soil enhancer and soil fertiliser (see 3.2.).

The gas can be used as a local energy source in the households or in combination with possible solar thermal power stations for night operation of the related steam turbines. The exhaust gas from this process can be redirected to neighboured closed greenhouse areas as a CO2 source – thus closing a part of the carbon cycle.

The pyrolysis reactor has to be operated at temperatures around 450°C. (Zobel et al 2007). As the process is endothermic, supply energy has to be spent. Conventionally, this energy is provided by the produced process gas. An interesting alternative is the use of Solar concentrated power system, as the gas can remain as a storable fuel while the solar load then also contributes to the energy content of the final products.

The process of relatively high temperatures with reduction / absence of air allows to crack organic constituents, which leads to the production of more simple organic compounds. This
is very important in the context of the waste management, as also most of the toxic organic compounds are converted into less harmful matter. In this way, the process contributes as a pollutant sink in the urban matter cycle.

3.1.2. Hydrothermal carbonisation and biogas processing as a low-tech alternative for pyrolysis

Hydrothermal carbonisation can be discussed as an alternative to the pyrolysis process. The process of biomass conversion is provided with cooking under pressure at temperatures of about 150°C. (Yu et al 2004, Titirici et al 2007). The process is exothermic, that means that it has a lower energy efficiency than the Pyrolysis, as the energy is released provided as thermal energy below 150°, while the Pyrolysis provides energy rich and storable fuels like oil and gas.

Anyway, hydrothermal carbonisation has two major advantages: The process is much more simple, can be realised in decentralised mode within small units and the total carbon is converted as a durable soil enhancer. This means, there is no Gas and Oil provided, but much more carbon that can be stored, so that the carbon accumulation rate in the soil can be much higher.
The disadvantages is, that there might be less economic interest in such a conversion, as no gas or oil, as specific high price products can be gained from the process, so there might be less interest to invest in such a complicated system of collection, conversion of the biomass. Further more, hydrothermal carbonisation will not provide conversion of organic pollutants, so the system does not work as a pollutant sink in the urban matter circuit.

Anyway, there could be applications for this conversion method, especially at areas, that do not produce enough organic waste to justify a large and centralised conversion system. Longer transport of the biomass is not efficient, as transport costs could go beyond the energetic content of the waste.

The exploitation of the energetic content from biomass can be given by biogas processing, which also can be managed in a decentralised way. In this case, hydrothermal carbonisation would only convert the remaining residues from the biogas process.

A specific application could be in a situation, where the biomass has very low content of organic pollutants, and it is the specific aim to gain a really large quantity of soil enhancer to start an agronomic project, that at a later stage can change to the pyrolysis technology. Also there can be a situation, where the waste heat from the process can be used in a sufficiently effective way, e.g. for building heat supply or urban hot water generation, that before was provided by fossil energy.

3.2. Use of charcoal as remaining biomass as soil enhancer in the urban perimeter

The produced charcoal as the only solid residue can be used as a soil enhancer in the productive land around the urban area. Charcoal as a soil enhancer is discussed during the last five years under the term of “Terra Preta”. This method had been developed by native Amazonians before the Spanish invasion, in order to reach a sustainable agriculture on soils of the rain forests (Glaser et al 2002, Lehmann et al 2004) , but actually the fact that it can be produced as a pyrolysis by-product gives a new focus on this ancient technology. (Collins 2008, Eprida 2008, Dynamotive 2008).

Charcoal allows a retention of water and nutrients in the soil. This cultivation method did prevent the soils of rain forests from being washed out of humus and plant nutrients. It was also possible to accumulate the substance toward very deep black soils, as the char is almost totally non-biodegradable. (Hoshi 2001)

Problems with toxic constituents of the char (like benzenes) or its content of pollutants from the original waste have to be further examined, but the general principle is, that the char takes up water and keeps all its constituent particles, while during dryer periods, the plants take up the water and nutrients (including the pollutants) actively. This also includes the solving of certain particles by acid extruded by the plant roots.

Having rather problematic input material, this process can be used to concentrate the remaining toxic compounds like heavy metals. Having this matter transferred into the biomass, either the biomass can be combusted and the toxins can be concentrated and deposited. In a very polluted environment, this would be a needed process of systematic detoxification.
At less harmful concentrations, the biomass can be used e.g. as a building material and the harmful compounds become again spread but do get out of the agricultural soil and in the long term will not affect the soil life neither than the groundwater.

So a part of the pollutants will be taken up by the vegetation, but as the material itself is not degraded, after a certain period it is sufficiently clean to allow any agricultural use. This process, including the matter flow into the vegetation and possible matter flow into the groundwater has to be further examined.

In total, the method of pyrolysis with accumulation of charcoal in the soil can contribute to a dramatic change of urban systems, as it is the basis technology to change from a linear urban input/output economy, consuming finite resources and producing waste and pollution towards an economy that relies on renewable materials and that is self enhancing during time, as the soil quality is permanently enhanced (by constant input of permeable char).

### 3.3. Composting

Normally the practice of composting is seen as the main constituent of closed matter cycles, but during the composting process, already the largest fraction of the carbon is degraded and released to the atmosphere as CO2. Composting can be considered as a good practice to minimise the volume and pathogenic content of biological waste, but compared to the newer treatment methods will not be subsequently efficient for the re-use of the carbon.

Composting does not allow to integrate a pollutant sink, as the low temperatures of the process does not provide a cracking of organic pollutants. The low stability of compost in the soil then leads to a release of polluting particles (especially heavy metals) that are then accumulated in the biomass or leached to the groundwater.

As a new practice, a transfer of carbon into charcoal by methods of biomass flash pyrolysis or hydrothermal carbonisation in the urban matter stream is proposed. Unlike compost, charcoal can be accumulated in the soil without being degraded by micro organisms. Charcoal allows the retention of water and nutrients in the soil. Phosphorus from the waste stream is sealed within the char but can be solved out by vegetation root activity over longer periods.

This practice can turn an agro-urban system into a carbon sink, as vegetation takes up CO2 and always a part of this carbon fraction is captured in long term. As being practically non-degradable, charcoal will allow to increase the water holding capacity in the soils and this can be a base for a permanent improvement of the used surface and can provide a higher stability of vegetation systems against longer periods of drought.
4. Forth step: Use of new generation greenhouses in combination with concentrated solar power generation and co-production of thermo-chemical desiccant fuels for space heating- and cooling as well as seawater desalination

Concentrated solar power (CSP) from sunny desert regions is more and more discussed as the most interesting source of electricity supply for the European Union, as the growth perspective is much more interesting than for e.g. wind energy. At the same time, the technology is becoming less and less expensive, and gets close to the production costs of wind energy. The Trans-Mediterranean Renewable Energy Cooperation (TREC) is a consortium of scientists, companies and national governments, that support the idea of producing renewable power in Northern Africa and to use a High voltage DC, electricity grid to transport the power to Europe with only about 10% of losses. As there is about 100% more of sunlight in this region, the transport losses can almost be neglected. (German Aerospace Center, DLR 2006)

As the CSP based steam turbines do not only provide power but have to be cooled constantly, the concept suggests to combine the technology with solar-thermal desalination of water.

For the proposed greenhouse technology, there are three different possible synergies, that can be derived in combination with CSP:

- The cooling water return from the greenhouse cooling device (at temperatures of ~40°C) can be used to cool the CSP unit with storage of the heated water and return back to the greenhouse during night for heat release and seawater evaporation in the greenhouse. The process is similar to the standard solar desalination process, but can use the greenhouse instalments, so that a higher profitability can be gained from the

![Electricity Generation All Countries](figure.png)

**Figure 2:** Annual electricity demand and generation within the countries analysed in the MED-CSP scenario

**Fig. 4.1., 4.2.** Annual electricity demand and generation within the countries analysed in the MED_CSP scenario of DLR (source: [www.desertec.org](http://www.desertec.org))
Fig. 4.2. Concept of the TREC electrical grid network based on renewable energy, mainly CSP (source: www.desertec.org) From the point of greenhouse production, a further 2500 km², that are calculated for the surface need to provide 40% of the European electricity supply can be combined with water sustainable food production, that can give an enormous impulse to the food supply and urban water supply in Northern Africa.

Fig. 4.3. Concentrated solar power plant using parabolic trough design. (source: www.desertec.org)

multiple use of the surface. In the closed greenhouse, a cooling cycle can be built up, and the return hot water is used as supply cooling water at the steam turbine of the CSP unit. In this way, ideally no additional thermal capacity is needed, as only the amplitude of the temperature in the storage is increased. During night, the thermal capacity of the storage can be used to evaporate seawater in the greenhouse while having condensation yields at the inside of the rooftop.
In the open greenhouse, seawater that is heated by the CSP waste heat source can be evaporated in the air flow between the vegetation area and the heat exchangers at the air outlet. In this way, both the temperature and the water content of the air is increased, which allows increased water yields at remaining cooling temperatures.

Integration of the CSP mirrors inside of the greenhouse and (1) either using direct light for energy production and indirect light for photosynthesis or (2) using Near Infrared Light (NIR) for energy production and UV and visible light for photosynthesis using NIR reflecting mirrors. The specific advantage of this approach is, that on one hand, the mirrors will reduce the heat load into the greenhouse with related lower need for cooling, while on the other hand it is much cheaper to place mirrors into a wind protected environment, where much less material for the construction and tracking mechanisms has to be provided.

By this, existing greenhouse structures are sufficiently large to provide this surface. A change to additional power and water production would make the whole Mediterranean greenhouse business much more sustainable in terms of water efficiency but also in a total lifetime analysis, that also looks on the energy and material aspects.
Fig. 4.5. Scheme of a two-stage evaporation process with greenhouse vegetation (9) and water driven out of desiccants (4) within a closed air circuit (3). The air can be chilled down in the cooling duct (2), releasing condensed water much sooner than having the evaporation in the cooling duct only.

Three cascades of greenhouse integrated solar thermal power applications: Electricity applications, thermo-chemical applications and desalination.

An even more efficient system can be achieved, if the waste heat from the turbines is not directly used for desalination of seawater, but within a third application for regeneration of desiccants, that can be used as a working fluid to run desiccant cooling devices and heat pumps for heating- or cooling purposes.

The flow direction of the steam cooler can provide temperatures of about 70-80°C, which is sufficient for the regeneration of certain desiccants. The solutions can be disposed in the roof area of a greenhouse for evaporation of water. For this purpose it is beneficiary, that the greenhouse air under the roof is hotter and provides a much lower relative humidity than the air in the vegetation canopy. This means that the greenhouse at this point is able to take up the evaporated air. Heat and vapour can be transported through the air cycle and allows to initiate condensation at the air cooler much faster due to the much higher dew point temperature of the air, which is a result to the previous evaporation process.

The concentrated desiccants can either be used to cool the greenhouse by drying the inside air (provoking more evapo-transpiration and related evaporative cooling of the plants) or can be used in external devices, especially in desiccant cooling devices for buildings.

While heating up the thermal storage with the heat load from the solar power unit and the greenhouse unit, the whole thermal load can be used for seawater desalination during night. In this case, both can be used for the disposal of the seawater while having condensation on the greenhouse roof.
Fig. 4.6. Regeneration of desiccants in greenhouse units (attached to building facades and/or in the perimeter of cities) and use of concentrated desiccants for solar building climate control in combination with seawater for evaporative cooling. Flow of diluted desiccants and pre-concentrated seawater back to the greenhouses as a source of greenhouse evaporative cooling, for the production of condensed water and for the regeneration of the desiccants.
5. Fifth step: Interaction of the approaches as a fundament for sustainable development in coastal arid city regions

5.1. Interaction of the strategies in coastal arid city regions

The future of Gabes and Agadir are very much related to the future availability of water. Desalination by thermal or reverse osmosis plants is one solution, but will always be related to high operation costs, increasing costs of fossil energy and related CO2 emissions.

The scenarios for the two cities are not limited on the question of how waste water that is generated in the urban areas can be used for crop production. Moreover, the important question is:

Can these cities – chosen as general exemplary large cities in hot and arid climate - built their future in terms of future supply of water, food and biomass as a raw material on a system of new technology greenhouses?

The water supply from limited and extremely decreasing fossil water sources can minimised or even replaced by unconventional water sources like Rainwater harvesting, Wastewater and Seawater.

Wastewater from clearage fields can be used, if a sufficient post treatment in aerated ponds, soil gravel filters or membrane ultra-filtration is provided. In the long term, central cleaning units may consist only of mechanical treatment and these post treatment systems, as the conventional biologic treatment systems do not allow to keep plant nutrients in the flow runoff.

- If wastewater is available, it should be treated with the most economic filter system according to the given grade of pollution. Only if a gravel filter does not provide a sufficient quality of irrigation water, then membrane ultra filtration should be used (which is still much less expensive than seawater desalination)
- Only if the ultra filtration also does not provide a sufficient quality (e.g. in case of micro pollutants), the crop system should change from food crops to non-food crops. Sufficiently valuable non-food crops have been identified as specific building materials (e.g. Bamboo replacing steal in certain constructions) and fibre crops, processed into higher valuable products (textiles, cellulose) within the greenhouse by fermentation processes.

For the next step of development, a decentralised pre-selection of wastewater into greywater, urine and faecal is recommended at the level of the households or at the level of certain pollutant sources (factories, hospitals…), so that greywater can be provided as a water source with much lower pathogen content. This would allow to use the water with much lower effort of cleaning, e.g. just with a gravel filter or even without filters, if used within a sufficient advanced irrigation system (e.g. sub-ground hydroponic irrigation, or with sub-ground dissipation within a terra preta soil). In this case, the urine flow can be used almost directly as a plant fertiliser and faecal and other problematic organic compounds can be dried and processed as solids.
**Fig. 5.1.** Basic configuration of a self sustaining and self energising production and consumption system for arid regions based on the interaction of different conventional water sources, related treatment technologies, new generation greenhouse systems, solid state fermentation technologies, possible market products from the greenhouses including the feedback of waste and wastewater into the system

For the **waste water from the fishing industry**, one major economy in coastal cities, a separated treatment is proposed in combination with aqua farming and algae production to be able to use the waste water on an economic high level and the cleared saline water runoff can be used for desalination purposes.

Considering, that the urban water cycle can not be totally closed, a second unconventional water source is **seawater**, that can be desalinated within the new greenhouse systems, by using it in closed greenhouses for evaporative cooling with condensation on the inner roof surface. For open greenhouses, it can be used for evaporative cooling of the incoming air in modified wet pad systems.

Seawater can also be used for direct evaporative cooling in building air conditioning systems. The greenhouse systems can produce the today common horticultural fresh fruits and vegetables. Further more, protein food can be provided by greenhouse integrated solid state fermentation, aqua farming and algae production.
Sufficiently high valued industrial regenerative raw material can be produced as building materials (e.g. bamboo), processes textiles, cellulose, fermented enzymes, dyestuffs and flavours as well as basic minerals, selectively mined from the seawater by algae growth.

After the product lifecycle of these products, the produced organic waste can be re-introduced into the system by solar drying of the waste biomass and conversion into charcoal, that can be used for improving of the soil field capacity and related heat capacity in the greenhouses and the open landscape production systems.

5.2. Interaction with solar power generation and localisation in the regional context

Beside food production and production of regenerative industrial raw materials, electricity gained from solar concentrated power can be a second export good of the coastal arid city region. Anyway, the productive greenhouse areas can also provide food, raw materials and electricity for the local markets.

Further local products will be urban fresh water production and concentrated desiccants, that can be regenerated within the greenhouse systems. These two latter products can be integrated into an urban water cycle, that also includes the transport of nutrients back to the greenhouses.

The different solutions like freshwater, seawater, pre-concentrated seawater and desiccants of course have to be transported separately but in principle can be forwarded within different batch transports using only one pipeline. Greywater or wastewater has to be transported separately but in this case, transport in open ditches can be a cheap way of transport and would allow pre-treatment passing areas with water vegetation.

Fig. 5.2. Energy, water and matter flow in the regional urban system
In contrast to conventional waste water treatment- and desalination plants, that only need a very small spot of space within a city, the greenhouse solution will need a huge surface of land. Further more, this land shall be in the direct neighbourhood of urban areas to minimise transport costs for water, nutrients and produced crops.

Concentrated solar power units will be dimensioned towards turbine units of about 200 MW, which relates to a surface of 50 – 200 ha (according to of use of the full solar radiation or only use of the NIR spectrum). This means that several greenhouse areas will surround the cities, providing products for export and local use.

The unit of a pyrolysis units will need a capacity of at least 300.000 tons of dry biomass/year in order to be used in an economic way. This means, that in the case of a city of the size of Agadir or Gabes, only one centralised station could be built, using all the organic solid waste, the dried sludge from the wastewater and the agricultural waste.

The produced pyrolysis oil can also be used as an export good but has to be further processed in order to be used as a fuel or chemical raw material. This can be done on a even more centralised way (cleaning of oil from different pyrolysis station).

The produced pyrolysis gas can be used locally as town gas and to allow the continuous running of the power generators during night. In the latter case, the exhaust gas can be transferred into the closed greenhouses as a source of carbon dioxide.

The pyrolysis charcoal can be used for the enhancement of soil quality. In a first step, the greenhouses should be optimised. As the char is non degradable, after a certain period, the char can be used on other areas of agricultural or forestal use. In a late stage of such a system, the char can become an export good as the oil or gas fractions of the process.

The possibility of an import of brown coal as a subsidiary load for the pyrolysis process with conversion into gas and oil and with an additional fraction of cooks provided for the local agricultural soils should be further investigated!
Fig. 5.3. Localisation of processing units: (1.) multiple combined greenhouse and CSP units around a city, providing food and electricity and (2.) one single centralised pyrolysis unit using decentralised solar dried biomass from urban and agricultural waste and sludge.
Annex

A 1 Localisation of the scenarios in the area of Agadir and Gabes

A 1.1. Dimensioning of greenhouse areas based on quantities of wastewater from existing clearance stations.

Water is considered as the main limited resource to run the whole system. Wastewater and Greywater is considered as the cheapest available and constant water source.

Based on the available amounts of cleared wastewater from existing treatment plants, an equivalent surface of cultivatable land is calculated, that can be potentially supplied with actual amounts of available wastewater. Based on the scientific results made in the EU FP5 research project Watergy (Zaragoza et al 2007), an average water need of 2 litres/day and m² will be needed for irrigation of a closed greenhouse. 75% of that (1.5 litre) can be recovered by condensation. This amount can be returned to the city for freshwater supply after a minor post-treatment process (e.g. UV light filtration).

Pre-treatment in open greenhouse

As related to the scenarios for pre-treatment of wastewater (see chapter 2), which will be performed in an aerated pond or alternatively within greenhouse integrated gravel filters.

This part has a loss of ~5 litres/m², but on one m², 25-35 litres of water can be pre-treated. For the scenario, the lower value of 25 litres/m² is chosen for pre-treatment, with 5 litres being evaporative losses and 20 litres that can be provided for 10m² of closed greenhouses in the surrounding. This relates to a water consumption of 25litres/11m², which is 2.3 litres/m² or 2300 cbm/km²*d.

75% of the waste water can be recovered as condensed water for water supply of the city. The remaining 25% have to be supplied by other sources. Further more, some of the fresh water originally supplied to the city is not released to the effluents of the treatment stations. This is especially:

Water supplied to urban areas without waste water collection
Water that gets lost by leakages in the supply infrastructure
Water that is used in households or industry that is evaporated (e.g. at garden irrigation), that is drained into the earth etc.

This water also has to be supplied by other conventional or unconventional water resources:

Both cities Agadir and Gabes are located on the sea, so that seawater is available directly as a non-finite source of water.

Further more, especially in Gabes, a number of aquifers contain brackish water, especially due to overexploitation of freshwater and sub-ground pressure from the sea.

Saline water can be fed into the roof area of a closed greenhouse. While in the vegetation area, the humidity is almost saturated, hot air rises to the roof. Also parts of the greenhouse construction in the roof leads to further heating and a related reduction of relative humidity. In
this way, saline water can be supposed to surfaces, from where it can evaporate into the greenhouse air. The evaporated water can be recovered as fresh water in the condensation process. The estimated amount for this input is 1 litre per m² and day. This amount can over-compensate the losses in the greenhouse and additionally partially compensate the losses in the urban network.

Rain water harvesting can be easily integrated into greenhouse system. An infrastructure of freshwater re-direction from the greenhouse areas to the city can be combined with a transport facility for collected rainwater. The needed treatment of rainwater is similar to the treatment of greywater, but can be dimensioned with much higher capacity/unit.

Both cities, Agadir and Gabes have an average yearly rain fall of ~160 mm. Anyway, rainwater does not seem to be a reliable source. In Agadir, during the last three years (2006-2008), rainfall was below 100 mm. The same decrease had to be observed in other Mediterranean countries like e.g. Spain or Israel. Considering, that about 30% of this rainfall will be evaporated on the greenhouse roof or will be discharged for cleaning of roofs after periods of longer drought, a yearly amount of usable rainwater can be considered as 70 litres/m² and year, which relates to a daily yield of 0,2 litres of water. In average, this can already contribute to a compensation of 50 % of the water amounts that gets lost through the greenhouse cover.

Fig. A.1. Temperatures and rainfall in Agadir and Gabes
For the areas without existing wastewater infrastructure, as well as for new built urban areas, closed greenhouses can be proposed for decentralised water circulation. This will be a major part of the local scenarios but will not be included in the following calculation, as it can only by applied step by step during future development of the infrastructure.

Following the above mentioned rules, the following figures for required greenhouse water supply from the cities and related water feedback can be estimated per day and m²:

<table>
<thead>
<tr>
<th>Input to the greenhouse:</th>
<th>Litres /m²d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wastewater</td>
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<tr>
<td>Saline water</td>
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</tr>
<tr>
<td><strong>Sum:</strong></td>
<td><strong>3,3</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Output to the city:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Recovered wastewater</td>
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<tr>
<td>Desalinated sea- or brackish water</td>
<td>1,0</td>
</tr>
<tr>
<td>Rainwater harvested from the roof</td>
<td>0,2</td>
</tr>
<tr>
<td><strong>Sum</strong></td>
<td><strong>2,7</strong></td>
</tr>
</tbody>
</table>

**Tab. A.1. Wastewater/Freshwater balance for Agadir**

In total, the city gets 0,4 litres (17%) more in return. This can partially compensate water losses from leakages in the supply system and from evaporation (e.g. garden irrigation).

For the consumers that are not connected to the grid, decentralised greenhouse structures are proposed. The required water from these areas shall not be fed out of this balance.
A 1.2. Scenario Agadir

Main industries in Agadir are Horticulture/Agriculture, Fishery and Tourism. Horticulture is directly related to available water and good profits with export of agricultural goods are already leading to a strong over exploitation of fossil water resources.

During the last 20 years, the intensification of irrigated agriculture in Southern Morocco (Souss Massa Valley) has led to an annual water deficit of 240 Mm³/year drawn from the aquifer. In this region we are approaching full utilization of the surface water resources and the availability of good quality water supplies for agriculture is diminishing. Therefore, farmers are likely to be forced to use marginal quality water, either brackish water or treated sewage effluent.

Also fishery is known as an endangered industry due to over exploitation of global resources. A change to fish farming again will require availability of water and related feeding stuff, again coming from agriculture. Tourism as well is finally dependent to a sound and functioning environment and a sufficient supply infrastructure. It can be stated, that the complete economic base of the area is very much related to availability of fresh water.

A 1.2.1. Situation of water supply and wastewater treatment in Agadir Region

Several countries within the Mediterranean Basin and other arid and semi-arid regions are facing continuous processes of enlarging gaps between supply and demand for water. These gaps are closely linked with agricultural production, "green" water demands and environmental issues. It is probably due to reduced amounts of precipitation and low availability of natural water sources.

Morocco does present the same trend, and despite the influence of the Atlantic Ocean, and the Mediterranean Sea which provides it locally with relatively moderate water resources. During the last decade, Morocco, like most the other North African countries, have known the succession of many years of drought. The severe drought currently hitting Morocco will make the country lose 52.5 million working days; the drought will also cause a $ 900 million loss in agriculture value". Official figures show that Morocco's 60 water reservoirs are less than half full at some 5.3 billion cubic meters, of which 3.15 billion will be devoted to irrigating more than half a million hectares

Water Supply in Morocco: Out of 150 billion m³ annual rainfall, only 29 billion m³ are estimated to be renewable of which 22 billion m³ enter the streams/rivers and 8 billion m³ feed the aquifers (Ait Kadi, 1996). The annual regulated volumes are approximately 11.5 billion m³, 3.5 billion of which come from groundwater. Agriculture uses 93% to irrigate 1.2 x 10⁶ ha, including 0.85 x 10⁶ ha which are irrigated more or less permanently throughout the year. Gravity irrigation predominates with 80% of surfaces irrigated particularly on small farms. On the large farms and in irrigation schemes supplied with groundwater, more modern techniques have been used: sprinklers, mobile ramps, center pivots and drip irrigation. The water is sold to the farmers at a price between 0.04 and 0.06 Euros per m³.

As a semi-arid country, Morocco’s water resources are limited. The variability in rainfall and repeated droughts in recent years are having a severe impact on the water supply and pollution
in many regions in Morocco. Important economic areas such as the Agadir region in Southern Morocco are already experiencing water shortages. In addition, the high degree of urban expansion has increased the production of domestic wastewater that if not treated will threaten population health and the environment in major cities. Minimizing the impact of wastewater on water quality is a major challenge in Morocco. Key to meeting this challenge is the use of unconventional water sources such as the reuse of treated wastewater in agriculture. One of Morocco’s environmental priorities, as articulated in its National Strategy for Environmental Protection and Sustainable Development, is to have 40 percent of urban wastewater treated by 2020. This goal can provide significant opportunities for the reuse of treated wastewater.

Morocco Wastewater: Most Moroccan towns are equipped with sewerage networks. The actual volumes of wastewater collected are estimated at 600x10⁶ m³ per year. It is expected that they will reach 900x10⁶ m³ in the year 2020 (CSEC, 1994). For Casablanca alone, the annual production of wastewater is estimated at 350x10⁶ m³ in 2010. Out of the 60 largest towns only 7 have a treatment plant, but both their design and operation are considered insufficient. Most of the technologies used for treating wastewater are not adapted to the local soci-economical conditions; therefore 60% of the stations of purification using activated sludge are not functional, due to the very high costs of electricity, the lack of maintenance of the apparatuses of ventilation and low coordination between the various stakeholders involved in the management of these stations (Table 1). This is one of the reasons heading us to introduce more conventional and innovative systems of treatment adapted to the local social and economic situation and environmentally sustainable.

Most of the wastewater produced by the inland towns is reused. The annual volume of reused water is approximately 60 x 10⁶ m³. Therefore at least 16% of collected wastewater is reused. A very substantial proportion of the water which is not reused is discharged into the sea. The irrigated areas are estimated at about 8000 ha.

<table>
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<td>60</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>33.3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>75</strong></td>
<td><strong>38</strong></td>
<td><strong>33</strong></td>
<td><strong>7</strong></td>
<td><strong>50.6</strong></td>
</tr>
</tbody>
</table>

Table A.2. Situation of the treatment plants:
If the total volume of wastewater reused annually is indeed $60 \times 10^6 \text{ m}^3$, this resource would represent no more than 5/100 of all water used in agriculture. This probably underestimates wastewater use but it does give some idea of the order of magnitude. Wastewater reuse is not a major issue in management of water resources on a national scale at the moment. However, the authorities think that, in the long run, the situation may be different. In the coming years, one should see a rapid increase in drinking water consumption in towns because the urban population is growing by 500,000 inhabitants per year. The corresponding water requirements will necessitate the transfer of resources from one catchment’s area to another and replacement of fresh water with wastewater for irrigation. The volume of wastewater available for reuse will increase with the improvement of sewerage networks. Under these conditions the share of wastewater in the overall water resource could be several percentage points higher within a few decades, especially if the wastewater of coastal towns is also reclaimed (the figure of 10% sometimes mentioned does seem excessive). Even though wastewater only represents a small share of water resources on a national scale, it can help solve local problems. This is particularly the case for towns located in arid areas that are not sufficiently linked to the major supply systems. This is also proven by the high rate of spontaneous wastewater reuse in inland towns.

The reused water is mainly raw wastewater possibly mixed with water from the rivers into which they spill. The irrigated crops are mainly fodder crops (4 harvests of corn per year at Marrakech), fruit trees, and cereals. Morocco does have specific regulations with regard to wastewater reuse which comply with WHO recommendations.

Agricultural wastewater reuse is a component of water resources development and management that provides innovative and alternative options for agriculture. Reuse of reclaimed water for irrigation enhances agricultural productivity: it provides water and nutrients, and improves crop yields. However, it requires public health protection, appropriate wastewater treatment technology, treatment reliability, water management and public acceptance and participation. It must also be economically and financially viable.

**The Water Situation in Agadir Region:** The region of great Agadir (Souss-Massa) cover a surface area of 28 000 Km², and a population of 2.3 Millions inhabitants (54% rural, 46% urban); the region mobilize around 1 Billion meter cube of surface and ground water, inducing a water deficit of 290 Million m³. This negative balance between water supply and demand is covered by a ground water mining, and a lowering of the peizometric level with an average of 2 to 3 meters per years. Most of available natural water is consumed for agricultural purposes (95%) and the other 5% is consumed by the industry and potable water.

On the other hand, the hydraulic assessments prepared within the framework of the planning studies, carried out at the level of the entire hydrologic basin, have proved that this basin is showing a shortfall. In addition, the quality of the Water resources has undergone a considerable degradation during the last decades due to the different sources of pollution (domestic, industrial, agricultural wastewaters etc.)

On the basis of the climatic and geographic context, the resort to non-conventional waters, namely treated wastewaters, constitutes an alternative, especially in the zones suffering from droughts. The treated wastewaters are said to constitute a regional development factor through extending irrigated areas, exploiting arid lands, improving public health, controlling environment pollution and managing the quality of water resources at the level of hydrographic basin.
The gap between water supply and demand is expected to increase next decades due to population increase and per capita consumption and irrigated agriculture extension along with decline in water availability. Water availability is decreasing due to over pumping from groundwater along with significant decline in natural aquifer recharge due to low rainfalls and intense urbanization processes. Water gaps are due to a series of factors that include inefficient agricultural consumption (only 42% of the surface area use drip irrigation), urban and industrial development and low rainfalls. This shortage of water did lead to the loss of over 4000 hectares of citrus orchards.

Groundwater exploitation in the region has increased dramatically during the last decades due mainly to an increase in irrigated agriculture, tourism and industry. Thus, many groundwater resources are at risk of being exhausted through over-pumping. With withdrawal exceeding the internally renewable water resources, the resulting groundwater scarcity is rapidly becoming a major concern in certain coastal part of the region, as salt intrusion is threatening the deterioration of the ground water. The pressures on natural groundwater resources are higher in the summer period, when natural supply is minimal, while water demands are maximum (irrigation, tourism).

The typical arid conditions of the region are reflected in limited availability of water. Efforts are continuously in progress to solve the chronic water shortage in this region. Water supply is mainly based on two major sources that include the ground water aquifer and the surface water Current major efforts to create more waters are based on intensive use of reclaimed wastewater and sea water desalination.

The water demands in the region of Agadir are increasing to reach over one billion meter cube by the year 2020, and most of available natural water (92.3%) is consumed for agricultural purposes (fig 2 below). Around 1,000 liters are commonly required to produce 1 to 5 kg of food, according to the different crops. However, due to limited availability of water this picture is gradually changing and agriculture will soon rely on marginal water sources, primarily domestic treated effluent. Actual human water consumption is in the range of 10 to 100 m3/caper year. Domestic and industrial consumption is continuously increasing (7.6%)
along with elevated life standards. Around 70% to 85% of the domestic water consumed is seweraged and most of it is treated.

<table>
<thead>
<tr>
<th>years</th>
<th>2005</th>
<th>2010</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume of treated wastewater (m3/an)</td>
<td>3 100 000</td>
<td>15 500 000</td>
<td>24 820 000</td>
</tr>
</tbody>
</table>

**Fig. A.3.** Provisioned volume of wastewater in Great Agadir

Most of the Treated wastewater in the region of the great Agadir is a domestic treated sewage and can be reused for a large pattern of possibilities, primarily for agricultural irrigation (Salgot et al., 2006). Treatment level as related to the purpose and location of reuse is of special concern. Up to specific levels the nutrients contained in the TMWW are however, beneficial for agricultural use (Enriquez et al., 2003). Current efforts of wastewater reclamation focus on pathogen removal.

Actually, four treatment plants are treating a total volume of 53 000 m3/j, using the sand infiltration and lagoon system technologies (Table 2), and almost zero volume is recycled due to lack of institutional framework to reuse this treated wastewater in Agriculture, in landscape and golf course irrigation.

There are social reserves related to the use the treated waste water, (which is often perceived as unclean). This is paradoxical when one considers the quantities of wastewater re-used in its raw state. Wastewater goes through a processing station where influx of raw wastewater is clearly visible. The origin of used water is thus known. There is therefore natural hesitation to consume fruit and vegetables irrigated with used water. In the region of Agadir, farmers whose products are exported to foreign markets are very reticent to use treated wastewater as a precaution to compromises their markets.

<table>
<thead>
<tr>
<th>UWWTP Station</th>
<th>Treatment system</th>
<th>Starting Year and Treatment Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>BENSERGAO</td>
<td>Anaerobic lagoon and Infiltration–percolation</td>
<td>November 1989, 750 m3/j</td>
</tr>
<tr>
<td>Drargua</td>
<td>Anaerobic lagoon and Infiltration–percolation with denitrification and Reed bed for tertiary treatment</td>
<td>October 2000, 1 200 m3/j</td>
</tr>
<tr>
<td>Biogra</td>
<td>Lagoons system and ground water recharge</td>
<td>July 2006 for 12000 m3/j.</td>
</tr>
</tbody>
</table>

(*) emissary of 700 ml rejects wastewater primary treated to the sea

**Table A.3.** Description of the Wastewater Treatment Plant of the great Agadir
The sequence of urban wastewater treatment includes several processes:
Step 1: Primary treatment (anaerobic basins)
Step 2: Secondary treatment (filters with sand)
Those steps are in the three plants.

Step 3: Tertiary treatment (only for Drarga). This step of treatment is followed by:
1. A drying-bed for the treatment of sewage sludge is connected to the anaerobic basin
2. A storage basin filled with a 1 meter layer of gravel for treating wastewater using reeds beds

Treatment efficiency:

The qualities of the treated wastewater comply with the norms of WHO regulation to be used without restriction in Agriculture irrigation. The treatment efficiency (see below) prove the reliability of these technologies and respond the socio-economical condition of this region.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Bensergao</th>
<th>Great Agadir</th>
<th>Limits CEE(1991)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DBO₅ (mg O₂/L)</td>
<td>98.40</td>
<td>99.40</td>
<td>79-90</td>
</tr>
<tr>
<td>COD (mg O₂/L)</td>
<td>95.75</td>
<td>97.29</td>
<td>75</td>
</tr>
<tr>
<td>MES (mg /L)</td>
<td>99.50</td>
<td>99.00</td>
<td>90</td>
</tr>
<tr>
<td>NTK( mg N/L)</td>
<td>92.04</td>
<td>94.81</td>
<td>70-80</td>
</tr>
<tr>
<td>Fecal Coliforme (germs/100ml)</td>
<td>99.9</td>
<td>99.9</td>
<td>-</td>
</tr>
<tr>
<td>(Eggs helminths) (number/L)</td>
<td>100</td>
<td>100</td>
<td>-</td>
</tr>
</tbody>
</table>

Tab. A.4. The potential of using this treated wastewater irrigating agricultural crops and the greening of the city has established in the demonstration pilot station of the ORMVA Souss-Massa. The results confirmed that these conventional systems:

Offers several advantages as a reliable wastewater treatment plant (lower construction and operating, no energy requirement, easy maintenance, higher quality recycling of water and nutrients for irrigation and aquifer recharge).
The sanitary quality of treated wastewater corresponds to category A of the WHO recommendations for irrigation of products for raw consumption (the results are given in the table above): less than 1 000 faecal Coliform, less than 3 mg/l of suspended matter and free of helminth eggs.

The concentrations of major fertilizing elements of treated wastewater reduce the input cost fertilizer for horticultural crops

For the open field and protect crops, the quantity and quality of yields obtained using treated wastewater irrigation and complementary fertilization are generally higher than those obtained with irrigation using drinking water and classic fertilization (explained by the availability of fertilizing elements in wastewater including micro-elements and humic-acids).
About parasitological and bacteriological quality of the products: no contamination detected. There was no significant difference between tomatoes and melon irrigated with the two water qualities as far as faecal Coliform.
A 1.2.2. Implementation in Agadir

Available wastewater from the city of Agadir relates to an annual quantity of about 18 Mm³/year and so is less than 10% of the annual water deficit of the region. Anyway, in this scenario it is shown, that the water requirements for closed greenhouse horticulture with real water losses of only 0,5 litres/m² compared to 4 litres in conventional greenhouses (factor 8 of efficiency) and open field agriculture with 9 litres (factor 22 of efficiency) shows an enormous perspective for the region, that could potentially allow to maintain the economic successful horticultural activities. Provided that a circulation between urban water and horticultural irrigation water can be realised, also a sufficient water supply for estimated urban growth in the area can generally be prospected for the future.

The recovery of water requires space. At the other hand, this space can be used for high intense horticultural production. The city of Agadir is enclosed by the sea in the west and by high mountains in the north. The greenhouse structure shall be relatively close to the source of the available wastewater. As indicated above, a total greenhouse surface of 22,5 km² totally covered with greenhouses can be built on the provided wastewater. Another 20% of this area would be needed for supply infrastructure, mainly road but also some plantings for landscape integration and wind protection, so a total needed surface of 27 km² will be needed.

For the greenhouse structures, three different areas are proposed as indicated in the scenario map:

![Fig. A.4. Agadir, Wastewater distribution scheme](image)
**Area 1**

**Use of existing greenhouse structures in the city perimeter:** Area 1 is part of the huge intensively used agricultural landscape in the south of Agadir, that covers the largest part of a total amount of almost 100 km² of protected cultivation in the region of Agadir. A triangle, built by the roads between Agadir, the city of Biourga and the village of Ti nel Mekki covers an area of 44 km². In this area, already about 25% of the surface is already under protected cultivation. Enlarging this surface and changing the technology of internal greenhouse climate control and water management during a period of greenhouse life cycle to closed greenhouse technology would only cause little change of the actual landscape and will contribute to a major part of the required greenhouse area of around 20 km² to use and process the main part of the Agadir waste water.

**Area 2**

**Open greenhouses with chimney on mountain slope area with emphasis of simple solar desalination:** The mountain slope area is already about to be built up with new urban quarters. Anyway, the strong slope of the mountain foots would allow to integrate open greenhouses with use of saline water for greenhouse cooling and desalination:

The structure can also be combined with urban elements on the mountain slope. Saline water can also contribute to building air conditioning.

The existing area of around 30 km² could be built up with greenhouse structures on 20% of the surface, leading to around 6 km², that could provide a part of the waste water recycling within the horticultural used part of the greenhouse as well as a major part of water supply by solar desalination, that can balance the total water losses of the entire system.

**Area 3**

The space between area 1 and 2 and around the international Airport shall be left as a natural reserve, protecting and revitalising the original Argan bush forests that are leading from

**Fig. A.5.** Slope greenhouse structure integrated in urbanised area
Financial incentives for the forest restauration should be given by the Moroccan and local Agadir gouvernment as well as by main actors of the surrounding, especially the Agadir Agadir center into the drylands in the south-east of the region. international airport.

**Area 4**

Area 4 is at the mountain slope directly on the sea near the harbour, where the fish industry is located. Waste water from the fish industry may not be integrated into the greenhouse concept due to high salt input into the waste water stream. The scenario recommends to dilute this fraction with seawater and to use in open aquaculture farms in order to recycle the organic compounds of the wastewater, while forwarding the pre-cleaned saline water into the desalination section of the slope greenhouses of area 3.

![Diagram](image)

**Fig. A.6.** Development in Agadir, Further development of urbanised area and related greenhouse areas in the neighbourhood. A further use of the organic residues could be achieved if disposing the water flow from the aquaculture into greenhouse integrated algae production ponds within the area of the slope greenhouse, where air is too hot and water is too salty for higher vegetation.
Fig. A.7. Agadir (1) and Biougra (7): Urban water cycles from wastewater treatment sites to greenhouse area and back to the city. Development of decentralised greywater cycles from the urban stripe on the sea (5) and from the valley to Taroudant (9) into the surrounding area.
Fig. A.8. Regional distribution of seawater as input for self-sustaining greenhouse horticulture
Area 5 and 6

Urban concept of decentralised concentration for Agadir metropolitan region: As a close framework of urban areas and greenhouse areas is needed for the entire concept, a further growth of Agadir around the centre would be very problematic, as fewer areas for wastewater treatment would be available in the direct neighbourhood, while the waste water stream would further grow.

Because of this, the scenario shall represent a development strategy for the whole region. As further growth of central Agadir is not possible, a concept for a decentralised concentration within three areas (area 5/6, 7/8 and 9/10) is recommended, that again will enable a close interaction between urbanised areas and the surrounding productive landscapes. For the villages around Agadir, that are today partially without any wastewater treatment and also for new settlements within or around these villages, a separation of the wastewater stream into grey water, faecal and urine is proposed like described in chapter xx, that will allow a use of the water for irrigation without pre-treatment and also will allow a controlled way of using the nutrients within the wastewater stream.

The area in the south of Agadir along the coastal main road now consists of a number of different smaller villages with relatively low density. From this structure, a densification of the area and moderate growth of the built surface allows a huge potential for urban growth up to a kind of coastal urban strip. (Area 5).

This area is especially interesting for future tourist activities, that could benefit from the near distance to the sea and the dune landscapes in the west of the coastal road that can be further developed as a natural reserve, including measures of forestation for dune protection.

On the eastern side of the road will be the related area for closed greenhouse crop production and water recycling (Area 6). This area belongs to the same huge surface of intensive agriculture and already built up greenhouse structures like described at area 2.

In this area, no wastewater can be provided from existing clearance fields. The growth perspective for greywater use from existing buildings is relatively small due to the lower population density of the villages. Anyway, needed water deficit could be equalised by closed greenhouse desalination functioning. The condensed water may not be sold but directly re-linked into the irrigation system, as long as there are no water consumers in the direct neighbourhood. The potential offer of high quality condensed water on the other hand could provide a growth impulse for the neighboured settlements and a possibility to introduce an urban water cycle.

The transition gap between the coastal strip and the greenhouse area could be a part of the urban design, integrating hybrid buildings providing views from living areas into the green vegetation spheres of the greenhouses on one side and the further developed dune landscape on the other side as a specific spatial quality.

Area 7 and 8

Biougra as area 7 is the largest village within the area of agricultural production in the south of Agadir. It also can be envisaged as a node within the traffic road network of the region. Due to its vicinity to Agadir, it can be developed towards a regional center of the agro business while still being a part of the Agadir suburban area.
Fig A.9. Watergy Greenhouse prototype 2 in Berlin. An example for the hybrid interface between urban and greenhouse production area.

Fig. A.10. Example for decentralised urban integration of water recycling greenhouses, providing water, food and energy for space cooling from the direct surrounding of buildings.

Biougra has built its own wastewater treatment plant during the year of 2007. This water can be used as an input for greenhouse irrigation. Urban growth beyond the capacity of this station should be developed with wastewater separation technologies, providing less problematic greywater for the irrigation use.

As described for region 2 and 5, also area 8 is part of the existing large greenhouse production area, that can provide the needed surface for water recycling of the growing sub-centre of Biougra.

**Area 9 and 10**

A group of villages in the valley leading to the city of Taroudant (area 9) can form the back line for a third regional centre around Agadir. The villages El Bid, Douar el Koudia, Oulad Teime and Ain el Beida are grouped around the main road of the valley. They form a centre in the western agricultural area of the region (area 10), mainly irrigated with water from the nearby reservoirs of the atlas and anti atlas.

At the moment, open field irrigation especially for cultivation of citrus trees is the main crop. The extreme high water need of this crop will lead to a growing conflict between growers that can afford the water prices and who are linked to the supply network, versus growers that rely
on traditional water supply and much more water efficient cultivars like the argan tree, olives, cactus etc.

To diminish the conflict, further growth in cash crop sector should be limited to the water efficient closed greenhouse sector, that would also allow to continue production if groundwater stocks become more salty, due to the possibility of diluting salty input water with condensed water. Even if nowadays, there are only a few greenhouses in this area, the agricultural character of this spot can again provide the space for the needed water recycling structure for this sub-center.

On the other hand, the open field crops with low water consumption shall be further promoted and developed on the base of charcoal soil improvement and conventional techniques of rainwater harvesting, based on the modification of the micro relief in the landscape (e.g. argan trees planted on slight sinks in the landscape, that lead potential rainwater towards the tree, where a pack of improved soil can store sufficient water up to the state of a more developed tree that can explore deeper zones of the soil.
A 1.3. Scenario Gabès

A 1.3.1. Situation of Gabès

Gabès in Tunisia, with 350,000 inhabitants, has important industrial installations and some touristic activities. Gabès has serious problems with fresh water supply and an extreme high competition between agriculture, industry and households. Therefore, an expensive desalination unit has already been installed, functioning by reverse osmosis. The CYCLER-SUPPORT project can offer interesting economical alternatives for the water management of the city.

Fig.: A.11. Localisation of Gabès

On the other hand Gabes has very important non conventional water resources. In fact, this city is close to the sea (80 km of littoral), having an important brackish underground water springs and three wastewater purification stations. After the industry (chemical especially), agriculture is the most important activity in the city with an useful agricultural surface of 597 000 ha.

In the scenario, the city with its surrounding green spaces and oasis has not been changed. Furthermore, a system of water supply is proposed from the existing waste water treatment fields to areas in the dry, mostly unused surrounding of the city.

Gabes is located on the sea. Seawater and available sub-ground brackish water sources. Saline water distribution and desalination within greenhouse structures can be proposed as a second major source of water.

The area of Gabès has a rate of urbanization of 69%. The rate of connection to the network of purification is 81,1% of the urban population, being distributed on 8 communes on the totality
Governorate Population: 350800
Urban Population: 239700
Population in ONAS action zone: 228065
Number of inhabitants connected to ONAS sewarage: 189980
Connection rate: 83.3%
Network length: 531 km
Number of installations: 3 wastewater treatment plants, 26 pumping stations
Water volume collected per year: 8.2 million m³
Water volume treated per year: 5.8 million m³

Tab A.5. General data on water treatment in the city of Gabes and connection to ONAS
The network of purification of the ONAS is made of 531 km of drain connecting the 26 pumping stations and the 3 stations of purification. These three principal stations are that of Gabes, El Hamma and El Metouia. The general data concerning the three stations are represented in the table 6.

of the 10 (Gabes, Ghanouche, Chenini-Nahal, Ouedhref, Metouia, El Hamma, Mareth, Zarat). The general data are recapitulated in the table above.

Use of Treated Wastewater in Tunisia (ICARDA Contribution)

Water resources are limited in Tunisia, with per-capita available water resources of 450 m³/year only. Most (80%) of available water resources are used in agriculture, with only 13% for domestic use and 7% for industry. Therefore, the country since the early 1960s considered the possibility of using nonconventional water resources, including wastewater, to increase water availability for agricultural production. This need has become more urgent with the increased drought due to climate change, and the recent global hike in price of food commodities.

Water collection and distribution is assured by SONEDE (National Public Water Supply Utility) while ONAS (National Sewerage Board) assures wastewater management throughout the country. Farmers and other users are encouraged to use treated wastewater for irrigation to complement the limited natural water resources. Treated wastewater is also used to recharge the depleting underground water resources.

Legislation: A series of legislation acts have been issued by Tunisian authorities to define the conditions of wastewater utilization.

The 1975 water code (law no. 75-16) prohibits the use on non-treated wastewater and the use of treated wastewater for crops eaten raw. In July 1989, Decree no 89-1047 has been issued that binds the use of treated waste water for irrigation to a prior authorization from the Ministry of Agriculture, in agreement with both the Ministry of Health and the National Agency for Environment Protection. It also requires a proper treatment, and a defined set of
procedures for physical, chemical and biological analyses of the treated wastewater intended for irrigation.

Decrees issued in July 1985 and December 1993 define the conditions of use and reuse of treated wastewater for agricultural purposes, and the norms of disposal and reuse of treated wastewater.

Norms for use of treated wastewater have been developed in 1989, based on recommendations of FAO and WHO.

In 1991, decree no. 91-362 has been issued by the National Agency for Environment Protection, of the Ministry of Environment and Sustainable Development, to impose an impact study before treated wastewater can be used for irrigation.

A list of crops that can be irrigated with treated wastewater has been issued in 1994 by the Ministry of Agriculture, which includes: forage species, cereal crops, fruit trees, fodder shrubs, floral crops, and industrial crops.

In 2002, ONAS developed the Tunisian national strategy for using treated wastewater for irrigation. The strategy calls for a complementary treatment for a less restrictive use of treated wastewater. It also widens the spectrum of usage of treated wastewater to cover: green areas, hotel gardens, industrial uses, ground water recharge, ecological reuse, and inter-regional transfer. The same strategy suggests a better coordination among all stakeholders. It calls for capacity building to improve water resources management, promoting treated wastewater reuse among populations, improve the treatment of wastewater according to the usage of this water, and establishing a follow-up and monitoring system for aquifer recharge and strengthening sanitary control and hygiene measures.

Any violation of the water code in Tunisia is subject to penalties: illegally irrigated crops with treated wastewater are destroyed on the spot, by order of the regional authorities. Each region has a wastewater supervision and monitoring committee since 1995.

**Achievements:** Promotion of the sound use of treated wastewater resources in Tunisia resulted in the following achievements by year 2006:

- Irrigation at 24 sites, with a total area of 8,100 ha
- Irrigation of 9 golf courses, covering 910 ha
- Irrigation of (non-agricultural) green areas, covering 400 ha
- Recharge of underground water resources
- Ecological valorization (establishment and maintenance of wet areas)

Such use is expected to expand; for example, irrigation of agricultural lands is expected to reach 15,000 ha by year 2011.

The major crops so far irrigated with treated wastewater are cereals, forages and trees. Irrigation is predominantly basin irrigation, and to a lesser extent, sprinkler irrigation.

Different institutions are involved in assuring follow-up and monitoring of treated wastewater quality, that include ONAS (215,000 analyses conducted in 2006), Ministry of Health for health control, ANPE (National Agency for Environment Control) for environment control, and regional agricultural services (CRDAs) for irrigation.
However, the use of treated wastewater is still hindered by several factors, including: (a) limited agricultural areas available for irrigation near water treatment sites, (b) restriction of irrigation to a small number of crops, excluding such cash crops as vegetables, (c) seasonal demand for treated wastewater and absence of storage facilities, (d) low water quality, especially because of industrial waste, and (e) inadequate maintenance of water treatment facilities.

**Wastewater situation in Gabes**

*Treatment station of Gabes:* The purification station of Gabes treats each month a wastewater volume of 262,600 m$^3$ with an output of 93%. The percentage of treated water reused from this station is about 2% (4073m$^3$/month). The major part of this water is rejected into Chot El Jerid, which presents a significant possible source of fresh water for the irrigation and more precisely in greenhouse horticulture.

<table>
<thead>
<tr>
<th>Station of epuration</th>
<th>Site</th>
<th>Date of Commissionning</th>
<th>Treatment capacity (m$^3$/day)</th>
<th>Related supplyable greenhouse surface (net/total)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gabes</td>
<td>Gabes</td>
<td>1995</td>
<td>17300</td>
<td>can feed about 7,5 km$^2$ (9) of greenhouses</td>
</tr>
<tr>
<td>El Hamma</td>
<td>El Hamma</td>
<td>2004</td>
<td>4061</td>
<td>can feed about 1,7 km$^2$ (2) of greenhouses</td>
</tr>
<tr>
<td>Metouia-Ouedhhref</td>
<td>Metouia</td>
<td>2006</td>
<td>2700</td>
<td>can feed about 1,1 km$^2$ (1,3) of greenhouses</td>
</tr>
</tbody>
</table>

**Tab A.6.** General data concerning the treatment stations in the region of Gabes (2006) [2]

The water treated in the station of Gabes results from three principal sources, namely domestic water origin (92.4%), industrial origin (7.4%) and tourist origin (0.2%). The table 7 shows the various physicochemical characteristics of this water:

<table>
<thead>
<tr>
<th></th>
<th>max</th>
<th>min</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCO$^1$ (mg/l d’O$_2$)</td>
<td>580</td>
<td>80</td>
</tr>
<tr>
<td>DBO$^2$ (mg/l d’O$_2$)</td>
<td>373</td>
<td>30</td>
</tr>
<tr>
<td>Charge (DBO$_5$/J)</td>
<td>3245</td>
<td>244</td>
</tr>
<tr>
<td>MES$^3$</td>
<td>282</td>
<td>27</td>
</tr>
</tbody>
</table>

**Tab A.7.** Physicochemical characteristics of the treated water in Gabes Station
**EL Hamma treatment station:** The station of El Hamma has a monthly volume of wastewater treated of 140,370 m$^3$ with an output of 90%. The quantity of reused water, approximately 4% of the treated water, is used in the irrigation in arboriculture or in fodder plants. The remainder (96%) is, as in the case of the station of Gabes, rejected into Chot el Jerid. The wastewater in the station of El Hamma becomes also from the three principal sectors: domestic sector with 94%, the industrial sector with 5% and finally the tourist sector with 1%. The table 8 shows the various physicochemical characteristics of this water:

<table>
<thead>
<tr>
<th></th>
<th>max</th>
<th>min</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCO (mg/l d’O2)</td>
<td>475</td>
<td>58</td>
</tr>
<tr>
<td>DBO$_5$ (mg/l d’O2)</td>
<td>382</td>
<td>26</td>
</tr>
<tr>
<td>Charge (DBO$_5$/J)</td>
<td>1761</td>
<td>1023</td>
</tr>
<tr>
<td>MES</td>
<td>191</td>
<td>27</td>
</tr>
</tbody>
</table>

**Tab A.8:** Physicochemical characteristics of the treated water in El Hamma Station

**EL Metouia Station:**

The data concerning EL Metouia Station are not yet available

The different water treatment station’s locations are represented in the figure 5
A 1.3.2. Localisation of new greenhouse structures for waste water treatment

The recovery of water by using greenhouses requires a lot of space. Anyway, this space can be used for high intense horticultural production.

As the greenhouse structure shall be relatively near by the source of the available wastewater, different areas are proposed according to the location of the treatment stations. Following table xx, a total greenhouse surface of 10 km² totally covered with greenhouses is needed. Another 20% of this area would be needed for supply infrastructure, mainly road but also some plantings for landscape integration and wind protection, so a total needed surface of 12 m² will be needed.

For the greenhouse structures, three different areas (area 1-3) are proposed as indicated in the scenario map:

Area 1

The huge area almost all over the western perimeter of the city, with about 20 km² is urbanised with very low density. The area is mostly unused, the landscape is dominated by traffic infrastructure and different industrial installations.

The implementation of greenhouses into this structure is well possible. A use of 20% of the surface would lead to 4 km² of greenhouses, that could use the waste water from the central Gabes station. In the northern, more narrow part of this area, also the water from the station of Metouia-Ouedhhref could be used.

Before installing any greenhouses, an assessment of the soils has to be undertaken, in order to judge potential soil pollution from previous or neighboured industrial users. In the case of polluted grounds, greenhouse horticulture with non-food application should be installed, that on the long term can also decontaminate the soils with improvement of the soil life (Use of charcoal soil improver for soil life activation and related decomposition of organic compounds, uptake of pollutants by the biomass).

Area 2

The western hinterland of the city is characterised by slightly sloped mountains, where no greenhouse structure could be built on. In the distance of 4 and 9 km respectively, there are two valleys, that are sufficiently flat to allow the implementation of greenhouse structures. The first valley with an area of about 3 km² is only little used while the second part is one of the few areas of agricultural activity. Anyway, there is a huge surface of about 6 km² still unused, probably because of the lack of available freshwater. With a coverage in these areas of about 40%, a sufficient area for the use and recovery of the remaining Gabes wastewater would be available.
Fig. A.12. Gabes and El Hamma and the area of the Chot el Djerid
Area 3

The city of El Hamma is located 20 km west of Gabes. It is located directly on the southern border of the Chot El Jerid. An agricultural used area in the south of the city has a size of about 20 km². Needed greenhouse surfaces of 1 km² can easily be integrated into this area. Another arid, unused space is located in the north and north west of El Hamma. This surface would also fit to the needs of the greenhouse systems. Salinity and stability of the ground nearby the salt plain/lake still have to be further investigated.

Area 4 and 5

Area 4 and 5 are forming a relatively flat area in the triangle between the northern edge of Gabes (Metouia-Ouedhref), the city El Hamma and the southern border of Chot El Jerid. Due to the close neighbourhood to the Chot, this area is probably highly affected by saline soils. As for the wastewater greenhouses, soilless culture is proposed with plants growing within water submerged gravel beds, the original character of the soil is less important. Anyway, stability of the soils have to be further investigated.

Finally, there is a huge space of unused and mostly flat dry land (more than 100 km²) for a further step of the scenario:

A seawater channel from Gabes to El Hamma as a large regional infrastructure and demonstration project.

Gabes is located on the sea. The coast is on the east side of the city. In the north west, the Chot El Jerid, a huge salt lake/salt plane is the main characterising landscape element of the surrounding. It is reaching far into the desert of Southern Tunisia up to the Algerian Border.

The average height of this area is only about 20-25 m above sea level. A former connection between the Chot El Jerid and the sea is now separated by a bank of about 45 m above sea level at its highest point, building a water shed, leading rainwater either eastwards to the sea or westwards into the Chot basin.

From the north, the area could be easily fed with seawater for desalination purposes. The construction of a channel between the north of Gabes and El Hamma could be built at a level of about 40 m altitude starting at Metouia, a northern suburb of Gabes, located about 5 km from the sea. The water has to be pumped to this level of altitude, but from here, it can be transported without any more pumping on an equal level to El Hamma, to the already existing greenhouse areas in the west of El Hamma and principally further on over 300 km into the dry land of Southern Tunisia, having a further sink below sea level neighboured at the Algerian border. This makes the concept extremely interesting as it could be the basic concept for a huge development strategy.

To pump one cubic meter of water to the height of 40 m, an energy of less than 1 kWh is
needed, while this amount of water can provide a cooling effect of more than 660 kWh (Evaporative enthalpy of water).

A project of seawater fed greenhouses in the regional area between Gabes and El Hamma can be organised of as a huge principal demonstration project for seawater distribution and use around the Chot and other huge depression areas in Northern Africa, where water distribution can be organised without or with very few energy demand. Some of the depressions in Northern Africa are below sea level, so that even energy can be explored.

The perimeter of the Chot El Jerid is almost as long as the Mediterranean coast of Tunisia and water can be distributed from the area without being blocked by topography. The channel can also be used for transport purposes to link all the cities around the Shott and the Algerian areas south of the Atlas mountains to the coast.

In this part of the scenario, the desalinated water from greenhouse projects will be the triggering function, that will subsequently allow further urban growth as it generates urban water supply and also labour. In the long term, dry land agriculture around the channel can be replaced by intensive protected cultivation on a very large scale with seawater as the main water source for desalination and subsequent irrigation but also for evaporative cooling of the greenhouses.
A 2 Policy and research recommendations

Introduction
As the WATERGY and CYCLER-Support project have shown, closed greenhouse systems can provide a wide range of benefits for the operators but also for the society. By enabling the efficient production of economic valuable products under conditions of scarce fresh water resources by reusing unconventional water sources (esp. municipal wastewater) in a safe way it contributes to develop a stable local economy and ensure an overall sustainable local development. The innovative, multifunctional character of the new proposed systems as a productive unit for food/non-food crops and clean water on the one hand, and a treatment system for wastewater and saline water on the other, requires support on policy and administrative level to speed up the implementation of these technologies.

Additional research activities will be required to further optimise the overall performance of the system according to the specific local requirements (climate, quality of unconventional water sources, crop production etc) and to develop new technical standards which ensure e.g. a safe but efficient reuse of wastewater in new generation greenhouse systems.

In the following, recommendations for policy actions and future research activities will be provided to support implementation of new greenhouse systems as proposed in the CYCLER-Support project.

A 2.1. Policy recommendations
Policy recommendations comprise support actions on legislative and institutional level which shall enable a smooth implementation of the proposed greenhouse systems.

A 2.1.1. Starting up programmes to support implementation of the ECOSAN approach (incl. wastewater separation and safe reuse)

Ecological sanitation (ecosan) is a new paradigm in sanitation that recognises human excreta and water from households not as waste but as resources that can be recovered, treated where necessary and safely used again (GTZ, 2008). The concept behind ECOSAN is that sanitation problems could be solved more sustainably and efficiently if the resources contained in excreta and wastewater were recovered and used rather than discharged into the water bodies and the surrounding environment. Ideally, ecological sanitation systems enable a complete recovery of nutrients in household wastewater and their reuse in agriculture. In this way, they help preserve soil fertility and safeguard long-term food security, whilst minimising the consumption and pollution of water resources. On the other hand it lowers farmers’ dependency on increasingly costly mineral and chemical fertilisers.

Wastewater separation bases on the introduction of specific toilet and collection systems which enable the separate collection of greywater (from kitchens, bathrooms etc) and human excreta (urine, faeces). Furthermore, implementation of this approach will reduce the demand for scarce fresh water sources for flushing water by using water saving technologies or recycling of low polluted greywater.

The separated wastewater streams (greywater, urine, faeces) require less treatment efforts than mixed wastewater due to the biggest part of the wastewater fraction is low polluted greywater. Urine and faeces contain high amounts of pathogens but also valuable plant nutrients which under normal, mixed conditions would require an energy-intensive, costly treatment of the
whole wastewater stream. Due to separation, treatment of the remaining greywater remains low and after specific stabilisation, processes for urine and faeces to remove pathogens, these human residues can be used as valuable liquid N and P fertiliser (urine) and compost (faeces).

Especially in areas where no or insufficiently working wastewater treatment plants exist or access to such facilities is difficult and costly to manage, decentralised on-site treatment solutions based on wastewater separation can enable a proper treatment of the full wastewater streams without enormous investments in new sewer systems or treatment plants.

Specific required policy measures:

- Awareness raising among authorities and population on the potential of wastewater separation and safe reuse (to reduce potential cultural reluctances)
- Capacity building for skilled engineers and workers
- Revising existing legislation or programmes in case it hinders implementation of wastewater separation (e.g. compulsory access to centralised sewerage) and reuse (incl. prohibition of any use prior and after conventional wastewater treatment)
- Implementing existing international standards on safe wastewater reuse into national regulations
- Allowing private services to enter the new market for decentralised wastewater management incl. recycling into valuable fertilisers and purchase to farmers etc.
- Integration of the separation approach in development plans/programmes for new urban and peri-urban settlements

A 2.1.2. Implementation of existing standards on wastewater reuse and supporting development of adapted standards for new generation greenhouse systems

- Prior policy recommendations on wastewater reuse in greenhouses, the development of specific adapted standards compared to open field agriculture are recommended. Wastewater reuse in new generation open and closed greenhouse systems requires own “best practice” recommendations as the existing wastewater reuse guidelines concentrate on classic open-field agriculture (incl. risks for groundwater contamination, soil salinisation/acidification etc).
- For heavy metals it is of course recommended that only such wastewaters should be reused in the context of food production, which do not contain (valuated) high levels of organic and inorganic pollutants and this requires a certain quality control at the extraction point (wastewater source).
- Concerning the discussion on micro-pollutants, wastewater use in irrigation should be related to values remaining in the crop and not related to values of the treatment station runoff or of final irrigation water qualities, as those values do not consider the cleaning effect within the irrigation system (gravel filtration within in hydroponic system, cleaning capacity of the soil etc.) and also does not consider the behaviour of specific crops in uptaking of the polluting particles. Micro pollutants should not be used as a knock-out argument of reuse of treated wastewater.
- There should not be a general prohibition of reusing wastewater in agriculture and horticulture and also no general quantitative limitations concerning the content of nutrients, as those would not consider the different wastewater qualities, pre-treatment...
methods, cleaning effects within the irrigation systems and neither different quantities of water evaporation in open field, greenhouse or closed greenhouse, which can be at levels of up to 95 % less.

- Limitations regarding nutrient content for avoidance of groundwater pollution that are existing for open field agriculture should not be valid for hydroponic systems or other irrigation systems with substrates sealed to the underground

- There shall not be any maximum values of nitrogen per mg/l water being used in irrigation, as the evaporation in closed greenhouses is much lower than in conventional greenhouses or open field irrigation, and so a much higher content can be acceptable.

- Irrigation systems (food / non-food specific) in combination with filters like gravel filters or micro-filtration and irrigation systems should be officially accepted as a treatment method for greywater. This will be especially important to establish technologies of wastewater separation and decentralised treatment of greywater.

- Relevant methodologies have to be “transparent” rather than black boxes so there is a need to know what water quality comes in and what gets out and, especially for food crop systems, where are the compounds that remained in the box. The exact balancing of input and output and proper monitoring is the ultimate requirement for all “wastewater treatment methodologies”. As open-field irrigation as an “open” system cannot achieve this (groundwater leaching, ET) the “closed”-character of the proposed greenhouse systems can be established as a new level of controllable system.

- According to the wastewater directives of different countries, the soil-plant complex (incl. microbes) and related irrigation and fertilisation control systems shall be accepted as methods for tertiary treatment of pre-treated wastewater, especially for the removal (and use!) of the main plant nutrients being phosphorus, potassium and nitrogen. This needs proper institutional measures to ensure safe application of the pre-treated wastewater and avoid illegal reuse.

A 2.1.3. Recommendation for regional action plans, enabling wastewater reuse

Capacity building for institutions

- Policy: Main polluters may be taken out of the general wastewater network to minimise content of organic and inorganic pollutants. This should include e.g. hospitals, specific industries (in Agadir, mainly the fish industry) and even tourism (tourist using much more pharmaceuticals than local people. In arid regions, it is possible to convert pollutants out of these relatively small quantities of water by totally evaporating the water in green spaces or agro forestry areas, so it is possible to remove pollutants from liquid to dry biomass, which is much easier to handle.

- Policy: Incentives shall be given for the installation of domestic wastewater separation systems.

- Policy: Local micro-markets for collection of separated wastewater and urine shall be established in order to organise the nutrient reuse in neighboured horticulture. Such a concept could even include the re-distribution of the condensed water from greenhouses as a more or less non-monetary exchange. (“Plant nutrients for fresh water”). For greywater, transport channels can be established to minimise transport costs.

- Policy: Local micro-companies, who collect, dry, transport and sell solid waste biomass (faecal and household waste) to central pyrolysis processing units.
- **Policy:** Subventions on specific end user products like urine/faecal tanks and retrofit kits for existing toilets could push such a development.

- **Policy:** For areas, where wastewater separation and reuse seems practical, new pricing systems for urban freshwater shall include a progressive component based on the domestic water demand without flush toilets, as a market incentive for the separation.

- **Policy:** For more problematic users (e.g. hotels, hospitals), combined urine/faecal tanks can keep problematic substances out of the water cycle and transfer into the solid waste cycle.

### A 2.1.4. Greenhouse horticulture

- **Policy/Market:** A label for sustainable agricultural production should not only consider a low use of pesticides or chemical fertilizers, but shall include the sustainable use of water and fertilizer resources.

- **Policy:** Closed greenhouses shall officially confirmed as carbon sink in the international carbon trade system. In this way, CO2, sequestrated from power plants could be used as a plant nutrient, that would be freely available for farmers.

- **Policy:** Cooling water recovery (including water surplus concepts) of concentrated solar power units and methods for using the waste thermal energy for solar desalination processes within greenhouses should be supported by specific CSP directives and should be included in related subventions.

- **Policy/Planning:** Coastal saline water supply networks can be developed as a part of regional infrastructure planning.

### A 2.1.5. Urban master plan / landscape plan

- **Localisation and allocation of areas for urban and peri-urban horticulture**

- **Localisation and allocation of areas for urban and peri-urban areas (incl. brownfields and contaminated areas) for non-food biomass production. Setting a package of measures for reactivation including use of wastewater, fast growing biomass, greenhouse systems.**

- Organisation for the multiple use and access of these areas, to combine urban horticulture and recreation use of limited urban space.

- **Consideration of areas of sufficient size and sufficiently close to the neighbourhoods for future urban development, which allows the integration of water and matter circuits. Planning of decentralisation or decentralised concentration of future urban growth.**

- **Consideration of on-site and off-site collection and treatment systems for decentralised solutions**

- Creating design criteria for urban greenhouse systems design to achieve a better urban integration and acceptance by population and e.g. tourists. Integration in public building regulation and design code

- **Consideration of saline water grids connected to desalination units and to sub-grids providing water for evaporative cooling functions in greenhouses as well as in buildings.**
Transparency actions in water and matter circuits as population might be more careful with water pollution if they know it will be used locally for irrigation and food production.

- Establishment of research network on wastewater reuse in greenhouse systems
A 2.2. Outline for ten research programmes as first steps of implementation

Further more, it shall consist of different model projects, especially integrated research and development projects, that allows to improve and adjust a long term scenarios towards detailed decisions and measures. The short term scenario is relatively detailed and should be further discussed but then realised as soon as possible.

For the near term measures, a number of 10 model projects are proposed:

- Closed greenhouse for food crops
- Closed greenhouse for non-food crops including greenhouse integrated solid state fermentation.
- Open greenhouse with natural convection, built on mountain slopes, using saline water from the sea for evaporative cooling. Integrated aqua farming for fish and algae production using waste water and solid waste from fish processing
- Model urban area for wastewater pre-selection in urban areas with use of greywater in greenhouse projects
- Wastewater post treatment systems adapted to reuse of water and solved plant nutrients in horticultural production
- Sea- and brackish water pre- and post treatment systems adapted to use in horticultural production
- Pyrolysis model project for treatment of urban waste, sludge and agricultural waste with charcoal as a main output product to be used as a soil enhancer
- Rain fed cultivation based in arid areas based on charcoal soil supply and surface rainwater harvesting
- Concentrated Solar Power project with cooling water recycling in closed greenhouses
- Novel material research

1st model project: Closed greenhouse for food crops

As greenhouse horticulture is the main economic branch of the Agadir region and by far the most serious water consumer, the further development of a much more water economic production method is the most important measure to start a sustainable economy.

The following topics have to be further developed:

**Thermodynamic system of closed greenhouses**

- Development of cheaper heat exchangers. Especially direct contact air to water heat exchanger. Packing materials from plastic (based on cooling tower technologies) and low tech wooden fabrics.

- Testing of heat exchanger made of standard PVC tubes and welded L/T connectors. (Could be an alternative, as labour costs are low

- Placement of heat exchanger ducts minimising shading effect. (Placement out of the greenhouse, Movable ducts, tracked against the sun)

- Use of cheaper cooling water ponds
- Use of soil as heat storage, plastic tubes as heat exchangers in the soil

- Using soil enhancers (see model project 6, pyrolysis) to increase water capacity of soil and by this increasing heat capacity.

- Further investigating relation of CO2 content of air and heat acceptance of different crops

- Modified greenhouse shape with larger total surface to enhance heat transfer to the environment

- Testing of desiccant cooling systems (Dehumidification of greenhouse air, heat release of dried/heated air through the foil surface, heat release of the diluted desiccants during night, improved evaporative cooling capacity of vegetation, that can evaporate more water into dryer air).

- Use of seawater for removal of heat from the storage during night in order to gain freshwater condensing on the greenhouse roof. Seawater pre-treatment strategies to hinder accumulation of hard salts (especially CaCO3) on the heat exchanger surfaces

- Use of desiccant solutions to cool the storage through the night

**Construction methods of closed greenhouses**

- Using three dimensional curved surfaces to increase the stability against wind forces

- Using high slope shapes to allow removal of condensation droplets without the need for (not long term stabile) chemical foil additives

- Using high points for cooling duct placements within integrated, curved greenhouse shape (tent like or sphere like) instead of flat greenhouses and connected cooling towers to minimise construction material and to increase the buoyancy driven air movement capacity within the greenhouse.

- Using renewable construction materials like especially: Eucalyptus stems for greenhouse interior pillars and Bamboo for exterior fabric construction types.

- Use of long term stabile foil surfaces that allow lower input of labour (no 2-3 yearly removal of foils) and to allow more sophisticated foil shapes, that needs welding of foils from specific patterns.

- Use of welded foil patterns to allow sufficient sealing of closed greenhouses

- New connecting methods to fit foil on construction: Welded foil stripes to carry net of plastic ropes, Fixing Plates that distributes wind forces on a connection point to a much longer perimeter line
Horticultural concept of closed greenhouses

- Breeding of crop species more tolerant to high temperature / high humidity conditions
- Testing of new heat/humidity tolerant crops from tropical climate for greenhouse horticulture
- Further optimisation of relation temperature – CO2 content of air – light supply in the greenhouse (Optimising the cooling capacity in order to minimise shading and having lowest temperature possible, highest light supply possible and investigating optimum CO2 concentration for these circumstances)

Solid State Fermentation

- Development of specific bioreactors for fungal treatment of vegetables (Soy beans, beans, peanuts, potatoes) for increased content of high quality protein. T
- Tray bioreactor with non moved staples of thin substrates. Rotating drum bioreactors for continuous, more automated processes.
- Air supply to the bioreactor from the closed greenhouse cooling duct to allow input of vapour saturated air
- Identification of useful fungus species, that are adaptable to the specific temperature range in the closed greenhouse and according to various vegetable substrates.
- Optimisation of O2 / CO2 balance between greenhouse crops and fermentation substrates
- Assessment on reduction of wastewater derived pollutants by microbial degradation.
- Testing of population acceptance of SSF proteins as a substitute for fish or meat
- Marketing strategies for higher acceptance

Waste water use in closed greenhouse irrigation systems (related to model project 5)

- Further development of sub-ground hydroponic systems feded with wastewater
- Development of irrigation system for soil planting systems with enhanced soil water capacity (using charcoal as soil enhancer) that can be supplied with pre treated wastewater
- Further development of automation system allowing detailed salinity and nutrient management in the irrigation
- Investigation of direct use of pre-treated but high nitrogen concentrated wastewater in irrigation in high humid greenhouse climate that enforces reduced water and nutrient uptake of the plants
- Testing of crop quality of all relevant crops used in the area related to irrigation wastewater and greywater qualities of the area (pathogens, salts, micro pollutants) and related to reduced water and matter uptake in closed greenhouses.

- Development of regional standards of maximum values for certain contaminants related to specific crops in closed greenhouses and related specific waste water qualities (For water with value over xy, only non food crops can be irrigated)

- Crop specific recommendations for waste water post treatment methods related to given exemplary wastewater and greywater qualities (For values under xy- a gravel filter is sufficient; for values over xz, a membrane micro-filtration is needed, values under xa can directly be used in specific irrigation systems…)

- Mixing of wastewater and condensed water to achieve sufficient input water qualities for irrigation

- Testing of condensed water qualities to assess its usability as freshwater and related post treatment strategies to improve towards drinking water quality.

Saline water use in closed greenhouse irrigation systems

- Mixing of brackish water and condensed water to achieve sufficient input water qualities for irrigation

- Development of container planting system with compost substrate, that allows high uptake of salinity from the irrigation water and that can be used after salt saturation as a composite organic/salt building insulation material

- At high recycling rates of condensed water (>90%), mixing of seawater and condensed water to achieve sufficient input water qualities for irrigation (With constant uptake of salt by the crops, by the substrate (as a resource like in pt. 1) or by drainage water with post treatment of the drainage (eg. Further use in evaporative cooling, desalination in solar stills, salt production in salt works)

- Use of seawater for removal of heat from the storage during night in order to gain freshwater condensing on the greenhouse roof. Seawater pre-treatment strategies to hinder accumulation of hard salts (especially CaCO3) on the heat exchanger surfaces
2nd model project: Closed greenhouse for non-food crops including greenhouse integrated solid state fermentation.

Non food crops are not common in greenhouse horticulture today. The value of crops for bio energy production will not be sufficiently high to justify the cultivation in greenhouses also not in closed greenhouses. Anyway, there have been identified some specific crops that can be used as a more valued level as building material or industrial raw material.

Bamboo looks to be very interesting as a very rapidly growing crop and high value building material, that can replace steal in many construction. In arid areas, it is sufficiently stable due to the dry air.

Very good results in planting Kenaf, a fast growing C4 fibre crop in a closed greenhouse did show the high potential for growth of different fibre plants like also hemp and flax in these conditions. The special added value of growing in a closed greenhouse would be to combine with a post treatment of the fibres in the humid tropical atmosphere with solid state fermentation. In this process, specific mushrooms are used to reduce the ligning content of the fibre and to make it softer and more “cotton like”. This process needs a humid substrate and the humid air helps in preventing it from drying out. Further more, CO2 is released in this degrading process that vice versa can be used for the improved crop growth.

These points go well together with the scope of using wastewater for irrigation, that is too much contaminated to be used for irrigation of food crops. Bamboo and the fibre plants have a really high growth rate and their biomass can be considered as a sink for heavy metals, micro pollutants and also, to a certain extend for salt.

Beside the thermodynamic system and the construction methods for closed greenhouses, that can be investigated and developed almost in the same way as with using food crops, the following specific topics have to be further developed:

**Construction methods**

- A closed greenhouse can be built out of bamboo, so that it can be produced with much lowered material embodied energy consumption and reduced costs. Further more it is possible, that such a system can reproduce itself by planting bamboo within the greenhouse.

- Construction methods have to consider, that the construction lies outside of the tropical indoor climate. The foils have to be attached under the carrying grid.

- Bamboo elements have to be protected against UV radiation to allow a long term stability. Specific construction methods with plastic sun screens over the elements or with special paintings have to be developed

- Traditional methods to connect several bamboo beams with flat ropes have to be compared in long term stability with more sophisticated casted connectors out of steal or plastic.
The model project shall be combined with architectural model projects, that can present the current state of high tech bamboo constructions.

**Horticultural concept**

- Use of productive vegetation within gravel wastewater filter systems (concept of constructed wetlands) to investigate the correlation of the filter system with plant root system. Filter clogging by roots versus slacken of filter. Synergies between root system and bacteria sub system.

- Development of irrigation system for soil planting systems with enhanced soil water capacity (using charcoal as soil enhancer) that can be supplied with pre-treated wastewater. Lysimeter controlled irrigation to measure matter losses through drainage water, accumulation of matter in the soil and matter uptake by fast growing crops for a better understanding of the total mass flow of problematic wastewater in irrigation.

- Urban pollutant sink (especially heavy metals) by capture of pollutants in the biomass with (1) further use of the biomass and further diffusion of pollutants, (2) burning the biomass within pyrolysis unit and long term deposit of pollutants in the soil but embodied/stabilised in charcoal and (3) conventional combustion of biomass and final deposit of pollutants as ash on special waste dump.

- Use of productive vegetation within gravel wastewater filter systems (concept of constructed wetlands) to investigate the correlation of the filter system with plant root system. Filter clogging by roots versus loosen/aeration of filter. Synergies between root system and bacteria sub system.

- Analysis of nutrient content of wastewater and calculation of specific further nutrient demand with additive supply.

**Solid State Fermentation**

- Development of specific bioreactors for fungal treatment of plant fibres (Hemp, Kenaf, Flax). Tray bioreactor with non moved staples of thin substrates. Rotating drum bioreactors for batch processes for more automated processes.

- Air supply to the bioreactor from the closed greenhouse cooling duct to allow input of vapour saturated air

- Identification of useful fungus species, that are adaptable to the specific temperature range in the closed greenhouse

- Optimisation for lignin degradation in fibre biomass (with further use of the fibres in textile industry)

- Optimisation for lignin degradation in general wooden biomass (with further use of produced cellulose as base product for pulp and paper industry)
- Optimisation of O2 / CO2 balance between greenhouse crops and fermentation substrates
- Assessment on reduction of product quality due to wastewater derived content of pollutants.

**Soil cleanup operation with closed greenhouses**

- Uptake of pollutants from contaminated areas by non food crops to diminish soil content of pollutants, esp. heavy metals
- Activation of biological soil activity by adding charcoal, allowing higher water and air content in the soil.
- Midterm cleanup of organic pollutant by soil micro organisms
- Highly water efficient method as combined with closed greenhouse. Biological soil activity for degradation of contaminants becomes possible even in hyper arid surfaces.
- Optional cleanup of high problematic organic pollutants by fungal growth in rotating drum bioreactors (Solid state fermentation application). Optimised process by addition of carbon and/or nitrogen sources or compost to activate growth conditions of the fungus.

3rd model project: Open greenhouse with natural convection, built on mountain slopes, using saline water from the sea for evaporative cooling. Integrated aqua farming for fish and algae production using waste water and solid waste from fish processing industry

The open slope greenhouse consist of an evaporative cooling pad at the bottom air inlet, a greenhouse production area within the cooled environment behind the pad, a slope greenhouse functioning as a solar chimney (replacing ventilators) with integrated solar still. At the air outlet (on the top of a mountain), a foil air to air heat exchanger is placed, that allows to cool down the outgoing air and to yield condensed water evaporated in the greenhouse and solar still areas.

The system is much easier to run compared to closed greenhouses as only evaporative cooling is involved. The water input relies to a large extend on seawater. Placed near the sea, the concentrated brine can be rejected back to the sea. A further advantage is the humidification of the air on the mountain top, that under certain climatic conditions could allow to provoke rainfall in the area.

Disadvantages to closed greenhouses are the open state, that does not allow CO2 accumulation and neither protection from pests. Also the placement on the slope needs pumping costs for the seawater input and placement of seawater basins along the slope needs shaping of terraces.
Slope greenhouse design

- Design layout for greenhouse with adequate areas for crop production and desalination

- Coupling with algae production on the slope, where specific algae can live at temperature and salinity far beyond values acceptable for higher plants.

- Cascade of different water tanks with algae adapted to different stages of salinity and temperature. Investigation of different known species.

- Algae production can be coupled with water output from neighboured aqua-farms. Creating a water cascade using waste water from the fishing industry, diluted with seawater as input for the aqua farm and using its water output for the algae production. Goal of 100% use of organic matter

- Separation of waste water from fish industry from general wastewater system. Diminishing of salt content of main wastewater system

- Dewatering/Drying of algae with the air stream in the slope greenhouse

- Collection and storage of condensed water on the top of the mountain. Distribution of fresh water to different valleys surrounding the mountain.

- Organic pollutants can be neutralised. Fish and algae can be part of human food chain.

- Algae biomass can be used as industrial raw material. Accumulation of specific chemical elements from seawater

4th model project: Model urban area for wastewater pre-selection in urban areas with use of greywater in neighboured greenhouse projects

Separation of wastewater in the households allows to reduce the urban water demand by replacing flush toilet systems by vacuum toilet systems.

Building integrated wastewater collection

- Development of greywater collection systems. Pre-filtering of kitchen wastewater, gravity based collection from showers, washing tables, washing machines etc.

- Separation toilets for collection of urine. Gravity based water less or minimum water consuming urine collection

- Development of a simple vacuum toilet system, based on mechanical foot pumps beside the toilets

- Use of hand washing water for remaining toilet flush needed

- Collection of faecal in vacuum tanks to collect the full load of carbon and plant nutrients. (Both, flush toilet systems and compost toilet systems are leading to massive
reduction of carbon and especially nitrogen due to biological degrading in the
canalisation or in the compost facility).

- Above ground greywater disposal systems with possible pre-treatment by vegetation

**Building – Greenhouse synergies**

- Connection to neighboured greenhouse model projects, where greywater can directly
  be used (non food crops) or can be pre-filtered in gravel filters.

- Testing of urine as a direct plant fertiliser, being used in automated irrigation /
fertilisation systems. Passive systems for urine disinfection / aeration

- Self-supply of fresh food in neighbourhoods

- Vertical greenhouses with paternoster plantations on façade systems

**Desiccant cooling for building climate control**

- Regeneration of desiccants in wet pad greenhouse shading systems

- Air drying with desiccants, air humidification / evaporative cooling using vegetation

- Evaporative cooling of buildings using seawater

- Heat exchange from supply air to humidified/cooled waste air

**Architectonic synergies**

- Model greenhouses that can be integrated in the direct neighbourhood of buildings or
  that are directly attached to building facades.

- Creation of view relations from buildings into greenhouses as contrast to vegetation
  free desert neighbourhoods

- Use of greywater for irrigation of public green areas
5th model project: Wastewater post treatment systems adapted to reuse of water and solved plant nutrients in horticultural production

In the present, water output from existing clearage fields is not used and is directly disposed to the sea (Agadir) or to the near Shott area (Gabes). The main reasons for not using the water are: (1) High salinity (Nitrogen), (2) High salinity (NaCl), (3) Problems with remaining pathogenic particles, (4) Problems with micro pollutants and (5) Non regular performance of the stations.

To manage those problems, the following steps are proposed for actions within the first scenario:

High content of NaCl in the wastewater of the coastal cities of Agadir and Gabes is related mostly to pollutants from the fish processing industries. It is recommended to separate the waste water from this industry. As the main residue from here is non toxic organic waste, it is recommended to use this wastewater as an input for fish farming in the direct neighbourhood of the related factories. (See model project 3)

NaCl as a general problem in waste water shall be further examined within the irrigation management. Here, a large fund of experience is existing and shall be used as proposed.

Today, several wastewater post treatment facilities, based on aerated ponds are in use. The denitrification of embodied nitrogen within anaerobic zones of the ponds until now is a specific benefit of this method. For use in closed greenhouses, a high nitrogen content of the wastewater is a specific advantage, as the total water uptake is lower and related nitrogen per vegetation area is lower.

In this context, denitrification in the pond means nutrient losses to the surrounding air. A further big disadvantage of the ponds is their high energy demand for the aeration pond.

In this model project, two alternative post treatment strategies shall be proofed for the situation in arid areas: Greenhouse integrated gravel filters and membrane micro filtration

Gravel filters

- Filter works with gravity pressure only, very energy efficient.
- Growth of bacteria within air volumes between gravel particles as permanently aerated humid surface for microbiological cleaning activity
- Permanent flow of water (20-400 litres / day*m²)
- Easy removal of sludge by submerging of the whole filter and sudden draining by gravity forces (advantage against sand filter)
- Famishing of bio-film for periodic unclogging of filter
- Use of filter in closed greenhouses for coupling with non-food biomass production and advantage of high CO2 content, caused by biologic activity of microbes.
- Use by farmers allows permanent control and maintenance of the filter as being part of a production system (not given by “end of pipe” cleaning systems, that only generates costs while performing well)

- Testing of achievable water output qualities

- Testing of sludge for total matter flow analysis

- Recommendation for use of water output for specific cultivations (food/non-food)

**Membrane micro-filtration**

- More expensive but still affordable. Economic practice against the value of the generated clean water for irrigation purposes

- Membrane effectively eliminates pathogens and pollutants like heavy metals. Very save technology, that allows sufficient save use of wastewater

- Membrane allows to pass all plant nutrients!

- Membrane let pass micro pollutants and NaCl salt. Specific in- and output values of water have to be evaluated to estimate its possible use in irrigation (food/non-food)

- Membrane let pass salt (NaCl). Irrigation management has to consider specific maximum values of salt (Dilation with condensed water/fresh water, different grades of salinity according to stage of vegetation growth

- Only needs pressure of 5 m water column, very low energy needed. Only costs and maintenance of the membrane generates costs

- The benefit of micro filtration shall be used to examine the difference to the constructed wetland method in terms of crop quality. A broad examination with the whole list of common agricultural crops of the region shall be done to examine the crop quality of high level waste water irrigation technologies to justify its potentially higher investment and maintenance costs.

**Management of high nitrogen content in the wastewater**

- High nitrogen content is no longer problematic if using closed greenhouses, where a water use of only about 2 litres/m²*d (+/- half of open greenhouses) will be needed due to higher air humidity in the greenhouse. In this case an optimum supply of nitrogen can be reached, as the water uptake is cut in halve and by this also the nutrient uptake.

- In field studies, the cleared waste water without nitrogen or phosphorus elimination shall be used, to examine the functioning of a greenhouse system for optimised nutrient removal and re-use.
Salinity management (NaCl)

- Dilution of the waste water with fresh water, rainwater or condensed water
- Automated drainage of saline irrigation water at a point of over-concentration. Reuse of the drainage with further dilution or within desalination units (model project 6)
- Adoption of water salinity to the kind of crop, stage of crop development and growth rate.

6th model project: Sea- and brackish water desalination systems adapted to use in horticultural production

Beside rainwater and wastewater, the use of saline water is a main unconventional water source. Seawater is in principle eternally available which makes it enormously interesting for future growth models. In many arid or desert areas, plenty of brackish water is available from wells. Also a growing salt content of former fresh water sources asks for solutions for brackish water use.

Solar still desalination systems

- Use of specific greenhouse constructions with sufficient slope of the walls to gain condensed water from solar stills
- Double layer rainwater storage and solar still units: Open water storages are leading to high water losses due to direct evaporation. A sealing of ponds should be constructed in a way, that it can be also used as a solar still. The water volume of the seawater can be used as thermal capacity to have heat captured during daytime to evaporate seawater during night with higher condensation rates due to lower outside temperatures.
- Also channels for distribution of seawater should be sealed and used as solar still and as thermal storage for night operation

Solar thermal desalination with waste heat from solar concentrated power stations

- Capture of heat from steam turbine cooling water to heat seawater and to process in multi stage evaporation units
- Combined use of heat storages for closed greenhouses (20-45°C) and steam turbines (40-80°C). Heat release by closed greenhouse integrated cooling towers with evaporation of seawater and condensation on the greenhouse roof
- High potential for large scale production units

Saline water use in closed greenhouse irrigation systems as an alternative desalination strategy

- discussed at model project 1.5.
7th model project: Treatment of urban solid waste, sewage sludge and agricultural waste with charcoal as a main output product to be used as a soil enhancer

A main reason for drought is the missing moisture field capacity of soils. Once an ecosystem is overused or destroyed, organic matter disappears and it can take either several decades to re-establish or will turn to final desertification of the area.

Increasing the soil carbon content is a standard technique within agriculture, mostly practiced as supply of compost (from organic waste) or green manure covered by specific crops. Anyway, the most part of carbon gets lost already within the composting process. Once in the soil, organic matter gets degraded by soil micro species and disappears – pulverised with the wind or digested and released as CO2.

A quantum leap of soil enhancement is possible if organic matter is processed into charcoal within specific processes like pyrolysis or hydrothermal carbonisation. Pyrolysis of solid waste only works economically at very large scale with temperatures of about 450°C and reduced oxygen supply. Then, a large fraction of the biomass can be transferred into energy rich oil and gas as a part remains as charcoal, also carrying phosphorus, that can be redirected into the landscape.

Hydrothermal carbonisation is a much more simple process (cooking of biomass with overpressure at 150°C) allowing more decentralised and low-tech like processing with higher soil carbon yield but with lower yield of biomass embedded energy and lower decomposition of problematic organic pollutants within the waste.

Model pyrolysis project

- Even if not economic at small scale, a pilot pyrolysis device shall be built up to test the whole process of organic matter accumulation
- Solar drying of biomass (solid organic waste, sludge, agricultural waste) in the open fields with mechanical turning / mixing.
- Process unit driven with solar concentrated power as main heat source. Pyrolysis is an endothermic process and can also be used as an organic solar thermal storage process.
- Use of process gas e.g. to drive solar concentrated power driven steam turbines during night or as gas supply oh households.
- Collection of process oil for centralised further processing (cleaning/removal of tar and other impurities). At large scale, can even be done at central units at Import countries.

Model project hydrothermal carbonisation

- Development of steam cooker applicable with low effort of specific knowledge. (Low tech approach) and as a decentralised application
- Use of solar thermal collectors to reach the supply temperature of ~150°C
- Investigation of the carbon yield quantity and quality compared to pyrolysis charcoal product
- Control of remaining micro pollutants in the produced substrate (problem of possible insufficient degradation of micro pollutants, especially pesticides from agricultural residues)

Investigation of the charcoal – soil interface

- Use of charcoal as soil enhancer
- Field tests to investigate plant response to the substrates generated by the different technologies
- Lysimeter tests to evaluate the possible impact of soil and groundwater contamination out of the charcoal (dissolving benzene, heavy metals...). This is not very likely, as charcoal takes up water and keeps it. It is only captured actively by plant roots. Also, charcoal is only supplied once to a certain area, which hinders long term accumulation of pollutants.
- Measurement of plant ability of active dissolving of phosphorus compositions out of the charcoal at sufficient supply of water and other nutrients (as a very simple system of closing the phosphorus cycle against the approach of chemically separation of phosphorus out of the charcoal or from ashes).

8th model project: Rain fed cultivation in arid areas based on charcoal soil supply and surface rainwater harvesting

Field tests and lysimeter testing in environmental situation

- Testing of different bio char sources and behaviour in the context of rainwater harvesting
- Testing of plant behaviour in comparison with standard rainwater harvesting practices
- Pollutant content and leaching of pollutants with irregular water availability
- Matter transport form the bio char into the crops in context with irregular water availability
- Water storage capacities
- Nutrient storage capacities
- Carbon sink characteristics

9th model project: Concentrated Solar Power project with cooling water recycling in closed greenhouses

Concentrated solar power (CSP) is increasingly discussed as a main source of electricity production in Northern Africa for local markets as well as for export to the European Union by high voltage DC connections. The potential goes far beyond the extend of wind energy, even if actually the production costs are still slightly more expensive.

The cogeneration of heat for desalination within CSP purposes is also broadly in the discussion. Anyway, the potential of closed greenhouses for use of thermal heat and the
recycling of the cooling water goes beyond the possibilities of pure desalination techniques, as water is mostly generated for irrigation purposes and has much lower value, if it can not be used with high efficiency.

Further more, a specific synergism is given by closed greenhouse integrated CSP units, that will only use the near infrared light (NIR) for power generation, while letting pass the visible light for the plant photosynthesis. In this case, almost 50% of the heat load from radiation can be reduced. This allows the reduction of cooling measures in the greenhouse, while at the same time, the light can be used to generate power. A further significant advantage can be derived by the use of very light mirrors and tracking systems within the wind protected environment of the greenhouse.

**Cooling water removal in closed greenhouse cooling system, coupled with desalination**

- Development of a very small scale CSP unit (~50 kW electric power) to run the different model projects
- Use of waste heat from steam turbines to evaporate saline water in the greenhouse roof area.
- Condensation of air humidity in the cooling duct with condensed water yield from vegetation and desalination units
- Uptake of latent heat by heat exchanger and heat transfer into thermal storage. Evaporation of further saline water, heated by the day/night thermal storage with condensation and heat release to the environment through the plastic cover of the greenhouse.

**Cooling water removal in open slope greenhouse, coupled with desalination**

- Use of waste heat from steam turbines to evaporate saline water in water tanks within the highest level of the slope area. Heat retention within the tanks into the night
- Condensation of air humidity in the air to air heat exchanger at the slope greenhouse condensed water yield from vegetation area and desalination ponds. Heat release to the environment

**Greenhouse integrated concentrated solar power unit**

- Development of a very small scale greenhouse integrated CSP unit (~10 kW electric power) to investigate the specific synergies with horticultural production
- Reflection of NIR light spectrum with curved plastic or light glass mirrors
- Mirrors attached to greenhouse roof with movable wires
- Large concentration ratio to reach needed temperatures of ~400°C for steam turbine operation. Use of modified fresnel lens type concentration system
- Remaining energy balance in the cooling system but with much higher temperatures allows use of smaller thermal storage with higher temperature amplitude
- Possibility of triple cascade, using energy (1.) for electricity production at ~400 °C (2.) for regeneration of desiccants at ~80° C and (3.) for night time desalination at ~40° C.
10th model project: Novel material research

This last model project consists of a number of different midterm actions, that shall help to establish the previous projects at large scale with minimised energetic and physical input. It is foreseeable, that the change into a real sustainable economy would be substantially hindered by supply lack of energy and finite material resources, especially oil and gas, steel, mineral fertilizers etc.

Basic materials can be derived from three different areas:
- In a greenhouse, biomass can be continuously produced, if a sufficient amount of water supply and plant nutrients can be supplied.
- On many places, water supply has partially to be organised by sea- or brackish water desalination. The salt generated from this process is a second basic material.
- Constituents from existing soils like sand, gravel or soil included minerals can be directly used as a resource.

Biomass based resources

- Use of Wood and Bamboo as described in the 2nd model project
- Splitting of wooden biomass: Biological lignin degradation for cellulose production. Cellulose can be used as an industrial basic resource. It can be directly used as insulation material. Fire protection can be reached if the cellulose is mixed with salt.
- There are different ways of producing plastics like Polyurethane or Polyamides from wooden biomass as a substitute for using mineral oils. These plastics could be used for greenhouse construction, especially for grids to carry the plastic covers and for the fabrications of pipes carrying hot water (>60°). For these methods, fibre plants like Kenaf or Hemp can be used instead of hardwood crops, as they are more adaptable to the tropical greenhouse climate. Fibre plants can usually achieve higher growth rates and are easier to treat due to the lower density and lower lignin content of the biomass.
- Non wooden biomass, especially the non eatable parts of agricultural crops can be transformed to biogas or ethanol. For the material aspect, these fuels can also be used to produce principals for plastic production.

Seawater based resources

- Sodium Chloride is the main constituent of sea minerals, and by this will be the major side-product of water desalination and is of high interest at forming a zero discharge desalination process. It can be split by electrolysis into sodium and chloride. Sodium is needed in many chemical products. In the context of greenhouse construction, it is interesting as a main substance of water glass, that is produced of sodium carbonate and purified siliceous sand. It can be used for corrosion protection and water proofing of wooden biomass. Also it can be used as a fire protection constituent if using biomass as a building material (e.g. insulation- or façade plates of straw).
- Sodium carbonate is the basic material of silica gel, that can be used as an adsorption product in desiccant cooling systems.
- Chloride can be transferred to PVC plastic, where about 55% of the final product is chloride based. This means, if using biomass for the organic part of the plastic, more
than 50% can be spared compared to other kinds of plastic. PVC products have a long life span and are seawater proof as well as proof to UV light. Hard PVC does not include flexibilisers and can be used for containers and pipes as well as for the weather protection of textile membranes. The products are 100% recyclable if not mixed with other plastics. Residues should in no way be burned, as e.g. dioxins can be produced.

- Chloride is a common used disinfection material. New automation technologies in irrigation allow a complete removal of chloride before the contact of the water with soil or plant surfaces, if guaranteed, that the concentration is sufficiently low and the chloride content is evaporated on the way from the sprinkler to the contact surface.

- Magnesium chloride can be separated from Sodium Chloride in the conventional thermal desalination process, as its solubility in water is much higher than sodium chloride and by this accumulates if removing the latter constituent. Bitter salts can be used as an absorption material for desiccant cooling for greenhouse climate control systems.

- Magnesium sulphate can be used as a plant nutrient
- Magnesium also plays a role as a precipitation agent in the removal of medicals from wastewater in closed nutrient cycles.
- Calcium sulphate and Calcium carbonate: Building materials like water pipes, containers but also constructive elements can be produced with the technology of mineral accretion. “In mineral accretion, a low voltage current is applied to a metallic structure to cause limestone to accrete or build on the surface, upon which planulae (marine mineral accumulating species) can attach and grow. The voltage is low enough that it can be generated by floating solar panels or from wave motion.” (Wikipedia, “artificial reef”).

- Potassium chloride can be used as a high valuable plant nutrient. It is a main constituent for curing of steel.
- Micro constituent of seawater can be extracted by special species of algae as described in the 3rd model project.

Soil based ressources

- Local soils can be used as a base for the plant substrates and as a filter material.
- Purified sand can be further processed to building materials like glass or, in combination with sodium, to water glass. The needed energy can be provided using solar concentrated heat. Liquid glass can be used as heat storage to run a process without phase change of the processed material.
- Clay can be further processed to ceramics and can be used for sealing of the ground for water containments.
Fig. A.15. Scheme for regenerative urban supply and self-reproduction for sustainable growth. Beside the supply of water, energy and food, the hardware to built the system can also be regenerated by its interior matter cycles and input from seawater minerals.
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