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Perspectives on environmental ethics in sustainability of membrane based technologies for water and energy production

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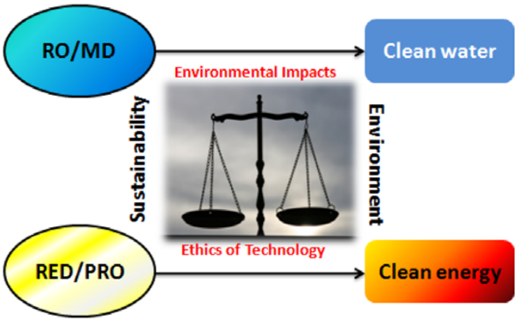
HIGHLIGHTS

- Assessed environmental impact from the emerging desalination technologies.
- Sustainability of desalination technologies evaluated.
- Methodology in consideration of environmental ethics for justification of sustainability.
- Process intensification and new developments as mitigation strategies.
- Future research directions in sustaining water and energy production technologies indicated.

GRAPHICAL ABSTRACT



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ABSTRACT

Securing a sustainable supply of water and energy is nowadays a key global issue. In the current practice of water and energy supply, there is still some gap in meeting the value criteria for sustainable development mainly related to environmental pollution as well as ecosystem disturbances. In this work, the sustainability of integrated membrane based processes for water and energy production is assessed with a special focus on environmental and ecosystem impacts. Feasibility of bridging the available gaps through process performance improvements is presented. Major environmental impacts from hybrid membrane based technologies for water and energy production are identified and considered for upstream balance of social benefits and burdens to the present and future generations. Ethical considerations were pointed mainly in the aspect of intergenerational justice (IRG-J) and ecological justice (EC-J) while setting value criteria for sustainability.

Abbreviations: DCMD, Direct contact membrane distillation; DT, Desalination Technology; EC-J, Ecological Justice; GHG, Green House Gas Emissions; IEA, International Energy Agency; IEM, Ion exchange membranes; IPCC, Salinity Gradient Power; IRAG-J, Intragenerational Justice; IRG-J, Intergenerational Justice; MD, Membrane distillation; PRO, Pressure Retarded Osmosis; RED, Reverse Electrodialysis; RO, Reverse Osmosis; SGP, Salinity Gradient Power; TDS, Total Dissolved Solid.

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The ethical significance of the identified impacts was predicted based on the associated difficulties to meet these criteria. The overall outcome will be beneficial in designing strategies for development and implementation of sustainable hybrid processes for clean water and energy production.

Contents

1. Introduction

The need to meet basic human needs in a sustainable manner is a major challenge nowadays for developing and developed countries. Key issues involve depletion of fossil fuels, global warming, water scarcity, rise in energy demand, loss of biodiversity and the human health impact which are exaggerated with the global expansion. The global demand for the two essential resources (water and energy) is drastically increasing due to economic expansion, population growth and increasing living standard in emerging countries. In 30 years, it is expected that energy demand will be projected by 50% while water withdrawal could go beyond 50% in developing countries and 18% in developed countries over the same period (EIA, 2013). Thus, technological innovations for sustainable water and energy production are highly demanding for societal and ecological benefits in terms of economic advantages, environmental safety, public welfare and national security.

This study presents a methodology for an integrated analysis in planning and technological implementations for sustainability of membrane processes applied to water and energy production. Emphasis is mainly given to reverse osmosis (RO) for clean water production and reverse electrodialysis (RED) for clean energy generation. Trends in research progress and recent technological development are highlighted. Identification of potential environmental threats and ecological impacts is done for justification of related ethical issues. Integrated analysis of the various factors that should be considered in technological advance of desalination processes; possibly in reduction of energy demand, use of clean energy sources, advanced materials, innovative system designs and social acceptance, were performed and evaluated according to a value criteria set for sustainability. From ethical point of view concerning justice, the listed factors were evaluated in terms of intergenerational equity in sustaining the processes without any damage to humans, non-humans and the whole ecosystem. This will be helpful in paving a way for the technological advancement through upstream balance of social burdens and benefits.

2. Current state-of-the-art technologies

2.1. Reverse osmosis: water

Production of pure water is mainly done by desalination of seawater. The major Desalination Technologies (DT) currently in practice is based on RO and thermal distillation (multistage flash and effect distillation). Thermal desalination is energy intensive compared to the membrane based processes like RO seawater desalination which is expanding rapidly due to its lower cost and simplicity. Currently, RO is the most widely used technology and accounts for over 50% of the installed capacity. However, at the current state-of-art, desalination of 1 m^2 seawater by RO (50% recovery) results in about 0.5 m^3 of pure water and 0.5 m^3 of retentate (brine), which is usually discharged into sea. Fig. 1 presents major steps involved in a typical seawater RO process.

Recent advances in RO development involves new membrane materials, modules and process design (Shenvi et al., 2015). The search for optimal polymeric membrane materials started early in 1950s, and the RO industry is nowadays dominated by these type of materials. Promising progress is observed in membrane research mainly in performance optimization through

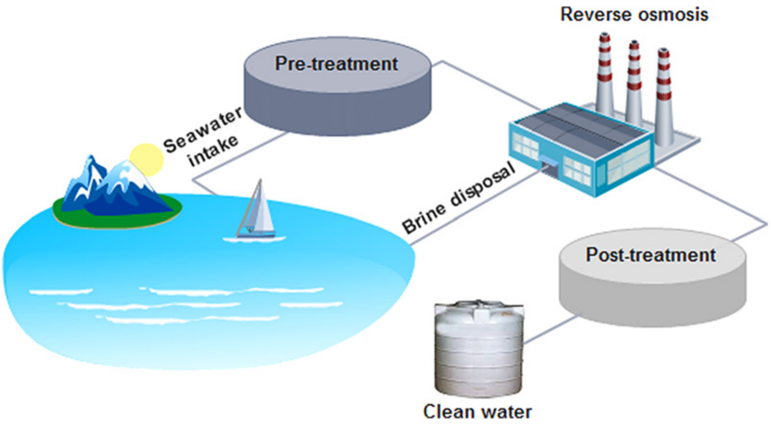

Fig. 1. Illustration of typical seawater reverses osmosis process. Technological advance is mainly observed in the improvements of pretreatment step allowing prevention of membrane fouling as well as in the RO process with high performance membrane materials, modules and process design.

improvements in physico-chemical properties (Perera et al., 2014; Gorgojo et al., 2014). In addition, significant improvement in mechanical, biological and chemical strength of RO membranes have been observed in the last decades. Modification of the structure and morphology of membranes for functionality improvement is observed to enhance the permeability and selectivity properties.

This together with energy optimization has reduced the membrane and operational cost per unit volume of water produced, thus reducing the overall energy consumption down to 1.06 kWhm^{-3} (at about 50% recovery) which is much lower than thermal systems.

Different types of RO membranes have come into applications from early stages up to now. New developments in polymeric membranes based on cellulose acetate asymmetric morphology formed with a dense 200 nm thin layer over a thick micro-porous body resulted in higher water flux than the early symmetric membrane (Sidney, 1981). However, formation of asymmetric membranes is based on a single step casting limited to a few soluble membranes and the level of permeability and salt rejection is not commercially attractive. This led to development of new membrane termed as composite membranes based on a two step-casting involving a separate optimization procedure for the barrier layer and support layer (Francis, 1966). Currently, thin film composite (TFC) polyamide membranes having high salt rejection, good chemical stability and mechanical strength dominate the RO market. Later, the development of novel membranes based on rigid star amphiphiles, ceramic membranes, and mixed matrix membranes come in to applications in RO desalinations (Lee et al., 2011). In very recent developments, nano-technology has emerged as an attractive alternative to polymeric materials (Celebi et al., 2014).

Various module designs can be used in RO for efficient recovery of pure water from seawater. This involves configurations like pleated flat sheet, spiral wound flat sheet, ceramic monolith element membrane and tubular membrane. Spiral wound membrane module which is cheaply produced from flat sheet TFC membrane configuration, is the most extensively used design in RO desalination due to its high specific membrane surface area, easy scale up operation and low cost. The dominant modules in the market are the ones based on polyimide membranes i.e. polyamide spiral wound membranes and asymmetric cellulose acetate hollow fiber membranes (Lee et al., 2011).

Although the emerging novel materials are envisaged to improve RO performance, challenges still remain with respect to their practical applications. There are still challenges in membrane permselectivity and mitigation strategies of membrane fouling. In this regard, other cost effective thermally-driven DTs like Membrane Distillation (MD) are emerging for production of high quality distillate (recovery above 90%) using low grade waste (Drioli et al., 2015). Other problem with the RO practice is the degradation of commercial membranes by chlorine. Thus, pre-treatment analysis, prevention of fouling and concentration polarization is urgently required in order to minimize these problems. Moreover, reduction of energy consumption has a huge advantage in terms of economy and environment.

2.2. Reverse electrodialysis: energy

There are two promising membrane based technologies for clean energy production in the form of salinity gradient power (SGP) from mixing two solutions of different salinity; reverse electrodialysis (RO) and pressure retarded osmosis (PRO). In RED, salinity gradient power is generated by ionic migration across alternatively aligned ion exchange membranes driven by the difference in the chemical potential of the mixing solutions. The scheme of red for conversion of SGP into electrical power is presented in Fig. 2. In PRO, power is generated by depressurizing a portion of diluted solution through a hydro-turbine when two solutions of different salinity are contacted by semi-permeable hydrophilic membranes.

Progresses in RED research have shown promising milestones in the past decades. The increasing demand for alternative clean energy resources as well as the new era in the development of membranes increased attention to development of a

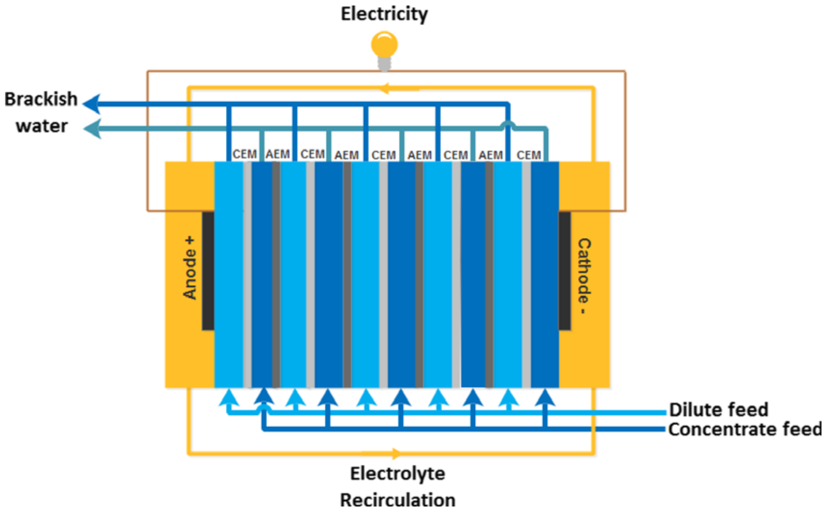

Fig. 2. Conversion of salinity gradient energy into electrical power by reverse electrodialysis. The outlet from RED is indicated as brackish water since the technology is mostly applied for seawater and river water. In the application for energy recovery from brine, the outlet concentration outlet can be of much higher than brackish water concentration.

research on this process, although the technological concept was introduced long ago in 1950s (Pattle, 1954). Interesting outcomes have been demonstrated through a research focusing on membrane development (Długołęcki et al., 2008; Vermaas et al., 2011a; Güler et al., 2014; Gi Hong and Chen, 2015; Hong et al., 2015), stack design and testing (Veerman et al., 2009b, 2010; Vermaas et al., 2011b), process modeling and optimization (Veerman et al., 2011; Tedesco et al., 2014), performance analysis and testing (Veerman et al., 2009b,a), investigation on fouling (Vermaas et al., 2013; Post, 2009), and scale-up potential (Daniilidis et al., 2014).

IEMs can be regarded as the heart of RED system. The commercial success of this technology is unthinkable unless the properties of IEMs especially resistance and permselectivity is not well optimized at an affordable cost for scaled-up application. Recently, lots of efforts have been done in preparation, characterization and modification of IEMs for enhancement of the overall RED performance. Commercial homogeneous and heterogeneous membranes as well as tailor made membranes have been tested in RED process involving lower feed concentration like seawater and river water (Długołçki et al., 2009; Post et al., 2008) and higher feed concentrations like brine (Tufa et al., 2014; Kwon et al., 2015). Some of the important millstones involve the application of profiled membranes in RED process. Vermaas et al. demonstrated that the use of profiled membranes significantly reduces the internal stack resistance (up to 30%) and hydrodynamic loss (4-fold lower) compared to classical stacks using non-conductive ion spacers (Vermaas et al., 2011a). The overall consequence is advantage gained in terms of enhanced power density and open circuit voltage, however with possibility to improve the performance further with different profile geometries. Güler et al. prepared profiled membranes in different geometries like ridges, waves and pillars profiles, and tested for the RED applications (Güler et al., 2014). They observed that 21% reduction in internal stack resistance results in up to 38% increase in power density compared to the stacks with flat membranes. Recently, Hong and Chen designed organic–inorganic nanocomposite CEM and analyzed their electrochemical properties for RED applications (Gi Hong and Chen, 2015; Hong and Chen, 2014). A maximum power density of 1.3 W/m^2 was achieved through control of the electrochemical membrane properties by optimization of the loading of sulfate functionalized iron (III) oxide within the sulfonated polymer matrix of the CEM (Hong and Chen, 2014). The maximum power density so far is about 2.2 W/m^2 using commercial Fumatech membranes (FAS and FKS) combined with the use of thin spacers within the RED stack. These membranes are very thin in structure and have low area resistance (below 1.5 Ωcm^2) compared to other commercial membranes. Although promising progress is achieved with respect to improvements in membrane performance so far, further optimization through appropriate design and IEM development is required for scale-up at an affordable cost and commercial success. The high cost of commercially available ion exchange membranes in the current market is the main limitation in this regard.

Research in RED is broadening from time to time. Other innovative applications are being introduced based on the power generation in hybrid applications with other technologies like desalination and bio-electrochemical systems. This has a huge advantage in terms of energy and environmental issues. For example, there is a huge possibility of concentration of the brine from RO desalination plant to be used in the LC compartment of the RED system (Brauns, 2010; Ramato Ashu Tufa and Drioli, 2014). Promising power density (up to 1.5 W/m^2) can be obtained when mixing brine with brackish water (Tufa et al., 2014). This is a good opportunity in reducing back the energy for desalination and environmental problems related to brine discharge. Other interesting applications involve the integration of RED with microbial fuel cells (Kim and Logan, 2011) and hydrogen energy systems (Ramato Ashu Tufa et al., 2015). Integrated application of RED with microbial fuel cell resulted in 6-fold power density (4.3 W/m^2) compared to the stand-alone microbial fuel cell when operating at feed flow

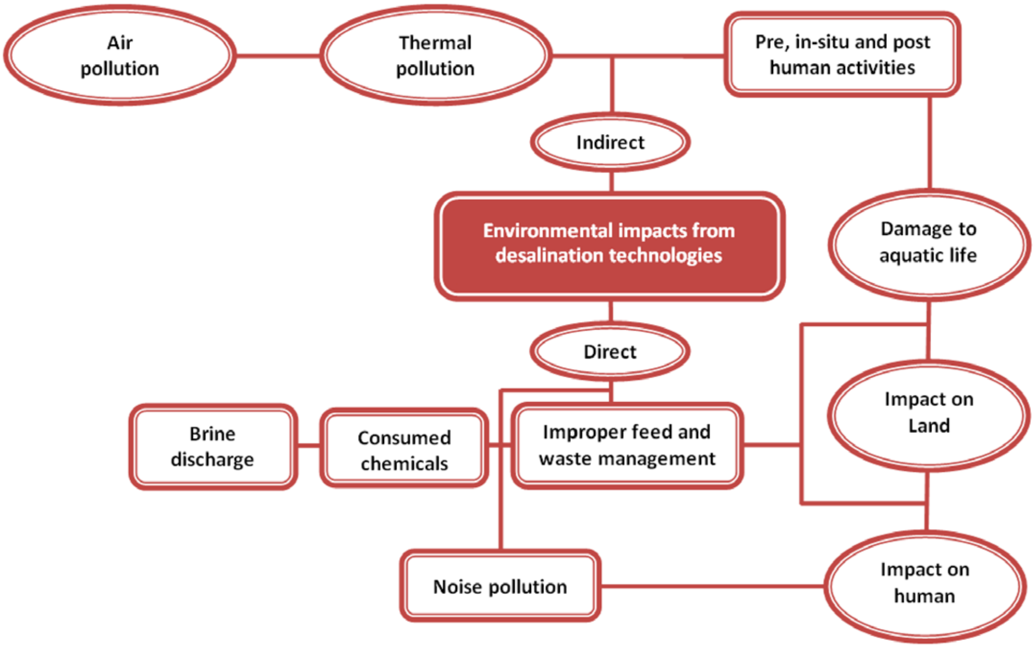

Fig. 3. Direct and indirect environmental impacts expected from membrane based DTs. In integrated application to energy technologies, membrane processes like RED for conversion of hypersaline brine in to energy could also have a similar environmental threat especially to the marine life if the concentrated discharge at outlets is not properly managed.

rate of 1.55 mL/min (Kim and Logan, 2011). In hydrogen production systems, RED can be a perpetual power source for sustainability as well as storage of SGP in the form of hydrogen (Ramato Ashu Tufa et al., 2015).

3. Key environmental impacts

DTs play an important role in potable water supply with a worldwide production capacity of 24.5 million m^3/day. However, the process is also accompanied by adverse environmental effects. Fig. 3 illustrates potential environmental impacts from DTs. The major impacts can be categorized in two aspects; '*direct*' and '*indirect*' impacts. One of the direct impact is the significant loss of aquatic organisms specially those at the early stage and planktonic ones due to impingement and entrainment resulting from seawater intake (Lattemann and Höpner, 2008). For example, the use of open intake may result in losses of aquatic organisms when drawn into the plant with water or collision with intake screens.

Huge amount of brine is rejected from DTs with high load of TDS. For example, Ashkelon desalination plant which is one of the largest in the world and the largest in the Levant Basin, has an annual seawater intake of about 315 MCM (million m^3) and produces brine with a salt concentration of 7.35% TDS (1.86 times that of seawater) that is discharged at a rate of 160 MCM per year (Einav and Lokiec, 2003).

Brine reject may contain residues of pretreatment and cleaning chemicals required for prevention of biofouling, scaling, suspended solids, foaming and corrosion. It may also contain chemicals due to side reactions of pretreatment and cleaning chemicals involving halogenated organics and heavy metals due to corrosion (usually at low concentrations). Rejects containing these chemicals are basically discharged continuously into the sea. Thus, the release of toxic anti-foulants and anti-scalants is also another issue of environmental concern of DTs. For example, about 10%–25% of the dosing concentration of Cl_2 (anti-foulant) in the process of desalination is released as a residue which can be hazardous threat to aquatic environment. Cleaning chemicals and their additives like dodecylbenzene sulfonate and sodium perborate can have a negative impact on the aquatic life if discharged into the sea without treatment.

Environmental threats may depend on the properties of the reject brine as well as the hydrographical feature of the accepting environment. Salinity and temperature are among the reject properties potentially affecting the distribution of aquatic organisms. Continues exposure of marine organisms to extreme condition of this properties might be intolerable (Lattemann and Höpner, 2008).

Other issues related to land use is also considered as a negative impact, however with a low emphasis.

Despite the fact that the level of overall effect of these elements differs from plant to plant and species to specie, there is no enough experimental data for clear understanding of the tolerance limit of marine organisms.

High energy demand of seawater desalination plants requires use of large amount of thermoelectric energy which is accompanied by emission of air pollutants and greenhouse gases that further exacerbate global warming. Modern seawater RO plants have energy consumption rate in the range of 3–4 kWh/m^3 with net CO_2 emission rate of 0.4–1.8 kg/m^3 (Meerganz von Medeazza, 2005). Unless alternative energy resources like renewable are developed for desalination, expansion of the plant's capacity with the projection of water demand is expected to raise the level of greenhouse gas emissions. Thermal stress associated with the release of heat associated with plant operation or effluents may also be considered as an indirect impact. Other concerns may involve the impact on groundwater due to leakage from seawater pipes and noise ($\sim$90 dB) due to high pressure pumps.

In general, many of the published literatures do not present enough data to support the ideas regarding the adverse environmental effects of desalination systems especially long term effects on marine organisms.

Environmental impact from the emerging SGP technologies like RED could be mainly viewed in terms of the effect of seawater intake and outlet discharge. If seawater and river water is used, outlet discharge from the SGP system is mainly composed of brackish water which is about 50 times less concentrated than brine, and it could not have a potential harm on the marine organisms. For example, in a RED pilot plant installed at Afsluitdijk (The Netherlands), salt water from Wadden sea is pumped at a flow rate of 200,000 L/h to be mixed with 740,000 L/h of fresh water from IJsselmeer to produce SGP, and the effluent (brackish water) is discharged back to the sea.

However, if brine and brackish water are used as RED feed, the outlet concentration will be about 3.5 M which is quite higher than the RO brine concentration, and this will have even more pronounced environmental effect. Though sufficient experimental data is not yet available to support the pre-treatment requirement of RED technology as well fouling potential of the membranes, discharges composed of chemicals that could possibly be used in pre-treatment and membrane cleaning may also be considered as a potential threat to marine ecosystem.

In addition, hexacyanoferrate/ferrite solution which is mostly used as an electrode rinse in SGP-RED system (Scialdone et al., 2012) can have a hazardous effect in case of high current leakage within the stack leading to the release of toxic HCN during plant operations. Decomposition products from the discharge of these chemicals into sea may involve the release of HCN which could have an acute or chronic toxicity to the marine ecosystem.

4. Sustainability assessment and ethical issues

From philosophical point of view, ethics represents systematizing, defending, and recommending concepts of right and wrong behavior (Fieser and Dowden, 2011). Environmental ethics deals with the conceptual foundations of environmental values as well as issues related to actions and policies of the society to protect and sustain biodiversity and ecological systems. The view involves concern to humans (anthropocentric view) and extends to non-humans (non-anthropocentric view) (Zalta and Abramsky, 2003). In the process of sustainability assessment of DTs, identification of the benefits used to evaluate distributive outcomes with time in relation to environmental ethics is crucial.

Environmental threats as a result of high emissions from non-renewable energy based intensive desalination practice can be viewed in many dimensions of ethical concerns; for example '*Intergenerational Justice*' (IRG-J). Barry (1997) quests the welfare of the present and future generations, and '*Ecological Justice*' (EC-J) in relation to consequential damage to marine organisms, land, aquifers as well as any useful non-living matter which can be adversely affected by the technological processes. Although not of significant importance, '*Intragenerational Justice*' (IRAG-J) considering the potential risk of desalination practice for the people leaving nearby and employees in desalination plant is also another consideration.

Despite technological progress, human beings are still dependent on environment as well as natural resources. In addition, the scale and the nature of these issues in a world striving for sustainable development have evolved over time. The focus of sustainability is mainly the changing of various practices in an effort to carry on certain patterns of human and ecological existence in a safe and secure way. Theories adhering sustainability to intergenerational equity as a main topic are emerging substantially in the world of sciences. IRG-J is basically interpreted as a concern for the welfare of future generations along a range of ecological and social dimensions. Thus, equitable sharing of benefits (values of sustainability) and the burdens (environmental threat) between generations is important. This complies with the Brundtland definition which addresses sustainable development without a compromising the ability of future generations to meet their own needs, with the aim to fulfill intergenerational equity (Brundtland et al., 1987).

The rate at which human activities adversely affect the environment and ecosystem as a whole is rising with global population growth and socio-economic production model. In the case of DTs and energy technologies considered here by which human actions are leading towards extinction of non-humans, the argument starts whether doing this is just or unjust. This could be viewed in different ways depending on the scope of different social aspects like culture, tradition or religion. However, any of the beliefs conceiving of the morality of human relationships with non-human organisms is similar to behavior influencing considerations obtained from the purely prudential concern to maintain a healthy non-human environment for the benefit of present or future generations. In short, apart from reasoning that peoples believe in verge of justice for non-humans, at least the moral responsibilities account for the way in which human beings conduct themselves towards non-humans in order to assure EC-J (Baxter, 2005).

There are lots of evidences regarding the negative impact of GHG emissions on the integrity of biosphere and well being of future generations and the whole ecosystem. From ethical point of view and supporting evidences that climate change will have an adverse impacts on health, cultural life and economic growth of future generations, Intergovernmental Panel on Climate Change (IPCC) concludes that global climate change issues raise questions of equity among generations (Arrow et al., 1996).

5. Mitigation strategies

It would be worthy to note that the future peoples have the right to have all the opportunities, if not exactly to the same, at least with present people being aware of their responsibility and obligations when practicing socio-economic and techno-economic developments. Thus, when it comes to DTs, it would be promising to find ways to mitigate the adverse environmental and ecological effects, now and in the future. Without this, it will be very difficult to lead a sustainable practice in fulfilling the need for ever-growing demand of water and energy with membrane based processes and other potential technologies for production of these essential resources. In this regard, approaches based on the concept of process intensification strategy as well as new material and technological developments could have a direct impact in minimizing the expected environmental threat.

5.1. New technological developments

Research advances show the possibility of reducing the energy demand of DTs by improving process performance through development of advanced materials and technological innovations thereby ensuring sustainability along with the ever growing global water demand (Elimelech and Phillip, 2011; Latteman, 2010). In the process of sketching the principles of distributive justice with respect to DTs, it is important to identify clearly the cause and adverse effects of factors involved and try to predict the extent to which emphasis should be given based on the different theories of justice; IRG-J, IRAG-J and EJ. Table 1 illustrates the sources for the environmental and ecological effects of DTs, as well as mitigation requirements, related ethical concerns and ethical significance of the adverse effects. Priorities can be made based on the related ethical concerns in order to lead a sustainable practice keeping the security of natural resources and non-human habitants in relation to the whole ecosystem. Level of ethical significance of each adverse effect is proposed based on an ethical scale developed through a value criteria consideration. Green house gas emissions (GHG) and ecological damage are marked as a significant consequence and hence open to the questions related theories of justice from ethical (environmental) point of view.

In comparing the problems on ethical scale, the benefit that can be obtained through control of the problem can be directly linked to the level of ethical significance. Prior inspection of solutions for the high energy demand of DTs is important and attention should be given to solve this problem which indirectly leads to the reduction of GHG emissions. The overall result is saving environment, avoiding climate change, and securing welfare for the present and future generations. Problems related to brine discharge and ecological damage are also important issues requiring more attention. The development of special discharge salinity devices for brine (Elimelech and Phillip, 2011) and utilization of brine in other processes like SGP (Brauns, 2010) generation can solve this problems. Problem related to the seawater intake can be of moderate concern which could be solved mainly by designing appropriate seawater intake technologies that have a minimal effect on the aquatic life. Effects from pre and post-treatment chemicals, the pipe leakages and noise pollutions are not of significant ethical concern and can be solved in the long run after the major issues are settled.

5.2. Process intensification-an integrated approach

As noted before, significant increase in water and energy demand with potential consequence of global warming is a critical issue requiring sustainable development all over the world urgently. Lots of research and developments are ongoing in search of green technologies for clean water and energy production. However, the route to meet sustainability requirement in the process of global development is complex and time taking. In this regards, process intensification (PI) is a promising approach to achieve sustainability through design and development of a fast, efficient, simple, cheap and safe processes.

The concept of PI can be implemented in disciples involving the application of membrane engineering; like desalination, membrane processes based on reactive separation and/or hybrid separations (Drioli and Curcio, 2007). Fig. 4 shows a scheme of integrated approaches for sustainable water and energy production by membrane processes.

There is a huge possibility of integrating membrane process for sustainable applications in the concept of process intensification for water and energy production. Brauns elaborated the potential integration of the membrane based DTs and/or solar power DTs with SGP technologies for efficient production of clean energy as well as desalted water; this enables adequate production of large amounts of pure water by renewable energy resources (United States Pat, 2012). For instance, RO produces large amount of hypersaline brine that can be recovered as a source of clean energy generation by RED (Brauns, 2010; United States Pat, 2012). Further integration of MD with these processes can increase the water yield, brine volume reduction (concentration) and energy recovery by RED.

In addition, there is a possibility to use the energy recovered from the brine for the desalination itself. This will not only reduce the operating costs, but also keeps a sustainable desalination practice by avoiding the emissions from the traditional power plants.

6. Burden–benefit balance

Assessment of methodologies to fairly distribute benefits and burdens (burden–benefit balance) among the present and future generations is important in the sense of IRG-J. Fig. 5 shows the achievement of IRG-J through distributive justice in

Table 1
Identification of sources for the environmental/ecological effects, mitigation requirements based on technological advances and innovations, and related ethical concern in membrane processes for water and energy production.

Source[a]	Agents[b]	Acceptor	Environmental/Ecological effects	Ethical issue	Mitigation requirements/Goal to ethical justification	Significance of ethical concern
Requirement of high energy	Greenhouse gases-CO_2, NO_X, SO_X, NMVOC	Ecosphere	Air pollution; *Global warming*	IRG-J	*For operational factors* Ultrahigh-permeability membranes (Cohen-Tanugi and Grossman, 2014; Kumar et al., 2007) Nanotube or aquaporin based membranes (Kumar et al., 2007; Holt et al., 2006; Majumder et al., 2005) Fouling-resistant membranes (Kang et al., 2007; Reddy et al., 2005) Chlorine-resistant membranes (Park et al., 2008; Zhou et al., 2007) High energy recovery devices and use of efficient pumps (Fritzmann et al., 2007; Stover, 2007) Use of alternative energy resources (renewable energy) (Brauns, 2010) *For socially induced factors* Reducing water network losses (Farley and Trow, 2003) reducing the water demand and consumption (Bodini and Bondavalli, 2002)	[g]
Sea water intake	–	Aquatic organisms	Impingement and entrainment of aquatic animals; *damage on aquatic life*	EC-J	Design of equipment with optimal plant's life cycle as well as minimal effect on aquatic life (Pankratz, 2004)	[f]
Corrosion products	Heavy metals; Fe, Cu, Ni, Zn	Sea/sediments/aquatic organisms	Ecosystem disturbance; Sediment loading, Molecular/cellular/organismic effects, accumulation in organisms[c]	IRG-J, IRAG-J	Thermally stable and corrosion resistant materials (Schorr et al., 2012)	[e]

(continued on next page)

Table 1 (*continued*)

Source[a]	Agents[b]	Acceptor	Environmental/Ecological effects	Ethical issue	Mitigation requirements/Goal to ethical justification	Significance of ethical concern
Pre- and post-treatment chemicals	Anti-scaling additives (polycarbonic acids, polyphosphates)[c], antifouling additives (chlorine and hypochlorite), anticorrosion additives	Sea/sediments/Aquatic organisms	Ecosystem disturbance; eutrophication, anthropogenic effect	EC-J	Membranes less susceptible to fouling (Elimelech et al., 1997; Ostuni et al., 2001)	[e]
	Halogenated organic compounds, antifoaming additives, Oxygen scavengers (Na_2SO_4)	Seawater/drinking water	Seawater pollution	IRAG-J, EC-J	Non-chemical pretreatment strategies; efficient membrane pretreatment (Prihasto et al., 2009) Efficient technology (high recovery) (Khawaji et al., 2008) Highly permeable membranes (Cohen-Tanugi and Grossman, 2014; Kumar et al., 2007) Fouling resistant membranes (Kang et al., 2007; Reddy et al., 2005)	
Distillate/Retentate accidental spills, feed drills	Hot concentrate (Brine)	Seawater	Seawater pollution, thermal pollution	EC-J	Appropriate site selection (hydro-geological, hydrodynamic conditions, local ecological value, etc.) (Tsiourtis, 2008; Roberts et al., 2010)	[g]
	Contaminates from Pretreatment chemicals, brine	Aquifer	Disturbance in the water table and aquifer damage	EC-J	Discharge devices that would ultimately reduce salinity (Roberts et al., 2010) Use of brine for renewable energy production by SGP-RE or PRO (Brauns, 2010; United States Pat, 2012) Proper discharge planning (Campbell and Jones, 2005) Strong, stable and durable materials (Schorr et al., 2012)	[e]
Noise	–	Humans	Noise pollution	IRAG-J	Appropriate site selection for construction of desalination plant (Tsiourtis, 2008) Acoustic technology: building canopies over the pumps (Einav et al., 2003)	[d]

[a] Sources are directly linked to elements in the process of DTs.

[b] Agents describe specific things (materials, chemicals, objects or solutions) resulting from the mentioned source pertaining to the cause for the effect bound to environmental or the whole ecosystem.

[c] Metals and hydrophobic by products from chemical pretreatment could have potential accumulation in edible sweater organisms and have adverse effect on humans depending on the threshold value.

[d] Less important but considerable effect.

[e] Of considerable concern and effect.

[f] Of moderate concern and adverse effect which can be minimized with proper technology utilization.

[g] Of high concern and appropriate technological developments required urgently.

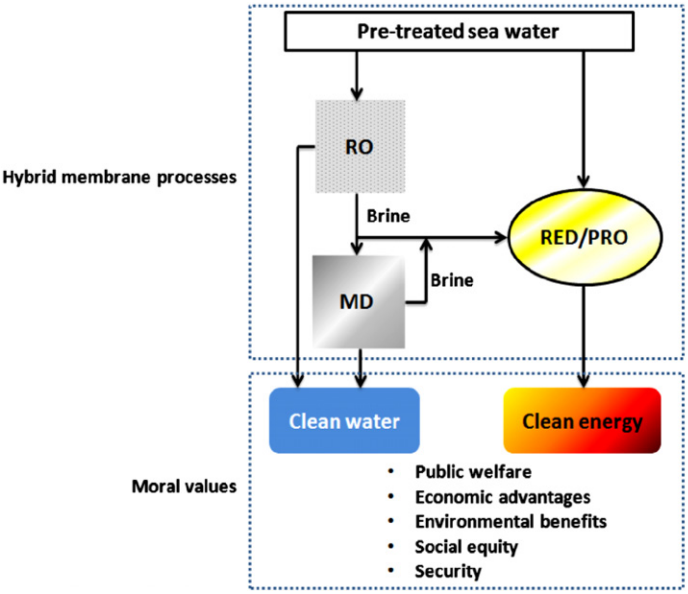

Fig. 4. Hybrid membrane processes for clean water and energy production. Moral values represent the driving forces for achieving sustainable development. In energy recovery unit, outlet from RED can also be recycled back to MD for further concentration and reuse.

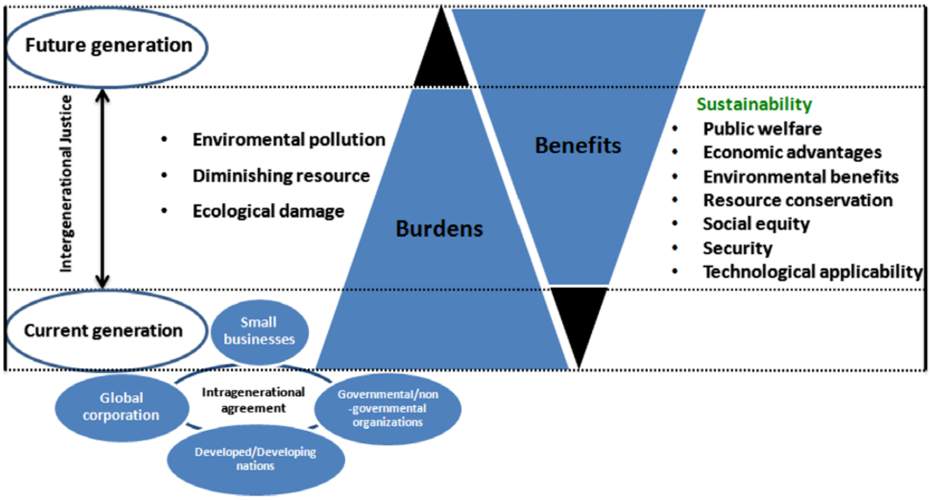

Fig. 5. Equity through distributive justice in a sustainable development. The burdens and benefits are identified for membrane based processes applied for water and energy production. Intragenerational agreement is considered as a base line for the burden–balance to present and future generation in the process of sustainable development.

a world striving for sustainable development. Obviously, the burdens considered mainly involve environmental damage, adverse effects on ecosystem and limited resources exploitation. The benefits gained include the moral values (motivating factors) from sustainability as described earlier. This is asserted as value criteria for sustainable development to assure environmental and ecological welfare, public welfare, social equity, security and resource durability.

In general, the notion of collective interests to bridge the gap between different understanding to the question of IRG-J among some philosophers asserts the difficulty of achieving IRG-J (Beckerman, 2006) and scientists predicting future harm of global climate change. For example, in the process of distributive justice, some believe that it is positive to give people of developing nations higher emission rights than the people of industrialized countries, for the implementation of burden–benefit balance (Meyer and Roser, 2006). This is based on the technological gap between the two categories of countries and a rapid development achievable at higher production and manufacturing rate in exhaustive operation of current technologies for the developing nations. In this sense, international agreements for sustainable advance and global environmental laws may compromise these types of constraints in the process of burden–benefit balance.

In general, a balance of burdens and benefits assures IRG-J through achievement of fundamental equality in the aspect of equal rights, responsibilities, vital interests and mutual advantages as described by Barry (1997). For this, intragenerational agreement among governments, global corporations, business sectors supported by all nations for actions to be taken for achievement of sustainable developments is highly important.

7. Conclusions and outlook

In the ever growing world where sustainable development is among the key issues, technological advancements are highly important to meet the needs of basic resources like water and energy. However, with the demands of these resources expected to be projected at a high rate from time to time, current DTs are posed to have an environmental issue.

When environmental ethics comes into play, current practice of DTs have a limitation mainly in the aspect of environmental pollution and damage to marine ecosystem. This study shows that continued usage of currently available DTs will automatically triggers ethical questions related to IRG-J and EC-J, which are in turn questions of environmental and ecological welfare as well as present and future generations, and hence its sustainability. Thus, the search to find answers to these ethical questions is feasible through strategic planning and implementation of appropriate mitigation methodologies. From scientific point of view, innovations of new technologies which are less energy intensive, design and development of novel materials for improved performance, and the possibility of use of alternative clean energy resources for desalination are recommended as the main mitigation strategies. For the challenges expected to occur in the era of distributive justice for equity, it is appropriate to consider anthropocentric view in prioritizing the welfare of present generations which evolve to future generations.

Although some technologies are in question if they are sustainable or fit to the theory of environmental justice eg. nuclear fusion, the search era is proceeding of course with a promising outcomes at some part. If we consider the sun, it can deliver about 6000 times (89,000 TW) the world's energy demand (15 TW), implying huge potential of solar energy. Nowadays, renewables energy resources account for only 19.5% of global energy generation, which is expected to increase significantly in all long-term scenarios. In addition, the global potential of SGP is estimated to be about 1.7 TW with a huge potential for clean energy supply. Moreover, International Energy Agency (IEA) sets the growth of renewables threefold from 2009 to 2035 based on broad policy commitments and plans set by different countries (IEA, 2014). This creates a good opportunity in implementation of renewable based desalination technologies for safe and efficient water supply. Thus, successes in innovative solutions that fulfill the value criteria directly avoid environmental problems related to technological advances in membrane processes for water and energy production.

Generally, the emerging salinity gradient power technologies like pressure retarded osmosis and reverse electrodialysis that are proposed as one solution for the brine managements have less environmental concern than DTs. Success in real application of these technologies will automatically imply the reality of hybrid desalination technologies for water and energy production and a relief from the huge environmental concern related to current DTs. Thus, the ongoing research and development progress with respect to SGP for clean energy generation is highly promising for those standing to be responsible to the welfare of the present and future generations (IRG-J and IRAG-J) and ecological safety (EC-J).

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